



# CODE OF PRACTICE FOR THE CARE AND HANDLING OF BEEF CATTLE:



## REVIEW OF SCIENTIFIC RESEARCH ON PRIORITY ISSUES

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**Beef Cattle Code of Practice Scientific Committee**  
October 2025

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### Beef Code of Practice Scientific Committee Report October 2025

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## 1 Introduction

### 1.1 Purpose and Objectives

The purpose of this report is to review and summarize the scientific research on priority welfare issues for the Canadian beef industry. The specific topics and scope of this report were collectively identified by the Code Development Committee and the Scientific Committee. A prioritization exercise between these committees was undertaken, where members were asked to identify priority topics with the following criteria:

- Is the topic related to animal welfare and is it particularly important for the welfare of the species in question?
- Is there sufficient research to do a review?
- Is it a topic that would particularly benefit from a rigorous review of the research by a committee with diverse areas of expertise?
- Is it within the scope of the Code (on-farm, an issue for which producers have control)?
- Are there already established protocols that can be relied upon instead?

The mandate of the Scientific Committee was to address the implications of the scientific research for beef cattle welfare within the priority issues identified by the aforementioned committees, as outlined in the [NFAACC Code Development process](#). The Code Development Committee for which this report was prepared represents considerable expertise in these areas and is tasked with considering such factors in its discussions.

The present report reflects a narrative review of the literature on the topics listed below. For each priority topic, we identified published review articles (e.g., systematic reviews, scoping reviews, meta-analyses, and relevant narrative reviews) that addressed the primary headings and subheadings listed as being of interest to the Code Development Committee. The search for scientific literature focused on review articles, followed by primary studies, and was conducted in the following journal databases: Google Scholar, PubMed, and Web of Science. Our key search terms, joined using Boolean operators, were comprised of the key words found in the list of priority topics below and were used to identify papers. We focused on including papers published since the Review of Scientific Research on Priority Issues was completed in 2012, with a preference for work conducted in North America. Articles focused on geographies in Africa, Asia, and Oceania were excluded, as were articles written in a language other than English.

Where possible, systematic literature reviews and meta-analyses have been leveraged to rely on higher strength of evidence. However, the existing research on many of these topics lacks a sufficient number of comparable randomized controlled trials to enable meaningful meta-analyses. In the absence of existing reviews that synthesize the science and offer insight into quality and strength of evidence, the original literature has been reviewed and summarized. The synthesis presented herein represents a summary of the significant findings, key conclusions, and reported outcomes of the existing body of peer-reviewed literature. It was, however, out of scope to conduct a more systematic assessment of study design, statistical power, and limitations that may have influenced study outcomes. This report provides a comprehensive review of the

current evidence on beef cattle welfare practices, incorporating high levels of evidence where feasible, to provide reasonable evidence-based conclusions from the reviewed science.

The specific priority issues discussed within this report include:

- Pain control for painful procedures
  - Main principles
  - Necessity for painful procedures and evidence for alternative management strategies
  - Assisted calving
  - Disbudding and dehorning
  - Castration
  - Branding
- Weaning
  - Welfare impacts of weaning on both the cow and the calf
  - Weaning procedures/practices
  - Pre- and post-weaning management
- Health conditions at different stages of production
  - Main principles
  - Neonatal calf diarrhea
  - Bovine respiratory disease (BRD) in cow–calf and feedlot production
  - Lameness in cow–calf and feedlot production
  - Nutritional diseases associated with high concentrate feeding (acidosis, liver abscesses, laminitis)
- End-of-life management
  - Current euthanasia method(s) and practices
  - Decision-making, especially for vulnerable animals

The Scientific Committee wishes to also highlight that, though out of scope for this review, a number of other topics are important to discuss when evaluating health and welfare in the Canadian beef sector. These include:

- Climate change and disease patterns
- Environmental conditions (e.g., heat and cold stress, drought)
- Housing conditions (pen stocking density, shade, resource availability)
- Stockmanship and low-stress handling
- Managing pregnancy in the feedlot
- Dairy-beef cross cattle in feedlots: tolerance to high-grain rations/liver abscesses, lameness, impact and prevalence of BRD, dark cutters, etc.
- Health protocols and record keeping for disease monitoring.

Some of these items were not included due to insufficient research or scientific evidence to summarize. Despite this paucity of evidence, it is imperative that these topics be acknowledged, and stress and pain mitigated when possible.

## **2 Pain Control for Pain and Painful Procedures**

### **2.1 Introduction, Scope, and Main Principles**

Before delving into the science behind pain and painful procedures in beef cattle, it is important to address several overarching principles and considerations. This section serves as a foundation, outlining key themes that set the stage for a deeper exploration of current research on these practices.

### **2.2 Beef and Dairy Cattle Comparisons**

In the sections on dehorning, castration, branding, and health conditions, this report aims to focus only on the scientific literature relating to beef cattle. However, much relevant research has been conducted on dairy cattle and/or under dairy management conditions. This distinction is important when evaluating research findings for two reasons. First, beef cattle and dairy cattle differ genetically and behaviourally (Haskell et al., 2014), and second, the handling and management systems for beef production are markedly different from dairy production (Endres & Schwartzkopf-Genswein, 2018). Researchers studying pain in domestic animals have cautioned against the extrapolation of behavioural and physiological pain related responses between and within a species due to breed, age, and sex differences (Anil et al., 2002, 2005). Despite these differences, there is little reason to suspect that dehorning, castration, branding, and health conditions do not cause similar pain and distress in beef cattle regardless of breed. However, the differences between beef and dairy cattle and between the production systems mean that care is required in interpreting how specific research findings in dairy cattle relate to beef cattle. Nonetheless, these comparisons are useful to assist in identifying gaps in scientific knowledge and future research needs for beef cattle.

#### ***2.2.1 Prevention of Painful Conditions and Procedures***

A useful practice for addressing pain in cattle, whether caused by procedures or painful health conditions, is to prevent it whenever possible. In some cases, alternatives to certain painful practices (e.g., disbudding vs. polled genetics) are becoming more commonplace. For example, a recent producer survey indicated that in 2022, 80.6% of Canadian beef producers reported having > 75% polled calves (BCRC, 2022). In other cases, improved pain control methods are being developed that may provide more effective pain mitigation (aimed at controlling both procedural and post-operative pain) compared to conventional approaches (Rudd et al., 2025; Ross et al., 2024; Lauder et al., 2020; Meléndez et al., 2018a, 2018b). It is therefore essential to consider the necessity of each procedure or intervention, recognizing that it will cause some level of pain or discomfort, and to select the least painful methods while ensuring appropriate pain control is provided for any painful condition or procedure.

#### ***2.2.2 Managing Pain in Cattle***

Managing pain in cattle is a critical aspect of ensuring animal welfare and optimizing outcomes in livestock production (Steagall et al., 2021). This section provides an overview of the key

pharmacological strategies used to address pain, aiming to establish a common understanding of their mechanisms and applications.

Effective pain management (mitigation of procedural, acute, and longer-term pain) in cattle often requires a combination of pharmacological approaches, including local anesthetics, non-steroidal anti-inflammatory drugs (NSAIDs), or sedatives, each addressing different aspects of pain and stress (Zoltick et al., 2024). Local anesthetics such as lidocaine block sodium channels in nerve cells, preventing the initiation and transmission of pain signals to the central nervous system (Zoltick et al., 2024) and are particularly effective for providing acute pain relief during and immediately after procedures such as castration or dehorning.

Often complementing local anesthetics, NSAIDs like meloxicam and flunixin meglumine function in part by reducing prostaglandin production through the inhibition of cyclooxygenase enzymes (COX-1 and COX-2; Zoltick et al., 2024). This lowers inflammation and pain by decreasing nociceptor sensitivity and pain signaling (Stock & Coetzee, 2015). COX-1 contributes to immediate inflammatory responses and COX-2 is involved in prolonged inflammation. Targeting both isoenzymes enhances pain relief; however, COX-1 inhibition can lead to adverse renal and gastrointestinal effects (Mushtaq et al., 2025). Although limited studies have been conducted in cattle, selective COX-2 inhibitors, such as meloxicam, may therefore be preferred for minimizing these side effects (Mushtaq et al., 2025). The dual analgesic and anti-inflammatory effects of NSAIDs make them valuable for managing both acute and chronic pain (Stock & Coetzee, 2015).

Sedatives such as xylazine complement anesthesia and analgesia by targeting stress and facilitating muscle relaxation, especially during invasive procedures (Stock & Coetzee, 2015). As an alpha-2 adrenergic agonist, xylazine decreases norepinephrine and dopamine release, resulting in sedation, mild analgesia, and muscle relaxation (Ball et al., 2022). Sedatives, particularly alpha-2 agonists, have an inhibitory peripheral effect on pain transmission pathways and help reduce the perception of pain, which may improve welfare during handling or procedures (Stock & Coetzee, 2015).

Together, these pharmacological tools provide a multifaceted strategy for managing pain and stress in cattle. The choice of therapy should be tailored to the specific type, severity, and duration of pain to ensure optimal welfare outcomes. A scientific review of pain control strategies for specific procedures—including dehorning or disbudding, castration, branding, dystocia and assisted calvings, spaying of female cattle, and painful health conditions—are addressed below. Our ability to mitigate pain in cattle is influenced by many factors, including the drugs' availability and duration of action. For example, NSAIDs, sedatives, and local anesthetics provide limited duration or relief compared to duration of pain experienced by cattle following common procedures (Meléndez et al., 2025).

### ***2.2.3 Working with a Veterinary Advisor***

Tools and strategies are available to manage short- and long-term pain associated with many of the procedures and conditions outlined below. As detailed in the following sections, evidence-informed protocols and drugs have been developed to mitigate pain, but their implementation and widespread adoption remain areas for improvement within the Canadian beef industry

(BCRC, 2024). Veterinary involvement is crucial in ensuring the appropriate use of these tools and protocols, providing expertise in pain management strategies and promoting animal welfare practices. This is particularly important to ensure the use of registered products for food-producing species that are labeled for the indication.

#### **2.2.4 Scope**

A review of the science on painful practices was included in the Code of Practice for the Care & Handling of Beef Cattle: Review of Scientific Research on Priority Issues (Schwartzkopf-Genswein et al., 2012), with a focus on dehorning, castration, and branding. As such, this review focuses on updates to the science since 2012 when referring to those specific conditions while also introducing new sections on dystocia and assisted calvings, spaying of female cattle, and painful health conditions.

### **2.3 Dystocia and Assisted Calvings**

#### **Conclusions:**

- 1. Dystocia causes pain and soft tissue trauma in cows, often leading to musculoskeletal injuries, nerve damage, and an increased risk of uterine infections.**
- 2. In calves, dystocia also causes pain and soft tissue trauma, manifesting in reduced vigour, delayed ability to stand, musculoskeletal injuries, hypoxia, and increased risks of illness and mortality.**
- 3. Administration of certain NSAIDs after calving can improve cow comfort, milk production, and reproductive performance, with meloxicam showing consistent benefits; however, flunixin meglumine is associated with negative outcomes, such as retained placenta and reduced milk yield.**
- 4. Pain relief for calves after birth, particularly with NSAIDs like meloxicam and ketoprofen, improves welfare indicators such as activity and play behaviour, but effects on long-term growth and health are inconsistent and perhaps should not be expected.**
- 5. Future research should prioritize optimizing the timing and dosage of NSAIDs for both cows and calves, evaluating the efficacy of different types of NSAIDs, exploring their long-term impacts on productivity, and assessing various pain mitigation strategies under commercial cow–calf conditions.**

Dystocia, defined as calving difficulty resulting from prolonged spontaneous calving or prolonged/severe assisted extraction (Mee, 2004), differs from assisted calving, which refers to any calving where assistance is provided, even if dystocia is not present (Mee, 2008). Both conditions are prevalent in the Canadian beef industry. In a study of 203 cow–calf herds during the 2002 calving season, 8.9% of calvings required assistance, and 3.7% were classified as severe dystocia (Waldner, 2014). More recent data from a survey of 97 cow–calf producers in

western Canada reported an average herd-level incidence of assisted calvings at 4.9%, with 13.5% in heifers and 3.2% in cows (Pearson et al., 2019a). Caesarean sections were uncommon, occurring at a rate of 0.2% (0.7% in heifers, 0.15% in cows). Additionally, in the same survey, most producers reported assisting at least 1 heifer (95.7%; 89/93) or cow (89.6%; 86/96) during the 2016 calving year. Data from 562 herd records collected in western and eastern Canada between 2019 and 2022 show that 7.4% of calvings required assistance, with easy pulls, hard pulls, and caesarean sections accounting for 4.7%, 2.8%, and 0.2% of cases, respectively (Waldner et al., 2024). Collectively, these studies highlight the frequent occurrence of both assisted calvings and dystocia in Canadian beef herds.

Dystocia and assisted calvings significantly affect the health and welfare of both cows and calves. Calves born from difficult or prolonged deliveries often exhibit lower vigour, delayed standing and walking, prolonged hypoxia, acidemia, and skeletal injuries (Barrier et al., 2012a; Murray et al., 2016; Pearson et al., 2019d; Homerosky et al., 2017a). These issues can hinder colostrum intake and transfer of passive immunity (Homerosky et al., 2017b), increasing the risk of illness and death (Barrier et al., 2013; Murray et al., 2016; Pearson et al., 2019d). Elevated creatine kinase, reflecting soft tissue trauma, can also be measured in calves born under these conditions (Pearson et al., 2019d). Injuries such as rib fractures, reported in 6% of preweaned dairy calves in one study, are frequently linked to challenging births (Ollivett et al., 2018).

For cows, dystocia causes considerable pain and trauma, often resulting in musculoskeletal injuries, nerve damage, and a higher likelihood of uterine infections such as metritis (Mee, 2008). This can often lead to a higher risk of culling, as demonstrated by Sewalem et al. (2008), who found that Holstein cows requiring a hard pull or surgery during calving were 1.27 and 1.92 times more likely to be culled, respectively, compared to cows with unassisted calvings. Lucio et al. (2024a) found that assisted calving reduced the expected profit by \$151.32 CAD in heifers compared to unassisted heifers, while in cows, assisted calving reduced the expected profit by \$187.18 CAD compared to unassisted cows. Additionally, cows in pain after calving may show behavioural changes, such as reduced activity, abnormal lying positions, and less grooming (Barrier et al., 2012b). These challenges are likely due to the force required to extract calves, with Pearson et al. (2020) reporting that for mechanical deliveries 380.6 kg minutes of force was used. Canadian producers also identify dystocia as painful, with 89% of surveyed western Canadian cow-calf producers agreeing it was painful if no pain control was provided (Moggy et al., 2017). Cumulatively, these findings highlight the trauma and pain associated with dystocia and assisted calvings.

### ***2.3.1 Pain Mitigation Strategies for Dystocia and Assisted Calvings***

There are a variety of different options to manage pain associated with calving. Administration of a local anesthetic is used to reduce sensation of a specific area and is mainly used to provide pain relief during surgical procedures, such as a caesarian section (Stock & Coetzee, 2015). It may also be provided as an epidural, though its effects during dystocia are not well studied. NSAIDs are commonly used and studied as a method to reduce pain caused by inflammation associated with calving.

A survey of western Canadian cow-calf producers found that 44.8% and 44.7% of respondents administered an NSAID to the majority of cows and calves, respectively, after a difficult calving

(Pearson et al., 2019a). A lidocaine epidural was rarely used with 2.1% of respondents administering it in the case of a difficult calving. Further, a 2014 survey of 109 cow–calf producers in western Canada found that the prevalence of pain mitigation strategies used for dystocia and caesarean section by respondents were 46% and 100%, respectively (Moggy et al., 2017).

### *2.3.1.1 Pain Mitigation Following Calving in Cows*

Research into pain mitigation in cows has highlighted the benefits of administering NSAIDs like meloxicam, ketoprofen, and acetylsalicylic acid after calving to improve comfort, milk production, and reproductive performance.

**Beef cows.** Research on pain control following calving in beef cows is limited. Lucio et al. (2024b) studied 23 cows assisted at birth and found no behavioural differences between those treated with meloxicam and placebo. However, studies on caesarean sections in beef cows have found that meloxicam administration can help reduce indicators of pain. Barrier et al. (2014) observed that meloxicam-treated cows spent more time lying and had more frequent lying bouts within 24 hours post-surgery, indicating improved comfort. Mauffré et al. (2021) also reported positive benefits, including higher pregnancy rates, shorter calving intervals, and a trend toward lower culling rates in Charolais heifers undergoing caesareans treated with pre-operative meloxicam. Finally, Guatteo et al. (2022) found that meloxicam administered prior to caesareans enhanced passive immunity transfer in calves, especially in multiparous cows, without affecting colostrum quality or time to first suckling, highlighting potential benefits for calf survival.

**Dairy cows.** In dairy cattle, NSAIDs have been widely studied for their impact on postpartum welfare and production, with meloxicam being primarily evaluated. Newby et al. (2013) found that meloxicam administered 24 hours after assisted calving increased feeding time and bunk visits but did not affect milk production or health outcomes. Similarly, Mainau et al. (2014) showed increased post-calving activity in meloxicam-treated heifers, suggesting improved comfort. Production increases have also been observed where Swartz et al. (2018) found that meloxicam given before calving increased milk yield in unassisted cows and improved milk fat, protein, and lactose production regardless of calving difficulty. Shock et al. (2018) also demonstrated improved productivity, where they evaluated 2,653 cows across 20 Canadian herds and found that meloxicam-treated cows had increased milk yield, reduced subclinical mastitis, and lower culling rates within 60 days postpartum. Similar results were found in Carpenter et al. (2016) which compared sodium salicylate, meloxicam, and placebo at calving. With either NSAID, whole-lactation milk and protein yields improved, with additional metabolic benefits, including decreased beta-hydroxybutyric acid, in sodium salicylate-treated cows and higher glucose levels in meloxicam-treated cows.

Other NSAIDs have also been studied. Gladden et al. (2021) administered ketoprofen within 3 hours of calving in 72 Holstein cows and found reduced lateral recumbency and more behaviours associated with greater comfort. Similarly, Stilwell et al. (2014) reported that carprofen given within 6 hours of calving improved early feed intake and increased 305-day milk yield in first-lactation cows, although it delayed conception and reduced pregnancy rates at 220 days postpartum. Barragan et al. (2020) evaluated the impact of post-calving oral acetylsalicylic acid treatment on inflammatory, nociceptive, and stress biomarkers (haptoglobin, substance P, and

cortisol) in 152 dairy cows across 3 organic herds. The key finding was that treatment with acetylsalicylic acid reduced haptoglobin levels in multiparous cows, but calving difficulty and parity had a stronger influence on biomarker levels regardless of treatment.

Unlike other NSAIDs, flunixin meglumine has shown disadvantages. Newby et al. (2017) reported that pre-calving administration increased stillbirth risk, while post-calving treatment raised the likelihood of retained placenta, high rectal temperature, decreased milk production, and metritis, leading to recommendations against its use within 24 hours of parturition. Importantly, meloxicam administration within 1 hour of calving has not shown such negative effects (Newby et al., 2014).

A single study evaluated dexamethasone in cows with dystocia (Swartz et al., 2023). Treated cows exhibited reduced activity, less restlessness, and increased lying times, suggesting reduced discomfort. However, these cows produced 2.7 kg/day less milk during the first month postpartum, highlighting potential drawbacks in milk production.

While NSAIDs such as meloxicam demonstrate consistent benefits for postpartum comfort, milk production, and reproductive performance, the timing of administration and choice of drug are critical. Negative outcomes observed with flunixin meglumine and the production trade-offs associated with dexamethasone warrant careful consideration.

### 2.3.1.2 Pain Mitigation Following Calving in Calves

Studies on pain relief in calves have highlighted potential advantages of using NSAIDs such as meloxicam and ketoprofen after calving.

**Beef calves.** Pearson et al. (2019b) investigated the effects of meloxicam in 33 beef calves requiring assistance at birth. Meloxicam-treated calves exhibited a higher average daily gain (+0.3 kg/day) during the first 7 to 10 days of life compared to placebo-treated calves. However, meloxicam had no significant effect on physiological pain and inflammation markers, standing and nursing behaviour within 1-hour, passive immunity, overall health outcomes, or average daily gain to weaning. Similarly, Lucio et al. (2024b) studied 23 assisted beef calves administered meloxicam or a placebo. Although meloxicam did not influence cow–calf bonding, treated calves showed increased activity and play behaviour, indicating improved welfare through reduced discomfort. In a larger cohort, Pearson et al. (2019c) enrolled 230 assisted beef calves but found no significant effects of meloxicam on serum IgG concentrations, growth, disease treatment risk, or mortality.

**Dairy calves.** In Holstein dairy calves, Murray et al. (2016) conducted a randomized double-blind trial to assess the effects of meloxicam administered shortly after newborn calves were discovered on calf vigour, health, and growth. The study revealed that meloxicam improved calf vigour, suckling reflex, milk intake, and health during the pre-weaning period. Similarly, Kovács et al. (2022) explored the effect of meloxicam administration immediately after birth on the standing behaviour of 180 Holstein calves born to eutocic or dystocic dams. The study found that meloxicam improved the duration and frequency of standing as well as the longest standing bout in low-vitality calves, but it did not affect calves with normal vitality. Clark et al. (2020) also investigated the effects of meloxicam on calves unassisted and assisted in delivery; however, it

was administered in pill form prior to colostrum feeding or mixed in solution with colostrum replacer. Few differences were noted between groups with respect to IgG concentrations; however, calves treated with meloxicam tended to consume more starter feed and had higher ketone levels, suggesting improved rumen development, compared to the control group. Further, those receiving meloxicam in pill form tended to gain weight at a faster rate and had lower glucose levels compared to meloxicam offered in colostrum. With regard to ketoprofen, Gladden et al. (2019) evaluated its administration to 75 Holstein calves at birth. Regardless of whether calves required assistance during birth, ketoprofen increased play behaviour during the 48 hours after birth, suggesting it alleviated neonatal discomfort.

These studies collectively indicate that NSAID administration can improve specific welfare metrics such as activity and play behaviour in calves after calving. However, effects on health outcomes and long-term growth appear inconsistent, although the latter perhaps should not be the primary outcome of interest for such studies. There remains a need for further research to optimize pain management strategies in newborn calves.

### **2.3.2 Future Research**

Future research in beef cattle should focus on optimizing the timing and dosage of anesthetic and analgesic administration, particularly around assisted births, to improve cow comfort, reproductive performance, and calf health, welfare, survival, and productivity. Further, there is a need to develop novel routes of administration that could make pain control use more practical for producers as well as veterinarians. Additional studies that explore the long-term effects of pain mitigation on herd productivity and economics might be beneficial to increase the uptake of pain mitigation among producers and veterinarians who are not currently using it. Comparative evaluations of different products and their impacts on both dams and calves under beef production conditions are also essential to guide practical, evidence-informed recommendations.

## **2.4 Spaying of Female Cattle**

### **Conclusions:**

- 1. Spaying, regardless of the method used, causes significant pain and stress in cattle, with flank laparotomy having more prolonged adverse effects compared to the Willis dropped ovary technique.**
- 2. Pain management strategies, such as NSAIDs like meloxicam in combination with an anesthetic or other NSAIDs, reduce pain behaviours and physiological stress following spaying, improving cattle welfare.**
- 3. Alternatives to spaying, such as improved reproductive management, are available to avoid the need for the procedure altogether.**

Some female cattle that are not required for breeding are spayed to prevent unwanted pregnancies and mitigate potential negative consequences associated with pregnancy in fed

heifers when alternative strategies are deemed impossible; such is the case with range cattle where mating may be harder to control. In these circumstances, spaying can help mitigate the risk of having pregnant heifers calving in the feedlot, which has the potential to create an even larger welfare issue. However, scientific evidence suggests that spaying offers limited economic advantages in many cases. Spayed heifers not implanted with growth-promoting hormones have a lower average daily gain compared to intact heifers not implanted with growth-promoting hormones (as reviewed by Pinner, 2006), and when implanted, spayed heifers perform similarly to implanted intact heifers (Cain et al., 1986; Popp et al., 1997). Given the painful nature of spaying and the lack of clear performance benefits, its use warrants critical evaluation, particularly in light of alternative management strategies that may mitigate the risks of pregnancy without causing significant welfare concerns.

Spaying methods include flank laparotomy and transvaginal ovariectomy (Pinner, 2006). Although limited, research consistently demonstrates that spaying, regardless of the technique, is associated with significant pain and stress in cattle. McCosker et al. (2010) investigated morbidity and mortality in yearling Brahman heifers spayed using either a form of transvaginal ovariectomy called the Willis dropped ovary technique (WDOT) or ovariectomy via flank incision compared to control unspayed heifers under commercial conditions. Spayed heifers exhibited acute pain-related behaviours within the first 6 hours post-procedure. Body weight and weight gain were significantly lower in spayed heifers compared to controls at 21 and 42 days, with 5% of flank wounds remaining unhealed at 42 days. Mortality rates were 0% for the control group, 1.5% for WDOT, and 2.5% for flank-spayed heifers, with WDOT deaths occurring later after the procedure. Petherick et al. (2011) compared the WDOT and flank laparotomy methods and found elevated cortisol concentrations in spayed heifers compared to controls subjected only to crush restraint. Flank-spayed heifers also had elevated haptoglobin levels until day 4 post-procedure. Petherick et al. (2013) evaluated the welfare outcomes of cattle spayed using WDOT or flank laparotomy, comparing these methods to control procedures such as physical restraint or mock artificial insemination. Plasma cortisol concentrations were significantly higher in cattle spayed using either method during the 8 hours following procedures compared to animals subjected to physical restraint or mock insemination. Flank laparotomy was also associated with elevated creatine kinase and aspartate aminotransferase levels, indicating greater tissue damage. Inflammatory responses, as measured by haptoglobin levels, were more pronounced and longer lasting in cattle spayed via flank laparotomy. Behaviourally, cattle spayed by either method spent more time standing with their heads down and less time feeding immediately after the procedure than controls, with these effects persisting longer in those spayed via flank laparotomy. Body weight changes were not significantly different across treatments. From these studies, it can be concluded that spaying causes significant pain and stress in cattle, with flank laparotomy having more prolonged adverse effects compared to WDOT. These findings highlight the need for improved pain management strategies and welfare considerations for spaying procedures, as well as exploration of potential alternatives.

#### ***2.4.1 Pain Mitigation Strategies for Spaying Female Cattle***

Regarding pain management, Lauder et al. (2020) investigated the effectiveness of pain management in cattle undergoing WDOT. Heifers treated with a combination of butorphanol, xylazine, and ketamine (an anesthesia protocol administered exclusively by a veterinarian) prior to spaying, along with oral meloxicam at the time of the procedure, exhibited significantly lower

salivary cortisol levels within 2 hours post-spaying and reduced haptoglobin levels at 2-, 4-, and 7-days post-procedure compared to untreated spayed heifers. Similarly, Yu et al. (2020) evaluated the impact of meloxicam administered post-procedure and a topical anesthetic applied before piercing the vaginal wall immediately before ovary excision during the WDOT procedure. Pain-related behaviours such as head tucking and tail stiffness were observed in all spay groups but were least pronounced in heifers treated with analgesia and anesthesia. Treated heifers also spent more time ruminating and eating and less time standing with an arched back or lying down, indicating a reduction in negative welfare outcomes. Together, these studies highlight the effectiveness of multimodal analgesia in reducing but not eliminating pain associated with WDOT.

#### **2.4.2 Future Research**

Future research should focus on optimizing multimodal pain management strategies for spaying procedures, including the timing, dosage, and combination of NSAIDs, anesthetics, and other analgesics. However, given the clear evidence of significant pain associated with spaying and the limited practical and effective strategies currently available to mitigate that pain, the necessity of the procedure itself warrants critical evaluation. Exploring and encouraging alternative management strategies to prevent unwanted pregnancies or reduce the need for spaying should also be prioritized, particularly in light of welfare concerns and the minimal evidence of long-term productivity benefits under commercial conditions.

### **2.5 Disbudding and Dehorning**

#### **Conclusions:**

- 1. Disbudding and dehorning are painful procedures that cause a range of stress and behavioural changes in calves, with animals facing greater health and welfare risks when dehorning is performed at an older age.**
- 2. Pain mitigation strategies, such as combining local anesthetics and NSAIDs, effectively reduce but do not eliminate acute and post-procedure pain in cattle of any age.**
- 3. Additional pain management, beyond the initial doses of local anesthetics and NSAIDs, are needed for effective management of chronic pain and inflammation.**
- 4. Sedation with xylazine could aid in reducing immediate stress during disbudding in addition to having analgesic effects.**
- 5. Research specific to beef calves is needed to evaluate methods, optimize pain control, particularly for chronic pain, and inform best practices for disbudding and dehorning in beef production.**
- 6. Breeding for polled genetics is a viable alternative to disbudding and dehorning, with no observed negative effects on productivity.**

Disbudding is the removal of horn-forming tissue before its attachment to the skull, whereas dehorning is the removal of the horn after this occurs at approximately 2 to 3 months of age (CVMA, 2022). These procedures are done as horned cattle are perceived to pose a risk of injury to people as well as other animals (Stock et al., 2013). Further, Lutz et al. (2019) found that horned dairy cattle exhibited more non-contact aggression and successful head butts than dehorned cattle, highlighting the potential for increased conflict and injury in horned cattle. While some researchers suggest that horns have some benefits and pose a risk only when cattle are housed in confined spaces where competition for resources is increased (Knierim et al., 2015; Algra et al., 2023), others acknowledge the economic and practical challenges of widespread housing adaptations needed to manage horned cattle in intensive production systems (Drwencke et al., 2025b).

As concluded in the previous Review of Scientific Research on Priority Issues (Schwartzkopf-Genswein et al., 2012), disbudding or dehorning causes pain and distress at any age. Specifically, animals that have been disbudded or dehorned have increased levels of cortisol, have higher heart and respiratory rates, seek physical and visual isolation, exhibit behavioural indicators of pain (e.g., tail flicking, head shaking, ear flicking, vocalization), and have increased sensitivity in the area of the wound (as reviewed by Reedman et al., 2022a). Although both are painful, disbudding is recommended over dehorning as it is less invasive and painful (Stafford & Mellor, 2005a, 2011).

More recent research in dairy calves has also highlighted long-term consequences associated with disbudding or dehorning. Specifically, Adcock et al. (2023) found that cautery disbudding in calves resulted in increased inactivity and lower rumination for up to 11 days post-procedure, as well as more head-down sleeping throughout the three-week study and increased lying on day 17. Further, Adcock and Tucker (2018), in young dairy calves, found that indicators of pain remained for 62 days following cautery disbudding. Hence, despite the use of pain relief, evidence from dairy calves raises concerns about long-term welfare implications.

### ***2.5.1 Use of Polled Genetics***

The use of polled genetics is common in the Canadian beef industry, with 56% of surveyed western Canadian cow-calf producers reporting that more than 90% of their calf crop is polled (Moggy et al., 2017). The 2024 cow-calf survey reported that the majority (80.6%) of survey respondents had more than 75% of their calves born polled (BCRC, 2024). Initially, it was feared that polled genetics would lead to lower levels of production; however, most studies point to no difference between polled and horned beef breeds (Schwartzkopf-Genswein et al., 2012). Randhawa et al. (2021) compared estimated breeding values for 12 production and carcass traits between 2.5 million horned and polled cattle. Prior to the year 2000, polled animals had lower genetic merit for traits like live and carcass weights, milk, and meat quality. However, between 2000 and 2018, significant genetic gains were achieved, with polled animals improving for most traits and showing advantageous estimated breeding values for live and carcass weights, despite slightly lower birth weights in some breeds. Therefore, recent selection for polled genotypes has not negatively impacted genetic merit, addressing concerns about reduced productivity in polled animals.

### **2.5.2 *Age of Animal***

As a calf ages, the size and degree of attachment of the horn increases, thereby changing the procedure from disbudding to dehorning, and the method used is adjusted accordingly (see section 2.5.3). The previous Review of Scientific Research on Priority Issues (Schwartzkopf-Genswein et al., 2012) highlighted the limited research that has been conducted on the impact of age at dehorning or disbudding; however, from the few studies it was clear that disbudding conducted in young calves (< 7 months of age) typically resulted in faster wound healing compared to older calves. Since then, few studies have explored this topic, and those that have primarily focused on dairy calves under 35 days of age. Adcock and Tucker (2018) compared cautery disbudding in calves at 3 and 35 days of age, reporting no differences in wound healing time or weight gain between the groups. However, calves disbudded at 3 days exhibited greater generalized pain sensitivity at 28, 42, and 56 days after disbudding, suggesting heightened long-term pain responses with earlier disbudding. Mirra et al. (2018) found that cautery disbudding at either 1 or 4 weeks of age caused comparable increases in pain and tactile sensitivity scores, with both groups experiencing acute pain and peripheral sensitization. Notably, calves disbudded at 4 weeks had lower pressure pain thresholds, indicating more intense localized pain than those disbudded at 1 week, despite no differences in physiological or behavioural measures. These findings highlight the complexities of timing for disbudding, as earlier procedures may reduce certain pain responses but still cause significant pain and sensitization, suggesting that even early disbudding carries welfare concerns.

### **2.5.3 *Method Used for Disbudding and Dehorning***

There are multiple methods that can be used to disbud or dehorn cattle. In 109 western Canadian cow-calf operations, most (51%) calves were disbudded with caustic paste at < 1 week, followed by 23% using cautery disbudding at 1 week to 3 months, and 14% using gouge or scoop disbudding at 1 week to 3 months (Moggy et al., 2017). In the most recent industry cow-calf survey, dehorning paste was the most common dehorning method used by producers at 34%, followed by electric disbudders at 25.6%, while spoons, saws, wires, keys, or guillotines were used by 26.3% of producers and 13.7% used other methods including hot iron, gouge and burn, or knife for dehorning. Only 0.4% of producers surveyed reported not dehorning their calves (BCRC, 2024). It is important to note, very few studies have completed direct comparisons between methods, with the overwhelming majority of studies conducted in dairy calves. Nevertheless, disbudding is preferred over dehorning (CVMA, 2022), as it causes less tissue trauma and lower risk of sinusitis, uncontrolled bleeding, fly infestation, and infection (Stafford & Mellor, 2011)

#### **2.5.3.1 *Caustic Paste versus Cautery Disbudding***

Newby et al. (2016) compared the behaviour and outcomes of three disbudding methods in dairy calves aged 1 to 15 days: caustic paste, caustic stick, and hot iron with a cornual nerve block lidocaine. Calves that had caustic paste disbudding were quicker to approach a person on days 1 and 7 post-disbudding. Cautery disbudding resulted in smaller scars but had higher odds of showing signs of infection (e.g., redness, purulent discharge, and crust formation) 3 weeks later compared to caustic methods. Weight gain and horn regrowth at 6 weeks and 6 months were similar across all methods. It should be noted that the rates of infection resulting from caustic

compared to cautery disbudding reported by Newby et al. 2016 were very low and therefore conclusions and recommendations based on this comparison cannot be made. In addition, a study evaluating the efficacy of novel disbudding methods in dairy calves found that the likelihood of infection was not the same for all methods of cautery disbudding evaluated. For example, leaving the bud in resulted in double the percentage of buds infected compared to removing them, suggesting that technique is also important for managing infection (Sutherland et al., 2019). Drwencke et al. (2023) found that caustic paste disbudding in 3-day-old Jersey and Holstein calves resulted in prolonged wound healing, averaging 18.8 weeks compared to the 7 to 9 weeks typical for cautery disbudding. Wounds were also more sensitive than intact horn buds for at least 6 weeks, highlighting the extended healing time and sensitivity associated with the use of caustic paste. Similarly, Drwencke et al. (2025b) reported that wound size and depth were larger with paste compared to hot iron disbudding, and wounds took at least twice as long to heal (i.e., 17–18 weeks paste compared to 10 weeks for hot iron). Cui et al. (2024) also compared caustic paste and hot iron and found both groups of calves showed an increase in pain behaviour after the procedures, but the paste group had higher frequency of these behaviours than the hot iron group. Further, calves in the dehorning cream group had higher blood haptoglobin concentrations, a biomarker for inflammation, compared to their hot iron counterparts at 48 hours post-disbudding.

Whether the area is shaved before application and the dose of paste applied both impact calf behaviour, wound healing, and success of the procedure. When the horn bud area was shaved before application, calves were more likely to rub, thereby disrupting the paste, compared to unshaved calves, and 30% of all calves had paste on their body or surrounding environment (Drwencke et al., 2025a). In that study, a smaller dose (0.2 ml) on unshaved buds re-epithelialized faster than a larger dose (0.3 ml) on shaved buds; however, the risk of regrowth was highest in the 0.2 ml dose unshaved group (8%) compared to the 0.2 ml dose shaved (0%), 0.3 ml dose unshaved (0%), and 0.3 ml dose shaved (2%) groups.

These studies highlight the potential trade-offs between caustic paste and cautery disbudding methods, with caustic paste delaying wound healing and causing higher pain sensitivity over a prolonged period, while cautery disbudding may carry a higher risk of infection despite faster wound resolution.

### 2.5.3.2 *Hot Iron Type*

Adcock et al. (2019) compared wound healing in 4- to 10-day-old calves disbudded with a Rhinehart X50A electric disbudder and a Portasol gas disbudder. Although wounds from both irons took 7 to 8 weeks to heal, Rhinehart wounds exhibited more days with detached necrotic tissue and fewer days with granulation tissue, likely due to the larger surface area of the Rhinehart iron creating a more severe burn. Despite these differences, re-epithelialization times were similar between irons. Building on this, Thomsen et al. (2021) explored how iron size and timing of anesthesia impact pain-related behaviours in 1- to 15-day-old dairy calves during cautery disbudding. It was found that calves disbudded with a large iron were 2.3 times more likely to react behaviourally (i.e., getting up, kicking, or lifting head) compared to those disbudded with a small iron. The interval from administration of local anesthesia to disbudding (ranging from 2 to 35 minutes) did not influence behavioural responses. The size of the horn bud of beef breed calves averaged between 13.8 mm and 15.1 mm and was significantly larger in

calves 4–8 weeks old compared to calves 2–4 weeks old, and in male calves compared to female calves (Marquette et al., 2021). However, age was a poor predictor of horn bud size, so the authors caution against using age as the sole factor in deciding the size of iron to use. The goal should be to create a wound that does not cause excessive damage and targets only the horn growing tissue (Dewencke et al., 2025b). Together, these studies illustrate the significant impact of iron size on calf responses during disbudding, suggesting that smaller irons reduce behavioural indicators of pain and improve wound healing.

### *2.5.3.3 Dehorning Method in Older Cattle*

One study evaluated the use of different dehorning methods in cattle arriving to a feedlot (Neely et al., 2014). They evaluated pain, behaviour, and wound healing in 40 feedlot cattle dehorned using high-tension banding, mechanical removal using a Keystone dehorner, or removal of the horn tip by using a hand saw to cut perpendicular to the horn's longitudinal axis at a diameter of 3.17 cm. Mechanical dehorning caused the most vocalizations, indicating severe pain, while banding elicited prolonged discomfort and delayed recovery, with higher scores for posture, lying, and wound healing. Removing the horn tip caused fewer signs of distress, compared to other methods of dehorning. The study concluded that while mechanical dehorning causes acute pain and banding leads to extended discomfort and slower healing, removal of the horn tip resulted in fewer signs of distress. However, removal of the horn tip is a less permanent solution as it does not fully remove the horn-producing cells, which could regrow and require additional intervention.

### **2.5.4 Pain Mitigation Strategies for Disbudding and Dehorning**

As highlighted above, dehorning and disbudding are painful. Western Canadian cow–calf producers also agree that it is a painful practice with 84% agreeing that dehorning was painful if pain mitigation was not used; however, less than 15% of respondents that dehorned their calves used pain mitigation (Moggy et al., 2017). The use of pain control among producers has increased since 2017, according to the 2023 Canadian Cow-Calf Survey (BCRC, 2024), which gathered data from 600 producers across 9 provinces. The survey found that among those who disbudded or dehorned calves, 47.3% consistently used pain mitigation, while 22.9% used it depending on the age of the calf and the method employed. Further, veterinarians acknowledge disbudding and dehorning as painful, with a position statement by the Canadian Veterinary Medical Association (CVMA, 2022) stating that cattle that are disbudded or dehorned should receive a local anesthetic and peri-operative analgesia.

#### *2.5.4.1 Combination of Local Anesthesia and Non-Steroidal Anti-Inflammatory Drugs*

There is clear scientific evidence that a combination of a local anesthetic and NSAID at the time of disbudding or dehorning will mitigate procedural pain as well as some post-operative pain. Specifically, Winder et al. (2018) conducted a systematic review and meta-analysis of 21 studies to evaluate the impact of local anesthesia and NSAIDs on managing pain from cautery disbudding in dairy and beef calves under 12 weeks of age. The review concluded that local anesthesia provides effective short-term pain relief, significantly reducing plasma cortisol concentrations for up to 2 hours post-disbudding, although cortisol levels rise again by 4 hours. Administering NSAIDs in conjunction with local anesthesia extended pain relief, mitigating the

delayed rise in cortisol, reducing pressure sensitivity, and decreasing pain behaviours between 3 and 6 hours post-procedure. Despite variability in study designs, the findings strongly support the combined use of local anesthesia and NSAIDs as best practice for managing pain associated with cauterly disbudding.

After the publication of the meta-analysis, other studies have also found that this mitigation strategy is effective at reducing pain associated with disbudding or dehorning, irrespective of age and method. In 1–9-day-old Holstein calves undergoing caustic paste disbudding, the concurrent use of local lidocaine anesthesia and systemic meloxicam analgesia effectively reduced serum cortisol concentrations, early pressure sensitivity, and inflammation compared to using either treatment alone or no pain control (Reedman et al., 2020). In addition, cortisol concentrations in the combined treatment group were comparable to sham controls, and haptoglobin concentrations tended to be lower 3 to 4 days post-disbudding, underscoring the benefits of this multimodal approach for pain management in young calves. In 6-week-old to 6-month-old Holstein calves, Qi et al. (2024) found that using meloxicam alongside lidocaine for amputation dehorning significantly reduced pain behaviours, physiological stress responses, and inflammatory markers while increasing mechanical nociceptive thresholds compared to lidocaine alone. In 7-month-old cattle, Park et al. (2020) examined the effects of lidocaine and flunixin meglumine on stress, inflammation, and behaviour during surgical dehorning with a gouge dehorner. Calves treated with lidocaine and flunixin meglumine displayed reduced head-shaking frequency, indicating alleviation of pain-related behaviours, though cortisol and haptoglobin levels were unaffected by the treatment.

Collectively, these findings provide robust evidence that a multimodal approach combining local anesthesia (e.g., lidocaine) with systemic analgesia (e.g., NSAIDs, such as meloxicam or flunixin meglumine) is required to effectively mitigate both procedural and post-operative pain associated with disbudding and dehorning across various ages and methods.

#### *2.5.4.2 Types of Non-Steroidal Anti-Inflammatory Drugs*

Several studies have assessed the efficacy of different NSAIDs alongside local anesthesia for pain management during dehorning and disbudding. Glynn et al. (2013) compared local anesthesia paired with oral meloxicam, oral gabapentin, a combination of meloxicam and gabapentin, intravenous flunixin, or a placebo in 6-month-old calves. While all analgesics improved average daily gain and reduced plasma substance P concentrations, only flunixin reduced serum cortisol, and meloxicam increased mechanical nociceptive thresholds, indicating localized pain relief. Gaab et al. (2022) evaluated lidocaine with transdermal flunixin meglumine, lidocaine with oral meloxicam, and lidocaine alone in calves undergoing disbudding. Although behavioural and cortisol responses increased post-disbudding, no significant differences were observed among treatments. Stock et al. (2021) compared four NSAIDs—meloxicam, flunixin meglumine, firocoxib, and carprofen—administered orally to 50-day-old calves during cauterly dehorning, with all calves also receiving a local anesthetic prior to dehorning. Placebo-treated calves, which received only a local anesthetic, produced approximately 25% greater cortisol concentrations over the first 24 hours compared to flunixin meglumine, meloxicam, and firocoxib-treated calves. Flunixin-treated calves also had lower cortisol concentrations at 4 and 8 hours after dehorning compared to placebo-treated calves. Meloxicam reduced heart rates and marginally affected nociceptive thresholds, while carprofen

was less effective, increasing cortisol and wound temperatures. Another study by Ede et al. (2019) examined the emotional impact of pain using calves disbudded with either meloxicam or ketoprofen in addition to local anesthesia. Calves treated with meloxicam showed a less aversive reaction to the location where the disbudding procedure took place than ketoprofen-treated calves, potentially because ketoprofen has a shorter duration of action. Lastly, Prior et al. (2023) compared a single injection of subcutaneous meloxicam and 3 days of oral sodium salicylate in 35-day-old calves undergoing cautery disbudding. Behavioural and growth performance outcomes showed no significant differences, indicating comparable effects between these two NSAIDs. Together, these studies demonstrate that while there are some differences in NSAID efficacy, the majority found that providing any NSAID yielded significant benefits compared to no pain relief, underscoring the importance of incorporating NSAIDs into pain management protocols for disbudding and dehorning. A more detailed systematic review is available by Wagner et al. (2021), although no general conclusions could be made from that analysis beyond that additional research is needed.

#### *2.5.4.3 Sedation*

The use of xylazine, a sedative with analgesic properties, has also been explored in beef and dairy calves. Caray et al. (2015) evaluated the impacts of cautery disbudding in 1- and 4-week-old dairy and beef calves and tested xylazine sedation combined with ketoprofen but without local anesthesia. Xylazine with ketoprofen reduced immediate stress responses such as salivary cortisol and heart rate, but pain responses persisted beyond 2 hours post-disbudding, with vocalizations continuing up to 7 hours after the procedure regardless of treatment group. Reedman et al. (2021) further explored xylazine use in Holstein calves alongside lidocaine and meloxicam. Sedated calves struggled less during disbudding, showed reduced pain sensitivity immediately after the procedure, and were more likely to play 24 hours later. However, sedation slowed milk drinking for up to 48 hours and reduced play in the first 3 hours. Both studies highlight that xylazine may mitigate immediate stress and pain sensitivity but has limited impact on long-term pain.

#### *2.5.4.4 Extending Pain Relief After Disbudding and Dehorning*

To address the prolonged pain associated with disbudding and dehorning, studies have explored additional doses of local anesthetic or NSAIDs. Reedman et al. (2022b) evaluated administering a second dose of meloxicam to 18- to 25-day-old Holstein calves 3 days after disbudding, following an initial lidocaine nerve block and meloxicam dose at the time of the procedure. While calves receiving 2 doses exhibited delayed wound healing, with larger wound diameters and slower re-epithelialization compared to those receiving 1 dose, they tended to show reduced mechanical nociception sensitivity at 7, 10, and 17 days and spent less time lying in the week following disbudding, suggesting improved pain relief. Adcock et al. (2020) examined the effects of lidocaine administered 11 days after disbudding on behavioural responses. Calves treated with lidocaine displayed fewer head shakes and ear flicks, indicating reduced pain, and increased head rubbing, suggesting diminished wound-protective behaviour. As the anesthetic wore off, head shaking and scratching increased, highlighting the return of wound sensation. Recently, a novel formulation of meloxicam-medicated pellet (120 mg of meloxicam/kg of pellet, fed at 1 kg of pellets per calf per day, resulting in a dose of at least 1 mg/kg, from the day before until 6 days after disbudding) explored the potential for provision of more sustained

NSAID delivery (Scerri et al., 2025). Calves receiving prolonged oral meloxicam via pellet had less wound inflammation and expressed fewer pain behaviours and more social behaviours compared to untreated calves; calves given a single dose of injectable meloxicam appeared to have similar short-term pain mitigation but poorer long-term mitigation. The findings of these studies together demonstrate that additional doses of analgesics may provide extended pain relief.

### **2.5.5 Future Research**

Future research should prioritize beef-specific strategies to improve outcomes in disbudding and dehorning practices, while also defining clear metrics to evaluate pain and welfare outcomes. Comparisons between methods, such as caustic paste and cautery, may be valuable given the number of beef producers using these techniques, enabling them to select the method that minimizes pain in calves. Additionally, few studies have compared dehorning methods across different calf ages, leaving gaps in understanding how age and method interact to influence pain and welfare. Pain mitigation strategies require further exploration, not only regarding the optimal timing and dosing of NSAIDs but also in terms of drug onset, half-life, and method of delivery (e.g., oral, injectable, or transdermal). Furthermore, understanding the combined effect of the pain mitigation strategy and the specific dehorning method is essential, as certain strategies may be more effective depending on the type of tissue damage caused and the length of healing time. The impact of greater handling stress in beef calves compared to dairy calves should also be considered in such studies. Finally, research should be directed towards identifying barriers to the uptake of pain mitigation strategies by producers, as this is critical for translating research findings into improved welfare outcomes on-farm.

## **2.6 Castration**

### **Conclusions:**

- 1. Castration causes significant short- and long-term pain, with sensitivity and behavioural indicators persisting for weeks or months after the procedure regardless of the age and method used, as evidenced by physiological and behavioural indicators.**
- 2. Younger calves heal more quickly and experience less overall pain and distress compared to older calves.**
- 3. Band castration causes less immediate pain but results in prolonged swelling and delayed healing, while surgical castration leads to greater acute pain but faster recovery.**
- 4. Combining local anesthetics and NSAIDs provides the most effective pain relief, addressing both immediate and prolonged discomfort at all ages of cattle assessed.**

- 5. The effect of pain control in castrated neonates is inconsistent and few studies have been conducted. Inconsistencies may be due to altered physiological and behavioural profiles in very young calves (0 to 7 days of age) associated with recent parturition or immature endocrine, digestive, and immune systems.**
- 6. Pain associated with knife-castration is more likely to be alleviated than band-castration since currently available pain control drugs are relatively short-acting.**

Castration is performed to prevent unwanted pregnancies, reduce aggression and mounting behaviour, and improve handling, ultimately leading to fewer injuries and reduced dark-cutting (Stafford & Mellor, 2005b; Marquette et al., 2023). Further, steers have higher quality meat, being more tender and marbled. Despite the benefits of castration, it is clear that all methods of castration cause pain as reviewed in the previous Review of Scientific Research on Priority Issues (Schwartzkopf-Genswein et al., 2012) and more recently by Coetzee (2013) and Marquette et al. (2023). Specifically, castration is associated with physiological stress markers, such as elevated plasma cortisol and increased heart rate, and behavioural responses, including avoidance, vocalizations, and changes in posture. Further, increased scrotal swelling and prolonged wound healing also occur as a result of castration. It is also important to note that most (72%) western Canadian beef producers agreed that castration was painful if a pain mitigation strategy was not used (Moggy et al., 2017); although only 10% of respondents reported using pain mitigation for castration. More recent estimates suggest that pain control is being more commonly implemented for castration. Specifically, in a survey of 600 producers across 9 provinces, 26.2% of producers reported always using pain mitigation during castration, and 20.4% used it depending on the age and method used (BCRC, 2024). The Canadian Cow-Calf Survey (BCRC, 2024) shows that 84.5% of calves are castrated at less than 3 months old and only 6.3% of producers typically castrate bull calves older than 6 months of age. A comprehensive review on this topic was recently published by Meléndez et al. (2025).

### ***2.6.1 Age of Animal***

The age at which calves are castrated influences their physiological, behavioural, and production responses. In the previous Review of Scientific Research on Priority Issues (Schwartzkopf-Genswein et al., 2012), it was concluded that the trauma caused by castration increases as the testes grow bigger, so castration at a younger age results in quicker healing and causes less pain and distress overall. Further, animals castrated at younger ages show lower declines in post-procedural growth rate. In more recent literature, similar findings have been noted.

Norring et al. (2017) observed faster wound healing in surgically castrated 0- to 8-day-old beef calves compared to those castrated at 69 to 80 days, with wounds closing in a median of 39 days versus 61 days. Further, younger calves recovered their daily weight gain quicker; however, they also experienced greater swelling and localized pain early in the healing process. Bergamasco et al. (2021) also found improvements in young Holstein calves, where those castrated at < 6 weeks old exhibited lower cortisol concentrations and faster recovery to baseline after surgical castration compared to 6-month-old calves. Younger calves also showed reduced autonomic nervous system activity, lower eye temperatures, and less stress overall, highlighting the benefits of early castration in mitigating physiological stress responses.

When evaluating Burdizzo castration, Marquette et al. (2021) reported that castration of 2.5-month-old beef calves was associated with lower cortisol concentrations and fewer pain-related behaviours compared to castration at 5 months. In band castrated beef calves, similar results were found, with calves castrated at 3 months of age healing faster and showing better liveweight gain over 45 days after castration compared to those castrated at 6 months of age (Petherick et al., 2015). It is important to note, however, that growth performance effects after castration are often masked over longer periods of time due to compensatory growths, so they should always be interpreted with caution when used as an indicator of pain and discomfort.

With respect to performance and carcass characteristics, Marti et al. (2017) found no differences in final body weight, average daily gain, or feed efficiency between Holstein calves castrated at 3 or 8 months, although earlier castration resulted in greater intramuscular fat and higher dressing percentages. Prado et al. (2014) similarly reported no differences in performance or carcass weight between Friesian calves castrated at 15 days or 5 months, though late castration altered muscle composition, increasing moisture and polyunsaturated fatty acids.

Based on these studies, younger calves generally exhibit faster healing, lower cortisol responses, and better growth recovery post-castration compared to older calves. While early castration may result in increased short-term swelling, it minimizes the duration of physiological and behavioural stress, suggesting it may be the preferred option for welfare and production outcomes.

### **2.6.2 Castration Method**

The main methods used for castration in Canada are banding and surgical castration. Moggy et al. (2017) surveyed 109 producers in western Canada and reported that among the 10,893 calves included, 53% were band castrated at less than 1 week of age, 26% were surgically castrated between 1 week and 3 months of age, and 15% were band castrated within the same age range. The Canadian Cow-Calf Survey (BCRC, 2024) indicated that 80.2% of calves were castrated using rubber bands, 18.3 % were castrated using surgical methods (e.g., blade or scalpel) and 1.2% used clamp or Burdizzo methods.

Differences between knife and band castration have been evaluated with these methods differing significantly in their acute and chronic effects, with distinct patterns of pain, stress, and recovery.

Meléndez et al. (2017a) examined acute pain in beef calves castrated using different methods at 1 week, 2 months, and 4 months of age. Knife castration caused the greatest immediate pain responses, with 1-week-old calves showing increased tail flicking 2 to 4 hours post-castration compared to banded calves. In 2-month-old calves, knife castration resulted in elevated cortisol, reduced lying and eating, and increased standing and walking, while band castration caused less immediate discomfort. In 4-month-old calves, band castration produced the highest cortisol concentrations, indicating prolonged stress compared to the intermediate responses observed with knife castration. Marti et al. (2017), following the same cohort of calves, found no differences in chronic markers of pain; however, swelling and inflammation were prolonged in band-castrated calves, particularly older animals.

Further studies corroborated these findings. Meléndez et al. (2018a) demonstrated that knife castration in 1-week-old beef calves caused more acute pain, with significantly higher cortisol and serum amyloid A (SAA) concentrations compared to band castration. Marti et al. (2018), who followed the same cohort, reported faster wound healing in knife-castrated calves with swelling resolving sooner, whereas band castration resulted in prolonged swelling. Knife-castrated calves also exhibited lower serum amyloid A concentrations from days 7 to 35 compared to band-castrated calves, indicating a reduced inflammatory response. When evaluating the impact of medicating calves with a subcutaneous injection of meloxicam as part of the castration procedure, they observed that hair cortisol concentrations were highest at day 56 in non-medicated band-castrated calves compared to medicated band-castrated calves and both medicated and unmedicated knife-castrated groups. Similarly, in 2-month-old beef calves, Gellatly et al. (2021) found knife castration caused intense acute pain, with increased standing, walking, tail flicking, and foot stamping during the first 11 hours post-castration. Knife castration also resulted in pain sensitivity lasting through days 6 to 34, while band castration led to prolonged sensitivity until day 62, with swelling persisting until day 34.

In older calves, similar patterns have been observed. Nordi et al. (2019) reported prolonged cortisol elevation and higher pain scores in knife-castrated compared to band castrated 6-month-old beef calves. Knife castration also resulted in longer meal durations and higher scrotal temperatures, indicating greater discomfort, while band castration caused moderate stress responses with cortisol peaking earlier and resolving more quickly. In 7-month-old beef calves, Moya et al. (2014) found that surgical castration led to more acute pain, characterized by elevated cortisol levels, higher visual analog pain scores, and significant reductions in average daily gain during the first week post-castration. Band castration, on the other hand, caused prolonged inflammation, with scrotal temperatures peaking around week 4 and persistent reductions in average daily gain during weeks 2, 3, 6, and 7. Finally, Roberts et al. (2015) examined feedlot cattle (approximately 8 months old) undergoing surgical and band castration. Surgical castration resulted in greater acute inflammation, as indicated by elevated haptoglobin levels and increased standing times immediately after the procedure. In contrast, band castration led to prolonged lying bouts and higher step counts, suggesting extended discomfort. Although surgically castrated cattle experienced reduced average daily gain during the first week, they recovered more quickly, with improved average daily gain from day 14 onward compared to band-castrated cattle.

Gonadotropin-releasing hormone (GnRH)-immunocastration offers a non-surgical alternative to castration in bulls, with evidence supporting that it suppresses testicular function reducing the negative effects of testosterone caused during the male reproductive development (Marti et al., 2015). However, Wang et al. (2023) have also described immunization failures due to insensitivity to antigens in some individuals, causing failure to elicit an immune response or a shorter duration of immune effect. These, along with the risk of accidental self-injection by farm workers (Weese & Jack, 2008) and uncertainty regarding consumer attitudes toward meat from pharmacologically castrated animals (Font-i-Furnols et al., 2022), has prevented immunocastration from being considered a real alternative to invasive castration procedures.

These studies highlight that castration methods differ significantly in their acute and chronic effects, with distinct patterns of pain, stress, and recovery observed across various ages. Knife castration consistently results in greater acute pain and stress, particularly in younger calves, but

allows for faster recovery, with inflammation and swelling resolving more quickly. In contrast, band castration causes less immediate discomfort but leads to delayed and prolonged inflammatory responses, with swelling and stress indicators persisting for weeks, particularly in older calves. These findings highlight the trade-offs between methods, emphasizing the need to balance welfare concerns with practical considerations when selecting a castration method. Importantly, the timing and duration of pain also influence pain management strategies, as acute pain is often easier to mitigate than chronic pain, particularly in beef cattle where frequent handling for repeated treatment may not be practical.

### ***2.6.3 Pain Mitigation for Castration***

The scientific literature about pain control for castration of cattle has recently been reviewed by Nogues et al. (2025). The results of their meta-analysis concluded that local anesthesia in combination with an NSAID was most effective in lowering serum cortisol in calves compared to control untreated calves for the first 4 hours after surgical castration. There was inadequate available information to assess any other types of pain mitigation, methods of castration, or outcome measures.

#### ***2.6.3.1 Local Anesthetic Alone***

The previous Review of Scientific Research on Priority Issues (Schwartzkopf-Genswein et al., 2012) concluded that local anesthesia reduces immediate pain from castration but neither eliminates it nor alleviates longer-term post-operative pain. Recent studies support this conclusion. Webster et al. (2013) found that Holstein × Friesian calves treated with local anesthesia 20 minutes prior to surgical castration exhibited transient cortisol increases, including a second spike 120 minutes after injection. These calves also displayed more pain-related behaviours such as head turning, statue-like standing, and postural changes compared to a sham group, indicating that local anesthesia alone does not fully mitigate the pain of castration. Meléndez et al. (2018b) found that lidocaine administered 30 minutes prior to surgical castration mitigated the signs of pain expressed by 7- to 8-month-old beef calves. Specifically, it reduced salivary cortisol concentrations within an hour of castration, resulted in fewer pain-related behaviours, including reduced visual analog scale scores (a measure of pain intensity), leg and head movements, and escape attempts, and lower serum amyloid A levels on days 1, 3, 21, and 28 compared to the control calves castrated without lidocaine. However, lidocaine had no impact on average daily gain, weight, or feeding behaviour. Together, these findings suggest that while lidocaine may be effective at reducing acute pain and stress responses during castration, it does not address longer-term discomfort or improve overall performance outcomes.

Recent studies highlight the potential benefits of lidocaine-impregnated castration bands as a method for pain mitigation during band castration. Saville et al. (2020) demonstrated that lidocaine-impregnated bands release lidocaine rapidly within the first 30 minutes, followed by sustained delivery for at least 48 hours. The sensitivity of the skin immediately above where the lidocaine-impregnated band was allocated was the same as that provided by injected lidocaine for up to 48 hours post-application, as measured via electrostimulation in 3- to 4-week-old and 5-month-old calves. Seven days after band application, calves with lidocaine-impregnated bands showed reduced sensitivity to electrostimulation and higher lidocaine concentrations in scrotal tissue compared to those receiving injectable lidocaine. No differences were observed between

groups in growth, tail flicks, or average heart rate. Similarly, Ross et al. (2024) compared the effectiveness of injectable lidocaine and lidocaine-impregnated castration bands for pain management during castration. Injectable lidocaine provided short-term anesthesia lasting up to 60 minutes, as indicated by response scores to electrocutaneous stimulation, but these scores returned to baseline by 90 minutes. Tissue concentrations of lidocaine also declined rapidly, with minimal levels detected at 240 minutes post-administration. In contrast, lidocaine-impregnated castration bands achieved effective tissue concentrations at 2 and 72 hours and sustained them above effective tissue concentration thresholds for at least 28 days. A study by Moya et al. (2024) found that injectable lidocaine provided pain relief for up to 60 minutes, while lidocaine-impregnated bands achieved effective tissue concentrations by 2 hours, peaked at 72 hours, and remained above effective levels for 28 days. Mancke et al. (2025) compared lidocaine-impregnated to non-medicated bands in dairy-beef cross calves under 2 weeks of age and found that the medicated bands improved ADG and feed efficiency and reduced behavioural signs of pain (increased lying and reduced wound licking) over a 49-day period post-castration. These results suggest that lidocaine-impregnated castration bands may offer some potential for prolonged pain mitigation as an alternative to injectable anesthetics, though further research is needed to evaluate their effectiveness, particularly when combined with NSAIDs.

#### 2.6.3.2 *Non-Steroidal Anti-Inflammatory Drugs Alone*

NSAIDs are the most frequently used option when pain control is applied for castration (Moggy et al., 2017). This section reviews the effectiveness of NSAIDs in managing castration pain, focusing on meloxicam, ketoprofen, flunixin, and their comparative efficacy. Studies explore variations based on timing, administration methods, and type of NSAID used. This topic has also been reviewed thoroughly by Wagner et al., 2021.

**Meloxicam.** Meloxicam has been widely studied for its effectiveness in reducing pain associated with castration. Crevier et al. (2024) reported significantly fewer pain behaviours, such as licking and tail flicking, in newborn Angus calves treated with either oral or injectable meloxicam during band castration, compared to calves band castrated without pain control, though weight gain was unaffected. Similarly, Meléndez et al. (2018a) found lower markers of acute pain, including substance P and tail flicks, in 1-week-old Angus calves treated with meloxicam compared to those without pain control during knife or band castration, though no improvements were observed in eating or standing behaviours. In contrast, a study by Brown et al. (2015) in knife-castrated beef calves found that that surgical castration performed near birth, with or without oral administration of meloxicam, had no effect on growth and little effect on behaviour or inflammation, so the impact of meloxicam on pain mitigation could not be demonstrated in neonate bulls. Chronic pain evaluations by Marti et al. (2018) showed that a single dose of subcutaneous administration meloxicam at the time of band castration reduced hair cortisol in 1-week-old calves at 56 days post-castration but did not improve wound healing or inflammation compared to no pain control. It should be noted that there is a lack of understanding of pain in very young calves (0- to 7-days-of-age) due to the fact that physiological profiles of calves at this age may be confounded by recent parturition as well as immature endocrine, digestive, and immune systems (Hulbert & Moisé, 2016). Similarly, the behavioural response to pain in neonates is poorly understood, and the absence of significant findings in observable pain expression may not fully reflect what the animal is experiencing, highlighting that assessments conducted in calves under 1 week of age require careful interpretation (Meléndez et al., 2025).

In older calves, Gellatly et al. (2021) observed limited effects of meloxicam in 2-month-old beef calves undergoing band or knife castration. Although meloxicam-treated calves exhibited increased suckling behaviour, there were no differences in acute or chronic pain markers compared to calves without pain control. Daniel et al. (2020) assessed the effects of oral meloxicam compared to no pain control in 3-month-old beef calves undergoing band castration. While no differences were found on average daily gain, fibrinogen, or haptoglobin, meloxicam-treated calves exhibited fewer steps and more lying bouts during the second week post-castration, indicating potential improvements in comfort. In 4- to 5-month-old Holstein calves, Olson et al. (2016) demonstrated that meloxicam reduced pain and inflammation following band castration, with treated calves showing lower heart rates, cortisol concentrations, and scrotal swelling compared to untreated calves. In feedlot cattle, Roberts et al. (2018) reported improved performance in those band or surgically castrated with meloxicam, including reduced inflammation and increased average daily gain and backfat thickness compared to untreated cattle. Brown et al. (2015) found that oral meloxicam reduced serum haptoglobin and improved ADG in weaned, knife-castrated calves.

Regarding the type of meloxicam to use, Meléndez et al. (2019) compared oral and subcutaneous meloxicam in knife-castrated calves and found minor pharmacokinetic differences, with oral administration showing faster drug clearance, potentially leading to a shorter duration of therapeutic effects compared to the subcutaneous route. Despite these differences, both routes provided comparable practical efficacy for pain management. With respect to timing of meloxicam administration, Meléndez et al. (2017b) found that administering meloxicam immediately before knife castration in 7- to 8-month-old calves was most effective, reducing substance P, scrotal temperature, and pain-related behaviours compared to those that received meloxicam 3 and 6 hours after the procedure.

Recent literature has explored other approaches for the oral administration of meloxicam, highlighting the need for extended analgesia beyond the typical 48-hour window provided by injections. Rudd et al. (2025) tested the ad libitum oral self-administration of meloxicam via molasses lick blocks in surgically castrated calves. Results showed that calves consuming the lick blocks had higher plasma meloxicam concentrations at most timepoints than those with a subcutaneous meloxicam injection, although with great individual variability leading to inconsistent plasma levels. Despite this, calves in the lick block group showed improved wound healing and reduced pain-related behaviours. The lick block method, therefore, offers a non-invasive, practical, and potentially long-acting route for pain relief, but dose control remains a challenge.

***Ketoprofen.*** Moya et al. (2014) evaluated the effects of single and multiple intramuscular injections of ketoprofen (administered 30 minutes before castration and at 1, 2, 4, 5, and 6 days post-castration) in beef calves undergoing either surgical or band castration. The study compared calves receiving ketoprofen to untreated calves (i.e., no pain control) for both castration methods. Ketoprofen showed limited efficacy, with minimal effects on scrotal temperature, salivary cortisol, white blood cell counts, and behavioural responses associated with pain. Additionally, reductions in average daily gain and feed intake observed in untreated castrated calves were not mitigated by ketoprofen treatment.

**Flunixin.** Kleinhenz et al. (2018) evaluated transdermal flunixin meglumine in 9-month-old Holstein calves undergoing surgical castration without local anesthesia. Flunixin reduced plasma cortisol concentrations during the first 12 hours post-castration, indicating a reduction in acute stress. However, no differences were observed in other pain markers compared to untreated controls, including infrared thermography, gait analysis, or substance P levels, suggesting limited broader analgesic effects.

**Meloxicam versus flunixin.** Cull et al. (2022) compared no medication, oral meloxicam, and intravenous flunixin meglumine in beef calves castrated with the Henderson tool technique. When looking at the effects on the visual analog scale pain scores as a measure of pain intensity, both meloxicam and flunixin reduced behavioural indicators of pain compared to the no pain control group (on days 1 to 3 and on day 1, respectively), with no significant differences between the two treatment groups.

Cumulatively, the studies summarized above indicate that meloxicam has demonstrated consistent effectiveness in reducing pain behaviours, acute inflammation, and chronic stress across various castration methods and calf ages over 1 week of age. Injectable and oral formulations perform similarly, and immediate administration yields the most significant benefits. Ketoprofen at a single time seems to provide minimal analgesic benefits, particularly for behavioural and performance outcomes, while flunixin effectively reduces acute cortisol levels but lacks prolonged efficacy. Compared to flunixin, meloxicam offers longer-lasting relief, likely making it a preferred option for managing castration pain.

### 2.6.3.3 *Combination of Pain Control Methods*

Combining local anesthetics with NSAIDs can address both immediate and prolonged discomfort. Local anesthetics target acute pain at the site of castration, while NSAIDs reduce inflammation and extend pain relief over time. This section reviews studies evaluating the combined use of these pain control methods.

**Local anesthetic and meloxicam.** Meléndez et al. (2018b) investigated the effects of meloxicam, lidocaine, and their combination in 7- to 8-month-old Angus calves undergoing knife castration. Lidocaine effectively reduced acute pain during castration, lowering salivary cortisol levels within the first hour and decreasing pain-related behaviours, such as escape attempts and leg and head movements. Meloxicam provided longer-lasting effects, reducing haptoglobin and cortisol concentrations at 24 and 48 hours post-castration. Additionally, calves treated with both lidocaine and meloxicam exhibited less scrotal swelling. Given that lidocaine and meloxicam impacted physiological and behavioural pain parameters at different time points, the authors concluded that their combined use was more effective at mitigating pain than either drug alone.

Martin et al. (2022a) also evaluated multimodal pain management, where bupivacaine, lidocaine, and lidocaine combined with meloxicam were evaluated in 16- to 20-week-old Holstein calves undergoing surgical castration. The administration of lidocaine alongside meloxicam resulted in the lowest concentrations of prostaglandin E2 metabolites and cortisol, as well as the fewest pain-related behaviours, such as hunched standing, compared to calves castrated without pain control. Additionally, gait improvements were also found in calves administered the

combination. Results were comparable to those seen with bupivacaine liposome suspension, a long-acting local anesthetic.

Laurence et al. (2016) found similar benefits in 6- to 8-month-old Brahman bulls undergoing surgical castration. The combination of lidocaine and post-operative meloxicam reduced cortisol levels on day 1, increased activity, and improved weight gain over 13 days compared to calves treated with either drug alone. Vindevoghel et al. (2019) further noted that calves receiving lidocaine and meloxicam were calmer and more alert post-castration compared to those castrated without pain control.

***Local anesthetic and flunixin.*** Nordi et al. (2019) evaluated flunixin meglumine combined with lidocaine in 6-month-old Angus calves undergoing knife or band castration. The combination significantly reduced salivary cortisol levels for up to 48 hours post-castration, improved feeding behaviour, and moderated increases in scrotal and eye temperatures compared to untreated control. Pain-related behaviours were also alleviated, suggesting effective pain control across both immediate and extended periods. Webster et al. (2013) also evaluated the effects of flunixin combined with a local anesthetic block in 2- to 30-month-old Holstein-Friesian calves. Local anesthetics alone temporarily reduced cortisol concentrations but was also associated with increased head turning and reduced feeding. Flunixin alone improved feeding behaviour and reduced crouching. However, the combination provided the most effective relief, minimizing behavioural pain indicators and reducing cortisol to baseline levels, comparable to sham-castrated calves.

These studies find that combining local anesthetics with NSAIDs provides superior pain relief compared to using either method alone. Local anesthetics, such as lidocaine, effectively mitigate immediate procedural pain, while NSAIDs, like meloxicam and flunixin, address systemic inflammation and extend analgesic effects. Studies consistently highlight the benefits of these combinations, including reductions in pain markers, fewer pain-related behaviours, and enhanced performance.

#### **2.6.4 Future Research**

Future research should aim to improve pain control methods for castration, focusing on options that balance efficacy with practicality for producers. In particular, on-farm evaluations of combination therapies to manage both immediate and prolonged pain are needed. Significant knowledge gaps exist regarding the effects of different castration methods, such as knife castration with a scalpel or Henderson tool, cutting versus pulling the spermatic cord, incision type, band tension, and placement on the testes, as well as their interactions with calf age and pain mitigation strategies. Additionally, alternatives to traditional castration, such as the use of GnRH vaccination, warrant further investigation as potential solutions to avoid testes removal and the associated pain. Finally, qualitative research, including interviews and focus groups, could provide valuable insights into producer perceptions, barriers, and motivators for adopting pain mitigation practices, helping to inform education and outreach efforts.

## 2.7 Branding

### Conclusions:

- 1. Branding causes significant short- and long-term pain, with sensitivity and behavioural indicators persisting for weeks or months post-procedure.**
- 2. Larger brand sizes and combining branding with other invasive procedures, such as castration, exacerbate pain-related behaviours and discomfort.**
- 3. Using NSAIDs like meloxicam and flunixin only provides limited pain relief, reducing some acute pain behaviours but failing to alleviate long-term pain or accelerate healing.**
- 4. Combining pain control methods, such as NSAIDs, with local anesthesia show mixed results, with minimal improvements in pain-related behaviours or healing rates.**
- 5. Future research should focus on multimodal pain management strategies, optimal branding techniques and timing, and evaluating and promoting alternative identification methods to improve welfare, minimize pain, and reduce the risks associated with improper application and substandard tools.**

Branding has long been a traditional method of livestock identification, serving essential purposes such as signifying ownership, deterring theft, distinguishing commingled cattle, and fulfilling requirements for interstate and international transportation. In a survey of 94 cow–calf producers in western Canada, it was estimated that 54% of calves represented were branded (Moggy et al., 2017). In this same study, only 4% of respondents reported using freeze branding, compared to 52% who reported using hot iron brands; or, looked at another way, 92% of producers who reported branding used hot iron brands. However, over 21% of these indicated they only branded a portion of their herd.

Branding causes significant pain and requires extended healing time. The previous Review of Scientific Research on Priority Issues (Schwartzkopf-Genswein et al., 2012) concluded that both freeze branding and hot iron branding cause pain and distress in cattle. More recent work has highlighted the persistent pain associated with branding. For example, Tucker et al. (2014a) found that hot iron branding in 4-month-old cattle led to sensitivity to pressure that peaked 7 days after the procedure and persisted for at least 71 days. Healing was also slow, with only 67% of brands fully healing by day 71 and the first complete healing observed 8 weeks post-branding, highlighting the potential for prolonged discomfort. Building on these findings, Keogh et al. (2024) found in 2-month-old beef calves that larger hot iron brand sizes increased pain-related behaviours, such as tail flicking and restlessness. Behavioural responses varied over time, with standing behaviour spiking 6 hours after branding and peaking at 24 hours. When branding was combined with castration, pain-related behaviours intensified, demonstrating the additive effects of multiple painful procedures performed at the same time. In Nellore calves, de Oliveira et al. (2024) found that hot iron branding increased skin temperatures at the branding site for up to 2 days. Additionally, electronic ear tags were found to be faster and more accurate for cattle identification than hot iron branding, though tag retention has been noted as an issue. Despite the

evidence of pain associated with branding, the use of pain mitigation remains uncommon. A Canadian survey revealed that while 85% of cow–calf operators agreed that branding was painful if pain management was not used, only 4% implemented pain relief practices (Moggy et al., 2017).

### ***2.7.1 Pain Mitigation for Branding***

The studies summarized below collectively highlight the ongoing challenges of effectively mitigating the pain caused by hot iron branding. While interventions like meloxicam show some efficacy, they offer only limited relief and fail to address the long-term pain and delayed healing associated with the procedure. Developing comprehensive, multimodal strategies or alternative procedures for animal identification remain essential for improving animal welfare.

#### *2.7.1.1 Non-Steroidal Anti-Inflammatory Drugs Alone*

Tucker et al. (2014a) investigated the use of flunixin meglumine in 4-month-old calves, finding that while the drug improved weight gain shortly after branding and influenced lying behaviour on specific days, it did not alleviate brand-specific pain sensitivity, surface temperature, or healing. Further, pain persisted for at least 71 days post-branding, and a single injection of flunixin provided no measurable relief. Similarly, Martin et al. (2022b) evaluated the effects of oral meloxicam in branded yearling cattle. Meloxicam reduced prostaglandin E2 metabolites at 6, 24, and 48 hours post-branding and minimized infrared thermography differences, an indicator of inflammation and burn severity, between branded and unbranded sites. Treated calves also exhibited fewer lying bouts in the first 12 hours, which may indicate reduced restlessness and immediate discomfort. However, meloxicam did not effectively reduce pain-associated biomarkers or behavioural responses. Finally, Keogh et al. (2024) investigated the effects of oral meloxicam in 2-month-old beef calves of both sexes undergoing hot iron branding. Meloxicam reduced the proportion of branded heifers displaying pain-related behaviours compared to untreated calves; however, its analgesic effect of meloxicam was less evident in calves that were both branded and castrated.

#### *2.7.1.2 Combination of Pain Control Methods*

Hernandez et al. (2022) examined interventions to manage pain in 92 Nellore heifer calves subjected to hot iron branding on the cheek, a practice banned in many regions worldwide. The study compared no pain relief, subcutaneous local anesthesia administered at the branding site, systemic meloxicam, and a combination of both local anesthesia and systemic analgesia. Although untreated calves exhibited more tension in masticatory muscles 5 days post-branding, no significant differences in behaviour, speed of exit from the squeeze chute, or weight gain were observed across treatments over 60 days. The limited detected effect of these pain management protocols may reflect confounding factors, such as stress and fear during handling or other factors related to study design, underscoring the complexity of addressing welfare concerns, particularly for the facial location of branding in this study.

### 2.7.1.3 *Alternative Methods of Pain Control*

Exploring non-pharmaceutical methods, Tucker et al. (2014b) explored the potential of a cooling gel with tea tree oil to mitigate branding pain and improve skin healing. Although the gel lowered surface temperatures immediately after application, it did not reduce pain sensitivity or accelerate healing. Brands remained painful throughout the 70-day study, with over half of wounds still unhealed by the end. In one of the groups, where gel was applied twice, delayed healing was found compared to single applications or controls, suggesting potential negative effects.

### 2.7.2 *Future Research*

Future research should focus on alternative methods to branding, such as electronic identification or biometrics, to evaluate their efficacy and welfare impacts. Current pain mitigation strategies, including NSAIDs and local anesthetics, provide only limited relief, underscoring the need for more effective multimodal approaches that address both acute and prolonged pain. Additionally, little is known about how specific branding methods interact with factors such as the animal's age, the location on the body where the procedure is performed, and the effectiveness of various pain mitigation strategies, underscoring the need for further research. Furthermore, research should consider the method and technique of branding, as improper application or the use of substandard tools may contribute significantly to increased pain, swelling, and the risk of secondary infections.

## 2.8 Painful Health Conditions

### Conclusions:

- 1. BRD elicits a clear sickness response, including fever, reduced activity, altered lying behaviour, and decreased feed intake. Evidence of hyperalgesia and increased pain scores suggests that pain is likely a component of the condition.**
- 2. Lameness leads to altered mobility, reduced activity, and production losses, highlighting the pain associated with this condition.**
- 3. The use of NSAIDs has shown potential in alleviating pain and clinical symptoms in both BRD and lameness, but further research is needed to better understand their efficacy and optimize treatment protocols.**

In addition to the painful procedures and conditions discussed earlier, certain health issues can also cause significant pain in beef cattle. Two primary examples are lameness and BRD.

### 2.8.1 *Bovine Respiratory Disease*

BRD is the most prevalent illness affecting beef cattle, yet the extent of pain associated with this condition remains unclear. Evidence from existing literature suggests that cattle alter their behaviour during episodes of respiratory disease. For instance, a systematic review in feedlot

cattle (Wolfger et al., 2015) found that cattle with BRD exhibit significant behavioural changes, including reduced activity, decreased feeding time and intake, increased lying time, and altered movement patterns, which often precede visible clinical signs of the disease. Further, in beef heifers, Toaff-Rosenstein and Tucker (2018) found that fever occurred 2 days prior to and on the day of BRD diagnosis, although feeding time was only reduced on the day of diagnosis. In this study, it was also found that BRD did not affect brush use, though behaviour was influenced by acclimation to a novel grooming device. In young beef bulls with BRD, Marchesini et al. (2018) reported reduced daily activity and rumination several days before clinical signs became evident. Pillen et al. (2016) also observed that feedlot beef calves experienced declines in activity levels up to 6 days prior to BRD detection, with the most significant reductions occurring the day before diagnosis. Toaff-Rosenstein et al. (2016) described a clear sickness response in BRD-induced steers, including fever, reduced dry matter intake, lower average daily gain, increased total lying time, longer lying bouts, reduced grooming, and hyperalgesia, as indicated by lower mechanical nociceptive thresholds. Further supporting the association between BRD and pain, Martin et al. (2022c) demonstrated that Holstein steers with experimentally induced BRD exhibited reduced activity, decreased force on the right front limb, and increased visual analog scale pain scores. These findings collectively highlight the complex sickness response associated with BRD and suggest that pain is a likely component, though further research is needed to fully understand its impact and implications for welfare and management practices.

#### *2.8.1.1 Non-Steroidal Anti-Inflammatory Drugs Use for Bovine Respiratory Disease*

Several studies have explored the use of NSAIDs as an ancillary treatment for BRD in combination with an antibiotic in both beef and dairy cattle.

**Beef cattle.** Several studies have evaluated the use of NSAIDs as ancillary treatments for BRD in beef cattle. Bednarek et al. (2003) demonstrated that calves treated with meloxicam in combination with oxytetracycline showed faster clinical improvement and more rapid normalization of body temperature compared to oxytetracycline alone. Lockwood et al. (2003) assessed flunixin, ketoprofen, and carprofen in combination with ceftiofur for treating BRD in 66 beef cattle. The NSAID-treated groups experienced faster reductions in fever, with flunixin and ketoprofen acting most rapidly, and flunixin significantly reducing lung consolidation compared to ceftiofur alone. In 280 cattle of various breeds with BRD, De Koster et al. (2022) compared tulathromycin alone to tulathromycin combined with ketoprofen. While both treatments had high success rates and low relapse rates, the tulathromycin-ketoprofen combination provided better temperature control within the first 24 hours and faster improvement in respiration and depression scores. In 264 fattening bulls with BRD, Masebo et al. (2024) compared individual antimicrobial treatment, metaphylactic tulathromycin, and tulathromycin combined with a second antimicrobial, with 128 bulls also receiving NSAIDs in addition to these treatments. Bulls treated with NSAIDs showed higher white blood cell counts, neutrophil counts, and neutrophil-to-lymphocyte ratios compared to those not administered NSAIDs, and fewer cattle with lung lesions at slaughter. It is important to note that not all studies have shown a positive effect. For example, in an experimental BRD model, Toaff-Rosenstein et al. (2016) found that meloxicam administered alongside an antibiotic had limited impact, with no significant effects observed apart from an interaction with lying time. The authors attributed the lack of differences with NSAID therapy to study design limitations, namely the small sample size likely causing the study to be too underpowered to detect a difference.

**Dairy cattle.** In young dairy calves, the efficacy of NSAIDs as supplemental treatments for BRD has been explored in multiple studies. Guzel et al. (2010) found that Holstein calves with BRD treated with either diclofenac sodium or flunixin meglumine, in addition to tulathromycin, showed improvement in clinical signs, such as pyrexia and respiratory rate, within 48 hours compared to antibiotic treatment alone, with diclofenac achieving the greatest reduction in pyrexia. In 6- to 7-month-old Holstein steers with experimentally induced BRD, Martin et al. (2022c) demonstrated that administration of transdermal flunixin led to increased force applied to the right front limb by affected calves and improved activity levels compared to untreated BRD calves. Achard et al. (2018) evaluated the efficacy of combining florfenicol with either meloxicam or flunixin in 40-day-old dairy calves with experimentally induced BRD. Both combinations significantly reduced rectal temperature and clinical scores compared to saline-treated calves, with cure rates of 100% for the florfenicol-meloxicam group and 96.6% for the florfenicol-flunixin group, whereas the saline group had a cure rate of only 29.6%. It was also noted that calves treated with florfenicol and meloxicam were cured more quickly and experienced fewer relapses than those treated with florfenicol and flunixin. Similar to above, not all the studies found a positive effect. Ferree et al. (2023) did not detect differences in growth, behavioural attitude, or clinical and lung ultrasound scores when a single dose of oral meloxicam was administered alongside tulathromycin compared to tulathromycin alone at the onset of respiratory disease in preweaned dairy calves, although again, this may be related to study design rather than a true lack of difference.

In summary, NSAIDs have shown potential as ancillary treatments for BRD in both beef and dairy cattle, offering benefits such as faster clinical recovery and reduced fever when combined with antibiotics. However, further research is needed to better understand their likely efficacy and to optimize treatment protocols for different contexts, including addressing pain associated with BRD.

### **2.8.2 Lameness**

Lameness is a common condition in the beef industry (Erikson et al., 2024). Erickson (2023) conducted a retrospective analysis of 1,772,565 cattle in 28 western Canadian feedlots (2014–2018) and found that lameness represented 28.5% of all treatments, with foot rot, digital dermatitis, and toe-tip necrosis syndrome comprising 71.8% of lameness cases. Marti et al. (2021), who evaluated records from 9,719 calves from 2 Alberta feedlots, also found a similar proportion of treatments being attributed to lameness (36.3% of all treatments), with the most common diagnoses being foot rot, digital dermatitis, upper-limb lameness, joint infections, injuries, and toe-tip necrosis syndrome. Davis-Unger et al. (2019) highlighted similar trends, noting that lameness was influenced by cattle type and sex, with foot rot being most prevalent (74.5% of lameness cases) and joint infections accounting for nearly half of lameness-associated deaths. Their findings also revealed a significant association between BRD and subsequent lameness diagnoses, underscoring the importance of early intervention and targeted resource allocation for at-risk groups.

As reviewed by Coetzee et al. (2017), lameness is a painful condition in which cattle alter their mobility and posture, exhibiting behaviours such as head bobbing, arching the spine, and changing stride length due to pain experienced during walking and standing. In beef cattle, several studies have explored the impact of digital dermatitis. Thomas et al. (2022a) found that

digital dermatitis in feedlot cattle is strongly associated with pain-related gait abnormalities, including reluctance to bear weight and asymmetric gait, particularly in cattle with active lesions, although a substantial proportion of cattle with digital dermatitis did not show visible pain-related behaviours. In beef heifers, Thomas et al. (2021) investigated the behavioural changes associated with digital dermatitis and found heifers with digital dermatitis spent less time ruminating and more time inactive compared to unaffected heifers, with those exhibiting active lesions showing the most pronounced changes in behaviour. Further, Thomas et al. (2022b) provided objective evidence that digital dermatitis causes significant pain, as cattle with affected feet, especially those with active lesions, showed reduced mechanical nociceptive thresholds, indicating heightened pain sensitivity. Pain was most severe in lame cattle, who also exhibited higher foot temperatures linked to inflammation. Beyond the behavioural changes, there are also production consequences, with Kulow et al. (2017) finding that indoor-housed feedlot cattle with digital dermatitis had a lower average daily gain, final body weight, and hot carcass weight. Although most of the research has focused on lesions in the foot, pain occurs regardless of cause of lameness, whether septic arthritis, laminitis, musculoskeletal injuries, or diseases of the feet.

#### *2.8.2.1 Non-Steroidal Anti-Inflammatory Drugs Use for Lameness*

Several studies have investigated the use of NSAIDs for lameness in cattle, with most focusing on dairy cows (as reviewed by Roche et al., 2024). Field studies evaluating ketoprofen have demonstrated several benefits, including improved weight distribution across all four limbs and more symmetrical steps in cows with abnormal gait (Flower et al., 2008), higher recovery rates from lameness 35 days post-treatment when used alongside therapeutic trimming (Thomas et al., 2015), reduced risk of culling when administered at the onset of lameness (Wilson et al., 2022), and a lower likelihood of persistent lameness with increased milk yield during treatment for digital dermatitis (Kasiora et al., 2022). Beyond ketoprofen, Warner et al. (2021) found that oral meloxicam or intravenous flunixin administered at the onset of induced lameness in dairy cattle led to reduced lameness severity, as assessed by visual lameness scoring and lower cortisol levels compared to the placebo group. Mason et al. (2022) conducted a systematic review assessing NSAID use during the treatment of claw-horn lesions in dairy cows. Although NSAIDs showed a tendency to reduce lameness risk and increase nociceptive thresholds in some comparisons, significant differences were not consistently observed across outcomes, and substantial heterogeneity was reported. Similarly, Sadiq et al. (2024) conducted a systematic review of 10 studies evaluating claw-horn lesion treatment, finding that cows treated with a hoof block or a combination of a block and NSAID alongside claw trimming had higher rates of complete lameness resolution and faster recovery compared to claw trimming alone. However, this review also noted considerable heterogeneity across studies.

Very few studies have evaluated the use of pain control in lame beef cattle. In beef calves with experimentally induced lameness, Coetzee et al. (2014) found that calves treated with meloxicam had increased activity and improved weight distribution compared to placebo, while the combination of meloxicam and gabapentin showed additional benefits in pressure and force metrics. Nagel et al. (2016) evaluated the use of oral meloxicam in 53 beef cattle with musculoskeletal lameness and found that when lameness was reassessed 3 days after treatment, 92.8% of meloxicam-treated cattle showed reduced lameness scores compared to only 12% of control animals.

### **2.8.3 *Future Research***

Future research should focus on better understanding pain mechanisms in lameness and BRD to improve treatment strategies. While NSAIDs show promise, more studies are needed, especially in beef cattle, to evaluate their long-term effects on welfare and productivity. Early pain detection methods, such as behavioural and physiological indicators, and multimodal treatments combining NSAIDs with other approaches, warrant further exploration.

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### 3 Health Conditions at Different Stages of Production

#### 3.1 Health Management in the Cow–Calf Sector

##### Conclusions:

1. **Respiratory disease, diarrhea, and umbilical infections remain the leading causes of calf morbidity in Canadian cow–calf herds, although overall antimicrobial use remains relatively low.**
2. **Earlier calving seasons (December to March) and longer calving seasons are consistently associated with higher risks of treatment for calf disease, mortality, and outbreaks of diarrhea and respiratory disease.**
3. **Management practices such as providing timely colostrum, intervening after difficult calvings, and minimizing herd mixing are key strategies associated with improved calf health outcomes.**
4. **Vaccination of dams against diarrhea-related pathogens, particularly *Escherichia coli*, is associated with reduced disease risk, while evidence for respiratory disease vaccination strategies is more mixed.**
5. **Although several management strategies show promise, the certainty of available evidence is generally low, highlighting the need for further high-quality cohort studies and randomized controlled trials.**

Maintaining calf health is a critical component of cow–calf production systems, with early-life disease having lasting impacts on animal welfare, productivity, and antimicrobial use (AMU). Diarrhea and BRD are the most common and economically important conditions affecting preweaned beef calves. Effective health management focuses on early disease identification, implementation of preventive strategies, and targeted treatment where necessary. Crucially, antimicrobial stewardship is an essential consideration, emphasizing judicious use of antimicrobials to preserve their effectiveness while ensuring animal health and welfare are not compromised. This section summarizes recent research on the prevalence and management of these key health conditions in cow–calf herds, with a particular emphasis on evidence generated since 2012.

##### **3.1.1 Prevalence of Disease**

Recent research provides important insights into the prevalence of key health challenges in Canadian beef cow–calf herds. Wilhelm et al. (2023) conducted a scoping review of AMU and antimicrobial resistance (AMR) in beef cow–calf herds in Canada and the United States (US). Across 23 included studies, most reported low frequencies of AMU, with fewer than 10% of calves treated for major diseases such as BRD, diarrhea, and umbilical infections. Two Canadian studies provided detailed within-herd estimates of AMU. In a 2013–2014 survey, 71% of herds reported treating fewer than 5% of cows with antimicrobials and 46% of herds reported treating fewer than 5% of calves (Waldner et al., 2019). In a 2019–2020 survey, 91% of herds treated

fewer than 5% of cows and 88% treated fewer than 5% of calves (Fossen et al., 2023). Pinkeye and lameness were the most common reasons for AMU in cows, whereas BRD, diarrhea, and umbilical infections were most common reasons for AMU among calves. The review by Wilhelm et al. (2023) also identified herd size and livestock class as significant predictors of AMU, with larger herds and calves having higher odds of treatment. Operations that disinfected water troughs or quarantined introduced animals had lower odds of AMU, while herds retaining ownership of calves post-weaning had higher odds of using Category I antimicrobials as classified by Health Canada.

Waldner et al. (2022) provided specific estimates of disease treatment patterns in western Canadian cow–calf herds. Among 89 surveyed herds, BRD was the leading cause of treatment, affecting 5% of calves, followed by calf diarrhea (3%) and umbilical infections (2%). Treatments for BRD were reported in 51% of herds before calves reached 2 months of age, whereas diarrhea treatments peaked between 6 days and 1 month of age. Umbilical infections were most common in calves shortly after birth. Approximately 20% of herds reported routine prophylactic antimicrobial administration at birth, a practice that contrasts with veterinary opinion in western Canada, where such strategies were rated among the least useful for disease control (Sanguinetti et al., 2024).

Building on this, Waldner et al. (2024) analyzed herd-level calving and weaning data from 171 herds across Canada, collected between 2018 and 2022. Across 565 calving record questionnaires representing 110,658 calving female records, the mean percentage of calves treated with antimicrobials between 24 hours and 30 days of age was 3.9% for diarrhea, 3.1% for BRD, and 2.2% for umbilical or joint infections. During the same period, the mean proportion of calves dying between 24 hours and 30 days was 1%, with diarrhea accounting for 50% of calf deaths, BRD for 40%, and umbilical or joint infections for 10%.

Sanguinetti et al. (2025c) surveyed 125 Canadian cow–calf producers participating in the Canadian Cow-Calf Surveillance Network, the same population used by Waldner et al. (2024), to benchmark outbreaks of diarrhea, BRD, and calf mortality. Outbreaks were defined as a situation where at least 5% of a group of calves were treated for the same disease or a similar set of clinical signs during a single season, while mortality outbreaks specifically referred to at least 5% of calves dying during a single season. Between 2019 and 2021, more than 40% of herds experienced at least 1 outbreak of diarrhea, BRD, or mortality. Individually, 26% of herds reported a BRD outbreak, 24% reported a diarrhea outbreak, and 8% reported a mortality outbreak. Co-occurrence of disease was common, with 80% of herds reporting mortality outbreaks also experiencing diarrhea or BRD outbreaks and 40% of herds had outbreaks of both diarrhea and BRD over 3 calving seasons.

Finally, Fossen et al. (2025) evaluated calf treatment records from 56 herds and fecal samples from 31 herds to assess AMU and AMR patterns. Although most herds reported some AMU, the median cumulative incidence of any AMU was 10%, with notable variation between herds. A total of 30% of herds treated more than 25% of calves, and 13% treated more than 50%. Among the 2,045 calf treatments recorded, BRD accounted for 30% of treatments, diarrhea for 15%, and umbilical infections for 12%. Herds selling seedstock, maintaining larger herd sizes, and assisting a greater proportion of calvings had higher odds of AMU. Resistance levels were generally low, with no consistent association between AMU and resistance in *Escherichia coli* or

*Enterococcus* spp., although increased macrolide use was associated with higher macrolide resistance in *Enterococcus* spp. in fecal samples collected in the fall.

Together, these studies demonstrate that BRD, diarrhea, and umbilical infections remain leading causes of calf morbidity in Canadian cow–calf herds. While the overall frequency of AMU is relatively low, herd-level management practices and structural factors such as herd size and production goals continue to influence both disease occurrence and AMU patterns.

### **3.1.2 Managing Disease in Cow–Calf Herds**

Recent studies have highlighted key management practices associated with reducing disease and improving calf survival in cow–calf operations. Sanguinetti et al. (2024) conducted a modified Delphi study with 12 veterinarians familiar with western Canadian cow–calf management systems to identify the most useful disease prevention practices for reducing preweaning calf mortality. Experts scored each practice based on its effectiveness, ease of implementation, and economic feasibility across 2 questionnaire rounds, with feedback provided between rounds. Administering clostridial vaccines to calves and feeding colostrum or colostrum replacer using a nipple bottle or oesophageal tube when a calf had not nursed were the only practices considered useful “always for all herds.” Most other practices, including those related to breeding and calving management, nutrition and pasture management, biosecurity, and vaccination protocols, were rated as having intermediate usefulness. Practices considered least useful, described as “somewhat for some herds,” included the metaphylactic and prophylactic use of antimicrobials, vaccination of calves against neonatal calf diarrhea pathogens during the first week of life, and vaccination of dams against BRD pathogens at spring turnout.

Building on this work, Sanguinetti et al. (2025a) conducted a systematic review to evaluate the effectiveness of herd management practices in reducing preweaning calf mortality. Eleven studies were included, 10 of which were observational cross-sectional studies and 1 a randomized controlled trial. Eight studies originated from North America, with the remainder conducted in Estonia, Japan, and Brazil. Practices most consistently associated with reduced mortality included intervening with colostrum when calves had not nursed or required assistance at calving and managing the timing and length of the calving season. In 3 out of 4 assessments, the criteria used to guide colostrum intervention were significantly associated with calf mortality risk. Specifically, herds that intervened based on udder fullness or calving assistance had 0.7% to 0.8% lower mortality (Murray et al., 2016). In contrast, when producers reported intervening when colostrum had an abnormal appearance, this was associated with a 1.9% increase in mortality (Murray et al., 2016). Similarly, 3 out of 4 assessments, all conducted in western Canada or the northwestern US, reported that early-calving herds, calving in January or February, had a higher incidence of calf mortality compared to later-calving herds (Clement et al., 1993; Murray et al., 2016; Pearson et al., 2019a). Two assessments also found that longer calving seasons increased mortality risk (Dutil et al., 1999), with a 1.4% rise in risk for each additional week the calving season was extended (Murray et al., 2016). Nutritional interventions were less consistently studied, but 1 study in western Canada reported that calves not receiving vitamin E and selenium supplementation at birth had over 10 times greater odds of mortality compared to supplemented calves (Waldner & Rosengren, 2009). Overall, the certainty of the available evidence was rated as low, underscoring the need for further well-designed cohort studies and randomized controlled trials to better inform herd health recommendations.

These findings provide a foundation for understanding how broader herd-level strategies, particularly around calving and early calf management, can reduce disease burden and improve preweaning survival. The following sections will examine specific evidence and recommendations for managing diarrhea and BRD in cow–calf herds.

### 3.1.2.1 Neonatal Calf Diarrhea

Sanguinetti et al. (2025b) conducted a systematic review evaluating management practices for the prevention of neonatal calf diarrhea (NCD) and BRD in preweaned beef calves. Seventeen studies met the inclusion criteria, including 6 randomized or controlled trials and 11 observational studies, all reporting on naturally occurring disease. Studies were conducted in Canada (7), the US (5), France (2), Argentina (1), Belgium (1), and Italy (1). Most management practices demonstrated some evidence of effectiveness, although the overall certainty of the findings was low to very low.

For NCD prevention, 5 studies reported NCD-specific outcomes, while another 5 studies reported outcomes for both NCD and BRD combined or separately. Several key management strategies were associated with significant reductions in NCD risk. Two out of 3 assessments, again all from western Canada or the northwestern US, found that calves from early-calving herds had greater odds of treatment and higher disease risk compared to later-calving herds (Waldner et al., 2013; Clement et al., 1993). One out of 3 assessments found that a longer calving season was associated with a higher the risk of NCD outbreaks in large herds, defined as those with more than 40 females (Dutil et al., 1999). Breeding and calving season management practices also showed mixed findings: for example, breeding heifers earlier than cows was associated with either a higher (Clement et al., 1993) or lower (Waldner et al., 2022) risk of NCD depending on the study, and frequent night-checking during calving was linked to an increased risk of diarrhea in 1 study (Waldner et al., 2022). In general, practices associated with more intensive calving management were often associated with increased risk of NCD, which may be associated with higher disease detection and treatment rather than differences in disease risk or may be related to more intensive management being implemented in herds experiencing greater disease challenges.

Findings for nutritional management of dams were similarly inconsistent. One study, conducted in Belgium, found that selenium supplementation with 0.5 ppm of organic selenium derived from *Saccharomyces cerevisiae* was associated with lower NCD incidence in calves compared to 0.5 ppm or 0.1 ppm of selenium provided as sodium selenite (Guyot et al., 2007). However, another study, this one conducted in Saskatchewan, Canada, found no significant difference in NCD incidence when selenium was provided through pre-calving injections (Cohen et al., 1991). Feeding corn pre- or post-calving to dams was also not associated with NCD outcomes (Clement et al., 1993). For calf-level nutritional interventions, 1 study reported that calves injected with vitamins D and A within 2 days of birth had a higher risk of NCD than untreated calves (Waldner et al., 2022).

Evidence for biosecurity practices was limited. Only 1 out of 5 assessments reported a significant association, with sorting cow–calf pairs from the calving area into nursery pastures reducing the risk of NCD within the first 5 days of life but increasing risk after 6 days (Waldner et al., 2022).

Other biosecurity measures, such as commingling cows and heifers or the timing of movement out of calving areas, were not associated with changes in NCD risk (Waldner et al., 2022).

Vaccination practices were among the most consistently effective strategies for reducing NCD risk. Eight of 10 assessments found that vaccinating dams against NCD-related pathogens lowered disease incidence. In particular, 7 of 8 assessments showed that vaccines containing *Escherichia coli* antigens reduced NCD morbidity or mortality (Cornaglia et al., 1992; Myers et al., 1980). Protection was strongest when both heifers and cows received 2 doses, and calves born to vaccinated cows had lower NCD risk than those born to vaccinated heifers, suggesting a potential influence of parity (Cornaglia et al., 1992). Vaccinating dams against clostridial pathogens in the spring prior to calving was also associated with reduced NCD risk in 1 assessment (Waldner et al., 2013). However, 1 observational study reported that herds vaccinating calves directly against NCD pathogens had higher odds of detecting disease and increased mortality (Waldner et al., 2022), likely reflecting reverse causation.

The review by Sanguinetti et al. (2025b) concluded that although several management practices show promise for NCD prevention, the low certainty of evidence, particularly due to suspected reverse causation in cross-sectional studies, underscores the need for more high-quality cohort studies and randomized controlled trials to better inform herd health recommendations.

Additional evidence of management-related risk factors for NCD was provided by Sanguinetti (2025c), who surveyed Canadian beef cow–calf producers to identify practices associated with NCD outbreaks ( $\geq 5\%$  treated for NCD). Herds that brought dams into barns to calve only during bad weather had higher odds of experiencing NCD outbreaks compared to herds using more consistent outdoor or barn-based calving systems. Calving heifers and cows together in the same pasture, keeping all heifers in the calving area until the end of the calving season, and assisting more than 20% of calvings with colostrum consumption were also associated with an increased risk of NCD outbreaks. Some biosecurity practices were linked to higher risk as well, with herds that vaccinated cattle before introducing them to the herd reporting more frequent NCD outbreaks. Waldner et al. (2024), using data from 172 cow–calf herds in Canada, also identified associations between NCD and management practices. Specifically, it was reported that herds beginning their calving season between December and March had higher odds of NCD compared to later-calving herds (April to September). Regional differences were also noted, with eastern Canadian herds experiencing higher levels of NCD than western herds.

Neonatal calf diarrhea remains a major health concern in cow–calf operations, particularly in herds with early or prolonged calving seasons and more intensive calving area management. Vaccination of dams, especially against *Escherichia coli*-related pathogens, was found to be consistently associated with reduced NCD risk, while the benefits of nutritional supplementation and biosecurity practices were less clear. Observational data from Canadian herds also highlighted that herds calving earlier in the year and those located in eastern Canada faced higher levels of disease. Although several management strategies show promise, the overall certainty of the evidence remains low, largely because studies are observational, have a high risk of bias, or are underpowered to detect statistically significant differences. This underscores the need for additional high-quality research to strengthen prevention recommendations.

### 3.1.2.2 *Bovine Respiratory Disease*

Sanguinetti et al. (2025b) conducted a systematic review evaluating the impact of herd management practices on BRD in preweaned beef calves. Seven studies reported BRD-specific outcomes, while 5 studies reported outcomes for both NCD and BRD either separately or combined. Studies were conducted in North America (12), Europe (4), or elsewhere (1).

Among colostrum management strategies, only 1 out of 6 assessments found a significant association. In this cross-sectional study, herds that provided colostrum using a tube or bottle had a higher reported risk of BRD (Woolums et al., 2013), likely reflecting reverse causation, as producers may have intervened more often in calves already at greater risk of disease. In contrast, interventions based on udder fullness (3 assessments), colostrum source (e.g., maternal, frozen, or supplement product; 1 assessment), or method of feeding colostrum (1 assessment) did not demonstrate any consistent associations with BRD risk.

Management of the calving season showed more consistency. Two out of 5 assessments found that early-calving herds (winter or early spring) experienced higher odds of BRD treatment or disease incidence compared to later-calving herds (Waldner et al., 2013; Woolums et al., 2013). These studies were conducted in Canada (Waldner et al., 2013) and throughout the US (Woolums et al., 2013). Three out of 5 assessments found that longer calving seasons were associated with higher BRD incidence (Dutil et al., 1999; Assié et al., 2009; Woolums et al., 2013). In these studies, longer seasons were typically defined as lasting  $\geq 3$  months or averaging 5.75 months in herds with BRD compared to 4.04 months in herds without BRD. These associations were consistent, despite the overall low certainty of evidence. Use of intensive calving areas was associated with increased BRD risk in 2 out of 4 assessments (Woolums et al., 2013; Waldner et al., 2022). Similarly, 1 study reported that herds using intensive grazing had 3 times higher odds of BRD treatment than those that did not (Woolums et al., 2018).

Nutritional management of calves produced mixed results. Two out of 5 assessments suggested that feeding concentrate, maize, or creep feed influenced BRD incidence (Assié et al., 2009; Woolums et al., 2013); however, no clear protective or harmful effect was established. Injecting vitamins near birth was also not found to have a statistically significant association with BRD outcomes in 2 observational studies conducted in western Canada (Murray C.F. et al., 2016; Waldner et al., 2022).

Biosecurity practices showed more consistent associations with BRD outcomes. Six out of 12 assessments found that external biosecurity practices, defined as practices aimed at limiting the introduction of pathogens from outside the herd, impacted BRD risk. Five assessments reporting that introducing new cattle increased the risk of disease (Hanzlicek et al., 2013; Woolums et al., 2013; Waldner et al., 2022). In addition, 1 study found that herds that had 1–2 or more than 30 visitors per month had higher BRD rates compared to herds with 3–30 visitors per month (Hanzlicek et al., 2013). Internal biosecurity practices, such as gathering cow–calf pairs before pasture turnout or using the same area for overwintering and calving (25), were associated with higher BRD risk in 6 out of 9 assessments. However, findings on the use of nursery pastures were inconsistent. One assessment reported a reduced risk of BRD when cow–calf pairs were sorted into nursery pastures (Waldner et al., 2022), while 2 others found increased odds of BRD detection or treatment in herds using this practice (Woolums et al. 2013, 2018).

Vaccination practices yielded mixed results. Two out of 4 assessments found associations between dam vaccination against BRD pathogens and BRD outcomes, but the direction of the associations was contradictory (i.e., one showed reduced risk [Waldner et al., 2022] and the other showed a higher risk [Woolums et al., 2013]), and the certainty of evidence was low. Calf vaccination was evaluated in 11 assessments, with only 1 study showing a beneficial effect in reducing BRD treatment and mortality after 2 doses of an inactivated vaccine targeting BRSV, PIV3, and *Mannheimia haemolytica* (Makoschey et al., 2008). In contrast, 4 assessments found that herds reporting calf vaccination had higher rates of BRD detection or treatment (Assié et al., 2009; Hanzlicek et al., 2013; Woolums et al., 2013; Waldner et al., 2022); however, all were based on cross-sectional studies, so reverse causation is likely.

A scoping review by Chen et al. (2022) summarized 265 studies published between 1990 and 2021 on BRD prevention in cow–calf operations. Herd and farm management factors, such as transport practices, environmental conditions, herd mixing, herd size, and source of animals, were found to be associated with the incidence of BRD in 91% of observational studies. Key protective strategies included minimizing herd mixing, controlling herd density, and sourcing animals carefully. Metaphylactic antimicrobial use was evaluated in 65 studies, with 78% of field trials and 94% of controlled studies reporting reductions in BRD incidence, particularly with tulathromycin, oxytetracycline, gamithromycin, and tilmicosin. Vaccination was evaluated in 64 studies, with 74% of field trials and 69% of controlled trials showing a protective effect, especially for vaccines targeting viral agents, such as BVDV, BRSV, and BHV-1. Vaccines targeting bacterial pathogens, such as *Mannheimia haemolytica* or *Pasteurella multocida*, were less consistently effective. Diet and nutritional interventions showed less consistent effects, with only 30% of studies reporting significant reductions in BRD risk. Animal-level factors, such as younger age, lower body weight, male sex, and Hereford breed, were associated with increased BRD risk, and several genetic traits were identified as linked to disease susceptibility.

Further evidence from observational data in Canadian cow–calf herds support the influence of management practices on BRD outcomes. Sanguinetti (2025c) surveyed Canadian producers and found that herds leasing bulls for at least 1 season had 3 times higher odds of BRD outbreaks compared to herds not using this practice. Similarly, Wennekamp et al. (2021) reported that BRD outbreaks were associated with purchasing more than 10 bulls, purchasing cows, failing to vaccinate newly introduced animals, and using community pastures. Waldner et al. (2024), using data from 172 cow–calf herds, also found that herds beginning their calving season between December and March had higher odds of BRD and BRD-related mortality compared to later-calving herds (April to September).

With respect to vaccination, a randomized controlled trial by Erickson et al. (2024) provides additional evidence supporting the potential value of calf vaccination under natural exposure conditions. In a herd with previously diagnosed bovine coronavirus BRD, calves that received an intranasal dose of a commercial bovine coronavirus vaccine at 2 months of age had significantly lower odds of BRD treatment post-weaning compared to unvaccinated controls. While results are specific to bovine coronavirus and in a single herd context, the study highlights how targeted vaccination strategies may be effective in operations with known pathogen risks and underscores the importance of high-quality trials to inform BRD prevention in cow–calf systems.

In summary, BRD remains a major cause of morbidity and mortality in cow–calf herds, with risk influenced by calving season timing, calving area management, and biosecurity practices. While Sanguinetti et al. (2025b) found mixed effectiveness of vaccination strategies in cow–calf herds and low certainty of evidence when focusing only on natural disease challenge, a broader review by Chen et al. (2022) that included challenge studies reported more consistent protective effects of vaccination, particularly against common viral pathogens. Management practices such as minimizing herd mixing, controlling herd density, and careful sourcing of cattle were consistently associated with reduced BRD incidence. Recent Canadian data further confirmed that earlier calving seasons and leasing bulls were associated with higher odds of BRD outbreaks. Although several management practices show potential for reducing BRD risk, additional high-quality research is needed to refine prevention strategies in cow–calf operations.

### **3.2 Health Management in the Feedlot Sector**

#### **Conclusions:**

##### **Bovine Respiratory Disease**

- 1. BRD remains the most common reason for antimicrobial use, morbidity, and mortality in North American feedlot cattle, especially within the first 45 days on feed.**
- 2. BRD risk is additive and influenced by lighter arrival weights, recent weaning, commingling, long-distance transport, adverse weather, and pen-level management factors.**
- 3. Metaphylactic antimicrobials, particularly macrolides, consistently reduce BRD morbidity and mortality, but concerns around antimicrobial stewardship are driving interest in alternatives.**
- 4. Evidence supporting vaccination at arrival is mixed; viral vaccines may offer benefit under natural exposure, but bacterial vaccine efficacy is poorly studied and remains inconclusive.**
- 5. Preconditioning reduces BRD risk and improves early behavioural adaptation to the feedlot, though its effects on growth are variable, and adoption remains limited.**
- 6. Novel technologies, such as behaviour tracking, offer promise for earlier and more accurate BRD detection than traditional pen-checking.**

##### **Lameness**

- 1. Lameness is the second most common reason for treatment in feedlot cattle, with foot rot, digital dermatitis, and joint infections as leading causes.**

- 2. Foot rot remains the most prevalent lameness diagnosis. Risk is highest in fall- and winter-placed cattle and appears linked to environmental factors and mechanical damage to the interdigital skin.**
- 3. Digital dermatitis is less common than foot rot but can impair growth and carcass value. Risk is elevated in cattle from confined systems, larger feedlots, and muddy pens, with prevention efforts focused on footbaths and possibly mineral supplementation.**
- 4. Toe tip necrosis syndrome is sporadic but severe, typically emerging early in the feeding period and linked to claw abrasion, compromised hoof integrity, and possibly magnesium deficiency.**
- 5. Joint infections account for a disproportionate number of lameness-related deaths. Risk is elevated in younger, fall-placed calves and heifers compared to yearlings and steers. *Mycoplasmosis* species appear to be the predominant pathogen.**
- 6. The most informative signs for detecting lameness in feedlot cattle include asymmetric gait, reluctance to bear weight, and associated elevated locomotion scores, particularly in cattle with digital dermatitis. Automated behavioural monitoring and wearable sensors show promise for improving early identification and management of lameness in feedlot settings.**

#### **Nutritional Diseases (Ruminal Acidosis and Liver Abscesses)**

- 1. Transitioning to high concentrate finishing diets increases the risk of ruminal acidosis, which facilitates the mucosal injury and bacterial translocation (e.g., *Fusobacterium necrophorum*) that are essential for liver abscess formation.**
- 2. Greater forage inclusion in finishing diets, slower diet adaptation, and longer fiber particle size improve rumen health and reduce acidosis risk but with variable consequences on growth performance and carcass quality.**
- 3. Liver abscesses are common and economically important. Tylosin remains effective at reducing liver abscess prevalence, and evidence suggests that shorter durations of use may be similarly effective, though further research is needed to guide optimal timing and stewardship.**
- 4. Increasing dietary fiber and managing starch content in the diet can reduce liver abscess severity. These strategies may reduce feed efficiency and growth in some contexts, reflecting the trade-off between managing health and welfare challenges and maximizing performance.**

The feedlot phase of beef production presents distinct health challenges compared to the cow-calf sector, largely due to animal sourcing, commingling, nutritional management, and production intensity. BRD remains the leading cause of morbidity and mortality in feedlot cattle, but lameness and nutritional diseases, such as ruminal acidosis and liver abscesses, are also

important animal welfare and economic concerns. Effective feedlot health management emphasizes early disease detection, preventive strategies at arrival and throughout feeding, and minimizing the impact of high-concentrate diets. This section summarizes current evidence on the prevalence, risk factors, prevention, and management of these key conditions in feedlot cattle, focusing on research published since 2012.

### **3.2.1 *Antimicrobial Use***

Antimicrobial use (AMU) practices in North American feedlots have been described in several studies. Brault et al. (2019) evaluated AMU patterns on 36 feedlots in western Canada representing 2.6 million cattle between 2008 and 2012. In-feed AMU was substantially higher (28,690,598 animal daily doses) compared to individually dosed AMU (5,823,060 doses). However, it should be noted that this data is more than 20 years old and may not still be relevant in this quickly moving field (Hannon et al., 2020).

Apley et al. (2023) characterized antimicrobial use patterns in 20 feedyards in the US during 2018 and 2019, encompassing over 1.1 million cattle. Antimicrobial use was reported as milligrams per kilogram of liveweight sold and regimens per animal year. In a subset of 10 feedyards with detailed records, most AMU was associated with liver abscess control (98.4 regimens per 100 head), followed by BRD (37.1 regimens per 100 head) and lameness (0.8 regimens per 100 head). Within BRD-related use, metaphylaxis accounted for the largest proportion of regimens, followed by individual animal treatments and in-feed administration.

### **3.2.2 *Managing Bovine Respiratory Disease in Feedlot Cattle***

#### **3.2.2.1 *Vaccination***

Theurer et al. (2015) conducted a systematic review and meta-analysis evaluating the effectiveness of commercially available viral vaccines targeting bovine herpesvirus-1 (BHV-1), bovine viral diarrhea virus (BVDV), bovine respiratory syncytial virus (BRSV), and parainfluenza type 3 virus (PI3) for mitigating bovine BRD in cattle. Thirty-one studies comprising 88 trials were included, categorized as natural exposure or experimental challenge models, and further divided by viral antigen and vaccine type (modified-live virus or inactivated). In natural exposure trials, vaccination significantly reduced BRD morbidity risk compared to nonvaccinated controls. In experimental challenge trials, vaccination with BHV-1 and modified-live BVDV vaccines reduced morbidity, but no significant benefit was found for modified-live BRSV or PI3 vaccines. Theurer et al. (2015) cautioned that clinical efficacy estimates from experimental models must be interpreted carefully, as they may not fully reflect natural disease exposure.

O'Connor et al. (2019a) also conducted a systematic review and network meta-analysis evaluating the comparative efficacy of vaccines administered at or near arrival in feedlot cattle. Fifty-three studies reporting BRD morbidity within 45 days of arrival were identified through database and conference proceedings searches. Fourteen studies, comprising 17 vaccine protocols, formed the largest connected network and were included in the meta-analysis. The authors concluded that there is little compelling evidence that vaccines administered at or near feedlot arrival reduce the incidence of BRD.

Although both Theurer et al. (2015) and O'Connor et al. (2019a) reviewed BRD vaccine efficacy, differences in eligibility criteria, outcome selection, pooling strategies, and included studies likely explain their differing conclusions. Theurer et al. (2015) included younger calves and dairy cattle, extracted raw rather than adjusted data, combined studies involving concurrent bacterial vaccinations, and included studies with highly variable vaccine effects, all of which may have contributed to more favourable efficacy estimates compared to O'Connor et al. (2019a).

Bacterial BRD vaccines have also been evaluated, although fewer high-quality studies are available. Capik et al. (2021) conducted a systematic review to assess the efficacy of vaccines targeting *Mannheimia haemolytica*, *Pasteurella multocida*, and *Histophilus somni* for reducing BRD-related morbidity, mortality, or lung lesions in cattle raised in the US and Canada. Studies were eligible if they were peer-reviewed, conducted in the US or Canada, published after 1979, included a control group, demonstrated evidence of randomization or blinding, used appropriate statistical methods, and were available in English. Only 5 studies met these criteria. These included investigations of *Histophilus somni* and *Mannheimia haemolytica* vaccines in feeder calves, *Mannheimia haemolytica* vaccines in feeder and Holstein calves, and vaccines targeting *Pasteurella multocida* or *Mannheimia haemolytica* in nursing beef calves. Due to the limited number of comparable studies, no further analysis of bacterial vaccine efficacy was possible.

Overall, the evidence on vaccination for BRD prevention in feedlot cattle remains mixed and highlights important limitations. While one review suggested that viral vaccines, particularly those targeting BHV-1 and BVDV, may reduce BRD morbidity under natural exposure conditions, another concluded that there is insufficient evidence to support that vaccination at feedlot arrival significantly reduces BRD incidence. Evidence supporting the efficacy of bacterial vaccines against *Mannheimia haemolytica*, *Pasteurella multocida*, or *Histophilus somni* also remains sparse, with few high-quality studies available. Together, these findings emphasize the need for more robust, well-designed trials to better inform vaccination strategies for BRD control in feedlot cattle.

### 3.2.2.2 Prophylaxis or Metaphylaxis at Arrival to Feedlots

Prophylaxis and metaphylaxis are common strategies used in feedlots to control BRD. Prophylaxis refers to the administration of antimicrobials to healthy animals before any signs of disease are observed, while metaphylaxis involves treating a group of animals when disease has been identified in some individuals, aiming to prevent further spread within the group (Gomez & Weese, 2024). Both approaches are typically implemented at feedlot arrival in high-risk cattle.

Baptiste and Kyvsgaard (2017) conducted a systematic review and meta-analysis evaluating the effectiveness of antimicrobial mass medication for the prevention of BRD morbidity and mortality in cattle. A total of 58 publications, summarizing 169 randomized controlled trials (RCTs) conducted between 1966 and 2016, were included. Most studies were performed under feedlot conditions (149 RCTs), with fewer from veal, dairy, or cow-calf operations. After adjusting for publication bias, the combined relative risk estimate for reducing BRD morbidity with mass medication was 0.52, indicating a moderate risk reduction. For mortality, mass medication led to a relative risk of 0.62, but absolute reductions were generally small, particularly in trials where baseline mortality was low. Most trials (41.5% of prophylaxis RCTs

and 82% of metaphylaxis RCTs) reported 0 mortality in control groups, and mortality benefits were primarily observed when control group mortality exceeded 1.5%. Further, parenteral administration (subcutaneous or intramuscular) was more effective than oral antimicrobials. In prophylaxis trials, macrolides were the most effective antimicrobial class, followed by fluoroquinolones, tetracyclines, and cephalosporins, whereas no differences between antimicrobial classes were observed in metaphylaxis trials. Definitions of metaphylaxis impacted outcomes, with group treatment triggered by  $\geq 10\%$  morbidity performing better than strategies based on fever alone or cattle contact with clinical cases. Despite demonstrating reductions in BRD morbidity and mortality, the authors cautioned that the absolute gains were often small, and that the widespread use of mass medications likely reflects underlying systemic challenges in feedlot infrastructure rather than deficiencies in disease prevention alone.

Another systematic review and meta-analysis was conducted by O'Connor et al. (2019b), who aimed to evaluate the comparative efficacy of injectable antimicrobials for the control of BRD in weaned beef cattle entering feedlots. Eligible studies administered antimicrobials at feedlot arrival and reported BRD morbidity within 45 days after feedlot arrival. A total of 46 studies encompassing 167 study arms were included in the final meta-analysis. Most studies compared active antimicrobials to non-active controls, while others compared different active treatments. Results indicated that macrolides were the most effective antimicrobial class for reducing BRD incidence. Injectable oxytetracycline was also effective compared to no treatment but was less effective than macrolides. Rankings of treatment efficacy showed macrolides consistently associated with lower BRD rates, while oxytetracycline ranked lower but remained superior to no AMU. The review highlighted concerns about study quality: randomization was inconsistently reported, blinding was often absent, and many comparisons had wide confidence intervals reflecting imprecision. Nevertheless, the network meta-analysis supported the superior efficacy of macrolides for BRD prevention at arrival, while also acknowledging potential stewardship advantages of using oxytetracycline due to its lower critical importance rating for human medicine.

Finally, Abell et al. (2017) conducted a mixed treatment comparison meta-analysis to evaluate the effectiveness of parenteral metaphylactic antimicrobials for reducing BRD morbidity, mortality, and retreatment rates in feedlot and stocker calves. The analysis included 29 studies and 37 trials assessing 8 antimicrobials, with treatments administered within 48 hours of feedlot arrival. BRD morbidity was evaluated over 2 periods: day 1 to  $\leq 60$  and day 1 to closeout, with additional analyses for BRD-related mortality and retreatment. Tulathromycin, gamithromycin, and tilmicosin consistently ranked in the upper tier for reducing BRD morbidity within the first 60 days, while ceftiofur and oxytetracycline occupied a middle tier. For morbidity to closeout, tulathromycin remained the most effective, followed by gamithromycin, tildipirosin, ceftiofur, tilmicosin, and oxytetracycline. Trimethoprim sulfa and florfenicol were generally less effective. Although classification of treatments by efficacy for mortality and retreatment was limited due to overlapping credibility intervals, tulathromycin showed significantly lower BRD mortality odds compared to tilmicosin and oxytetracycline. These findings suggest substantial differences in performance between metaphylactic antimicrobials, particularly for tulathromycin, and underscore the need to consider drug-specific effectiveness when selecting metaphylactic protocols in feedlot cattle.

Collectively, these reviews support the use of metaphylactic antimicrobials to reduce BRD incidence in feedlot cattle, with macrolides consistently showing superior efficacy. Baptiste and Kyvsgaard (2017) reported moderate reductions in morbidity and mortality, though absolute benefits were often small. O'Connor et al. (2019b) confirmed the effectiveness of macrolides, while highlighting study quality concerns and the potential value of using oxytetracycline from an antimicrobial stewardship perspective. Abell et al. (2017) showed tulathromycin offered the greatest reductions in morbidity and mortality, outperforming tilmicosin and oxytetracycline. These findings underscore the importance of selecting antimicrobials based not only on disease risk but also on antimicrobial stewardship principles, with recognition that effectiveness may decline over time. Supporting this, DeDonder and Apley (2015) summarized North American studies showing increasing resistance of *Mannheimia haemolytica*, *Pasteurella multocida*, and *Histophilus somni* to antimicrobials commonly used for BRD treatment and control, reinforcing the need for judicious AMU.

### 3.2.2.3 Risk Factors for Bovine Respiratory Disease

The previous Review of Scientific Research on Priority Issues (Schwartzkopf-Genswein et al., 2012) identified multiple additive risk factors for BRD in feedlot cattle, including lighter weight, recent weaning, immune status, sex, commingling, transportation stress, and weather changes. Rather than a single dominant factor, the evidence pointed to the cumulative impact of these stressors in increasing BRD morbidity risk. More recent research has also identified this.

**Individual animal factors.** Multiple studies have highlighted the complex interplay of individual and environmental characteristics influencing BRD risk in feedlot cattle. In a retrospective analysis of 288,388 cattle across 1,904 cohorts, Cernicchiaro et al. (2012a) found that cattle arriving in September, weighing less than 318 kg, or housed in smaller cohorts had higher odds of BRD within the first 45 days on feed. Weather conditions, particularly wind speed, wind chill, and temperature changes in the week prior, were also significantly associated with the incidence of BRD, emphasizing how environmental and demographic factors combine to influence disease risk. In a prospective study of 35,131 cattle in Australian feedlots, Hay et al. (2016a) identified breed and arrival weight as key predictors. Specifically, Hereford cattle had twice the odds of BRD compared to Angus, while tropically adapted breeds were at lower risk. Further, heavier cattle ( $\geq 480$  kg) were less likely to develop BRD than lighter cattle ( $< 400$  kg). Season of arrival also played a role, with summer- and autumn-placed cattle having increased risk compared to those arriving in spring. Babcock et al. (2013) found similar results when analyzing data from over 8.9 million feedlot cattle. Using a multivariable negative binomial model, they found that lower arrival weight, male sex, and arrival during spring or summer were associated with increased losses, with significant interactions between weight, sex, and month. These studies demonstrate that BRD risk is not determined by a single factor but emerges from the cumulative impact of multiple interacting stressors present at feedlot arrival.

Transport-related stress has also been implicated as a risk factor for BRD. Cernicchiaro et al. (2012b), using data from 14,601 cohorts across 21 U.S. feedlots, reported that longer transport distances were associated with increased BRD morbidity, all-cause mortality, and reduced performance (hot carcass weight and average daily gain). These effects were modified by arrival weight, season, origin, and sex, indicating that the response to transport stress varies among demographic groups.

**Management-related risk factors.** A growing body of research highlights the substantial role that management practices play in BRD risk following feedlot arrival. Hay et al. (2017) estimated that 82% of BRD cases in Australian feedlots during the first 50 days on feed could be attributed to modifiable management-related factors. The most influential were shared pen water access, prior mixing with animals from other herds, timing of the move to the feedlot, group size prior to induction, presence of BVDV-1 in the cohort, breed, and arrival weight. Similarly, Hay et al. (2014) reported that mixing cattle from multiple sources and transport shortly before arrival to the feedlot increased BRD risk, whereas mixing earlier ( $\geq 4$  weeks prior), forming larger pre-feedlot groups ( $\geq 100$  head), and moving cattle to the feedlot vicinity at least 27 days before feedlot arrival were protective. Hay et al. (2016b) further identified that placing water troughs between pens and adding animals to pens over multiple days both elevated BRD risk. In U.S. feedlots, Rojas et al. (2022a) found that limited pen space ( $\leq 23.2$  m<sup>2</sup> per animal) increased BRD risk, particularly in cattle weighing 409–453 kg or in larger cohorts ( $> 175$  animals). Interestingly, within the 409–453 kg weight group, less bunk space ( $\leq 0.3$  m) was associated with lower BRD incidence compared to more bunk space, though reasons for this association remain unclear. In a separate study, Rojas et al. (2022b) found that 2 water sources per pen reduced BRD morbidity in medium-sized cohorts and lighter cattle, while shared fence lines and water access showed inconsistent associations. Finally, Wisnieski et al. (2021) linked higher BRD mortality within the first 60 days on feed to calves that were weaned at purchase, traveled over 1,082 km, came from multiple purchase groups, or weighed less than 255 kg. Environmental conditions at purchase, including rain, warmer temperatures, and arrival-week temperature fluctuations, further increased risk. Notably, low wind speeds on the purchase day were linked to higher BRD mortality in long-haul shipments, and heat stress effects were amplified in lighter calves.

Together, these studies confirm that BRD risk in feedlot cattle is driven not by a single dominant cause but by the additive and sometimes synergistic effects of multiple stressors acting at both the individual and management levels. Lighter weight, recent weaning, commingling, transport, and poor adaptation to environmental conditions continue to emerge as consistent contributors to BRD morbidity, especially when they occur in combination. The timing and manner in which cattle are prepared for and introduced into the feedlot, such as grouping strategies and housing conditions, can either mitigate or amplify this risk. These findings reinforce that effective BRD prevention must be multifactorial, proactive, and responsive to both animal-level traits and the broader production system context.

#### 3.2.2.4 Preconditioning

Research suggests that preconditioning, encompassing practices such as weaning, vaccination, and nutritional adaptation days before transport, can influence the risk of BRD and improve adaptation to the feedlot. In a longitudinal study of Australian cattle, Hay et al. (2016c) found that cattle that were yard-weaned, exposed to grain before feedlot entry, and vaccinated against BVDV or *Mannheimia haemolytica* were at reduced risk of BRD following arrival. Vanbergue et al. (2024) evaluated a preconditioning program in French beef herds by comparing calves that were weaned indoors 50 days before transport, given dietary supplements, dewormed, and vaccinated twice, with calves that remained with their dams until transport and received no interventions. Although the program aimed to improve health and performance, calves enrolled in the preconditioning group experienced higher morbidity during the preconditioning period

itself, likely due to suboptimal housing conditions. After arrival at the feedlot, morbidity was not different between groups. While early growth was improved in preconditioned calves, overall performance differences were inconclusive.

The effect of preconditioning on feedlot health and performance appears to depend on group composition. Mijar et al. (2023) reported that calves in pens composed entirely of preconditioned animals had significantly lower BRD morbidity (24%) than those in pens of only auction-derived, pre-sorted calves (50%). In commingled pens, BRD incidence was highest when preconditioned calves made up just 25% of the pen (63%) and lowest when they made up 50% (21%). Auction-derived calves had higher average daily gains than preconditioned calves, regardless of grouping, possibly because auction calves were pre-sorted before mixing. Within mixed pens, calves in the 25% preconditioned group had the greatest gains (1.08 kg/day), followed by the 50% and 75% preconditioned pens, while the 100% preconditioned group had the lowest gain. Commingling itself did not significantly affect BRD risk within either group, suggesting that exposure history and individual calf characteristics may be more influential than mixing.

Behavioural adaptations to the feedlot environment further support the benefits of preconditioning. Hodder et al. (2023) found that preconditioned calves spent more time eating and less time inactive than auction-derived calves, while ranch-sourced animals showed intermediate behaviour. As the proportion of auction-derived calves in the pen increased, time spent eating decreased, especially when preconditioned calves were in the minority. Similarly, Mijar et al. (2024) used activity monitors and hair cortisol to assess stress and adaptation to the feedlot. Although cortisol concentrations, levels of BRD, and growth did not differ between groups, preconditioned calves consistently spent more time eating, ruminating, and being active, and less time being inactive, compared to pre-sorted, auction-derived calves. This suggests that preconditioning supports more favourable patterns of adaptation to the feedlot environment.

Economic modeling also supports the value of preconditioning. Chiu et al. (2022) conducted an economic analysis comparing preconditioned cattle to non-preconditioned cattle given metaphylaxis on feedlot arrival. They found that preconditioned calves generated an average net return of \$48.15 USD more per head compared to non-preconditioned calves, indicating that feedlots could justify paying up to \$7.79 USD/cwt more for them.

Overall, the evidence supports that preconditioning can reduce BRD risk and improve early feedlot adaptation. While results on growth performance have been mixed, preconditioned calves show lower morbidity and more favourable feeding behaviours after arrival, such as increased time spent eating and reduced inactivity. These findings suggest that preconditioning helps calves better cope with the stressors of feedlot transition, even in commingled pens, by promoting stronger behavioural adaptation and health outcomes in the early feeding period. Despite the potential to reduce AMU and improve economic outcomes, widespread adoption of preconditioning is limited by current reliance on metaphylaxis and the absence of consistent market incentives to reward producers for preconditioned calves. The health benefits have been cited as a motivator for and the financial constraints as a barrier to the adoption of preconditioning practices; however, the lack of understanding of the perspectives of interest holders across the supply chain (Mijar et al., 2025) suggests that there remains a gap in knowledge that should be addressed using qualitative rather than quantitative methods.

### 3.2.2.5 *Diagnosis of Bovine Respiratory Disease*

BRD is typically diagnosed in feedlot cattle based on clinical signs or changes in behaviour. These signs, such as fever, anorexia, depression, coughing, nasal discharge, or abnormal breathing, reflect the animal's inflammatory response to infection. However, traditional diagnostic methods relying on clinical observation are limited in their accuracy and consistency. Timsit et al. (2016) conducted a Bayesian meta-analysis to evaluate the diagnostic accuracy of clinical illness detection by pen checkers, using lung lesions at slaughter as a proxy reference. They found that clinical observation had low sensitivity (27%) but high specificity (92%), meaning many true BRD cases are likely missed. Diagnostic performance also varied widely across studies, underscoring the need for standardized and more reliable diagnostic methods in feedlots.

Alternative approaches for confirming or facilitating earlier detection of BRD have also been explored. In a systematic review, Wolfger et al. (2015) found that serum haptoglobin is the most consistently useful biomarker for confirming BRD. In contrast, traditional tests like white blood cell counts, neutrophil–lymphocyte ratios, and cortisol showed low accuracy and are of limited value to confirm BRD in feedlot cattle. Further, clear differentiation between cases of BRD and healthy controls on the basis of BRD pathogen detection was found to be difficult. The review also highlighted the potential of automated behaviour and temperature monitoring for earlier detection of BRD. Feed intake monitoring and accelerometers could identify BRD-affected cattle several days before clinical signs of BRD presented. Reticulorumen temperature boluses and infrared thermography also detected early hyperthermia several days before visual signs. With regard to prognostic indicators, detection of specific pathogens, inclusion of automated stethoscope for lung scores, and ultrasonography could be helpful to predict BRD outcomes; however, rectal temperature did not seem to predict treatment outcomes.

Building on the findings of Wolfger et al. (2015), several studies have further evaluated behavioural and physiological monitoring technologies for earlier and more accurate detection of BRD in feedlot cattle. White et al. (2023) reported that calves later diagnosed with BRD were less active, spent more time within 1 metre of feed and water areas during the first 6 days on feed and overnight hours, and shifted from being more social to increasingly isolated after the first 7 days on feed. In an earlier study, White et al. (2016) compared visual observation to remote monitoring systems that track feeding and activity changes to diagnose BRD using Bayesian latent class analysis. Remote monitoring systems had higher sensitivity (81.3%) and specificity (92.9%) than visual observation (64.5% and 69.1%, respectively). Pillen et al. (2016), using accelerometers, found that reductions in standing time, step counts, and lying bouts were detected up to 6 days before clinical illness was identified. Further, on the day before diagnosis, BRD-affected calves stood 54 minutes less, took 629 fewer steps, and had fewer lying bouts compared to controls. Toaff-Rosenstein and Tucker (2018) also identified physiological and behavioural responses related to BRD in newly arrived heifers. Specifically, heifers that developed BRD showed elevated rectal temperatures 2 days before diagnosis and spent less time feeding on the day of diagnosis compared to healthy controls. Grooming behaviour, measured via brush use, did not differ between groups. Flattot et al. (2021) also found that monitoring temperature can be useful. Specifically, they found that steers with subclinical BRD experienced longer and more frequent episodes of elevated reticulorumen temperature ( $> 40^{\circ}\text{C}$ ) than healthy cattle. These temperature measures correlated with lung pathology at slaughter and were

associated with poorer performance. Schaefer et al. (2012) also found utility in using non-invasive, RFID-driven infrared thermography at water stations to detect BRD. They found that animals diagnosed with BRD showed significantly higher peak infrared thermal values (35.7°C) compared to healthy animals (34.9°C).

This growing body of evidence highlights both the challenges of diagnosing BRD accurately in feedlot settings and the promise of behavioural, thermal, and automated tools to support earlier and more consistent detection. Combining these approaches with better training and validation could enhance animal health outcomes and help guide more prudent antimicrobial use.

### ***3.2.3 Lameness in Feedlot Cattle***

Lameness is a common and significant health and welfare issue in feedlot cattle, consistently ranking among the top reasons for treatment. In a retrospective analysis of over 660,000 cattle from 28 North American feedlots, Davis-Unger et al. (2019) found that lameness accounted for 32% of all diagnosed disease cases. Similarly, Hendrick and Abeysekera (2014) reported that lameness represented 40% of all treatment events in 1.1 million cattle from 8 Canadian feedlots, second only to BRD (42%). Other studies have reported comparable findings: Marti et al. (2021) noted that lameness was the reason for treatment in 36.3% of pulled cattle in 2 Alberta feedlots, and Erickson (2023) found that 28.5% of all treatment events were for lameness in a dataset encompassing over 1.7 million cattle from 28 Canadian feedlots.

Across these studies, the most frequently diagnosed cause of lameness was foot rot. Davis-Unger et al. (2019) found that foot rot accounted for 74.5% of lameness diagnoses, followed by joint infections (16.1%), lameness without visible swelling (6.1%), and injuries (3.1%). Marti et al. (2021) similarly reported that foot rot was the leading cause (41.8%), followed by digital dermatitis (25.5%), upper limb lameness (5.9%), joint infections (5.5%), injuries (4.9%), toe-tip necrosis (3.9%), and laminitis (1.5%). Terrell et al. (2017) noted that the most common diagnoses were proximal limb injuries, followed by undefined lameness, septic joints or deep digital sepsis, and foot rot. Finally, Erickson (2023) identified that foot rot, digital dermatitis, and toe-tip necrosis accounted for 90%, 8%, and 2% of hoof-related lameness cases. These findings indicate that, while foot rot remains the most prevalent cause, other forms such as digital dermatitis and joint infections also represent a significant portion of lameness cases.

Lameness has also been associated with meaningful economic losses. Cortes et al. (2021a) reported that cattle with digital dermatitis had significantly lower average daily gain than healthy animals, with reductions ranging from 0.11 to 0.17 kg/day across several groups. Cattle with foot rot also showed lower average daily gains (0.05 to 0.06 kg/day) in some yearling heifers. Further, Cortes et al. (2021a) estimated that digital dermatitis had the greatest economic impact, based on treatment cost, processing labour, and additional feed, among lameness conditions, with losses of up to \$98 CAD per animal, while foot rot was associated with more modest losses of up to \$30 CAD per animal. Davis-Unger et al. (2017) also evaluated the economic impact of different forms of lameness using a modified decision-tree model based on 10 years of feedlot data. They found that feedlot cattle diagnosed with foot rot or foot rot diagnosed in heavier cattle (i.e., those with higher days on feed) had the highest average daily gains before treatment (1.14 and 1.57 kg/day, respectively), while those with joint infections or lameness without visible swelling had much lower gains (0.53 and 0.64 kg/day, respectively). After final treatment, cattle

with foot rot had an estimated net return of \$568 CAD per animal, while those with joint infections or were lame with no visible swelling had negative returns of -\$286 and -\$701 CAD per animal, respectively.

Marti et al. (2021) and Erickson (2023) both identified multiple animal- and management-level risk factors for lameness in Canadian feedlots. Marti et al. (2021) found that heavier cattle were more likely to develop lameness than lighter animals, which helps explain the greater risk observed in yearlings compared to fall- or winter-placed calves. Ranch-sourced cattle were more likely to become lame than auction-derived cattle, and reductions in dietary forage and pen density further increased the likelihood of lameness. Seasonally, the risk peaked in spring and was elevated by precipitation and temperature fluctuations, pointing to the role of pen condition. Erickson (2023) focused specifically on hoof-related lameness and found that risk was higher in cattle placed in small-capacity feedlots. Cattle from confined backgrounding operations or grass-based systems were also at higher risk, potentially due to increased commingling or poor hoof integrity before arrival at the feedlot. The effect of age varied by both source and feedlot size. For example, calves sourced from auction markets and placed in large-capacity feedlots were more likely to become lame than yearlings, while the opposite was true in small-capacity feedlots. These studies together highlight the complex interplay of weight, source, season, and feedlot conditions in shaping lameness risk.

### 3.2.3.1 Foot Rot

Foot rot, also known as interdigital necrobacillosis, is a polybacterial infection of the interdigital skin and underlying tissues, most commonly initiated by *Fusobacterium necrophorum* following mechanical damage to the skin between the claws. Additional organisms such as *Porphyromonas levii* and *Prevotella intermedia* are believed to contribute to lesion persistence or severity. Recent microbiome analyses also support the role of microbial dysbiosis in disease progression, with significant shifts in bacterial community structure observed in affected feet (Erickson et al., 2024a).

A single study specifically evaluated the risk factors associated with foot rot in feedlot cattle. Davis-Unger et al. (2019) analyzed health records from over 660,000 animals and reported that calves placed in the fall and winter had higher odds of foot rot compared to yearlings. The risk also varied by sex. Fall-placed steers were more likely than yearling steers to develop foot rot, while winter-placed steers had lower odds. Among heifers, those placed in winter had lower odds of foot rot compared to yearling heifers. These findings suggest that age at placement, season, and potentially associated environmental conditions may influence the risk of foot rot.

### 3.2.3.2 Digital Dermatitis

Digital dermatitis is a major cause of infectious lameness in cattle, marked by painful ulcerative lesions typically found near the heel bulbs. These lesions are most often associated with *Treponema* species; however, a recent meta-analysis by Caddey and De Buck (2021) also identified *Mycoplasma*, *Porphyromonas*, and *Fusobacterium* as consistently present, suggesting that broader microbial dysbiosis may contribute to disease progression. Building on this understanding of etiology, Thomas et al. (2022a) demonstrated that digital dermatitis lesions can be experimentally induced in beef calves using a model originally developed for dairy cattle. In

their study, both hind feet were abraded and wrapped to create an anaerobic environment before being inoculated with macerated digital dermatitis lesion material. Lesions developed in 3 of 5 inoculated calves within 14–18 days, while none of the mock-inoculated calves were affected. *Treponema* species were confirmed by PCR in lesion biopsies, reinforcing their central role in the pathogenesis of digital dermatitis.

Digital dermatitis in feedlot cattle has been associated with both individual- and system-level risk factors. Erickson et al. (2024b) analyzed health records from over 1.2 million cattle across 28 western Canadian feedlots and reported that cattle sourced from confined backgrounding operations had a higher incidence rate of digital dermatitis compared to those from auction markets. In contrast, ranch-direct cattle had a substantially lower rate than those sourced from auction. Female cattle were more likely to be diagnosed than males, although the magnitude of this difference varied by year. Larger feedlots were also more likely to report cases than smaller ones, highlighting the influence of operation scale. In a separate study, Cortes et al. (2021b) followed 2,854 feedlot cattle housed in 11 pens at 2 commercial feedlots. Digital dermatitis was diagnosed in 2.5% of cattle, although only 22% of affected animals showed clinical signs of lameness. Foot and leg conformation did not differ between affected and unaffected cattle, but poor pen hygiene was strongly associated with digital dermatitis risk. Compared to dry pens, cattle housed in pens with more mud than bedding or excessive mud had significantly higher odds of digital dermatitis. The evidence points to management practices, particularly cattle sourcing and pen hygiene, as key factors in the occurrence of digital dermatitis in feedlot systems.

Preventing digital dermatitis in cattle has primarily focused on the use of footbaths. Jacobs et al. (2019) conducted a systematic review and network meta-analysis to evaluate the effectiveness of walk-through footbath protocols for both treatment and prevention in dairy cattle. Among 14 studies reviewed, only the use of 5% copper sulfate at least 4 times per week showed consistent benefit, outperforming no footbath and water placebo in treatment efficacy. No other protocols demonstrated significant preventive or therapeutic effects, likely due to small sample sizes and high methodological variability. While footbaths are commonly used with dairy cattle, published studies evaluating their effectiveness for beef cattle are lacking. Their uptake in the beef industry in Canada is unknown.

Alternative preventive strategies have been explored in beef cattle. Anklam et al. (2025) used an experimental infection model to test the effects of a feed supplement containing *Saccharomyces cerevisiae* fermentation product on digital dermatitis development in Holstein steers. Although all animals developed early or active lesions, those in the control group were 1.5 times more likely to develop ulcerated lesions. While lesion size did not differ between groups, these findings suggest the supplement may reduce lesion progression and offer a nutritional approach to risk reduction.

Mineral supplementation has also been explored as a preventive strategy. In a longitudinal feedlot study, Kulow et al. (2017) compared a control diet containing only inorganic trace minerals with a diet that included a combination of organic and inorganic trace minerals fed throughout the feeding period. During the initial 60-day adaptation phase, a higher proportion of steers in the supplemented group developed digital dermatitis lesions. However, in the post-adaptation period, which continued until slaughter, the relative risk of digital dermatitis was

higher in the control group, suggesting a potential long-term benefit of including organic minerals. Building on this work, Anklam et al. (2022) conducted an 11-month randomized controlled trial with 1,120 beef heifers to assess the impact of organic trace minerals on digital dermatitis and carcass performance. Although no significant differences in lesion prevalence were observed at the pen level during the post-adaptation phase, animal-level analysis showed that cattle receiving organic trace minerals had a slower rate of lesion increase. These cattle also had significantly heavier hot carcass weights at slaughter, averaging 9.7 kg more than the control group.

### 3.2.3.3 *Toe Tip Necrosis Syndrome*

Toe tip necrosis syndrome is a painful condition in feedlot cattle, characterized by progressive necrosis of the third phalanx and surrounding hoof tissues (Erickson et al., 2024a). The most widely supported explanation is the abrasion hypothesis, which suggests that repeated mechanical trauma leads to excessive wear and apical white line separation, creating an entry point for bacterial invasion into the hoof capsule and bone. In a case-control study of 222 cattle, Paetsch et al. (2017) found that affected animals had significantly thinner soles and were more likely to yield heavy growth of *Escherichia coli* and *Trueperella pyogenes*, supporting bacterial colonization as a central feature of pathogenesis. Affected animals were also more likely to be acutely or transiently infected with bovine viral diarrhea virus, which may contribute to lesion development through virus-induced vasculitis.

Gyan et al. (2015) evaluated hind feet from feedlot cattle and found that apical white line separation was highly predictive of toe tip necrosis. Gross and histologic findings demonstrated a consistent pattern of ascending infection beginning at the distal toe, reinforcing the hypothesis that infection initiates at the apical white line. Johnston et al. (2019) extended this understanding by examining cadaveric limbs under mechanical loading. Claws from animals with toe tip necrosis exhibited significantly greater white line separation than controls, with separation worsening as compressive load increased. These results highlight how organic material may become lodged within the hoof capsule of claws, contributing to the development of toe tip necrosis (Erickson et al., 2024a). More recently, Hedayati et al. (2025) used an abrasion simulator to replicate claw wear on concrete flooring. Compared to controls, abraded claws had significantly lower stiffness in the apical white line, and imaging data suggested that abrasion may create pathways for foreign material to enter the claw. These findings offer further support for abrasion as an initiating factor in the development of toe tip necrosis.

Several risk factors have been associated with toe tip necrosis syndrome. Jelinski et al. (2016) analyzed health records from 1,904 cattle lots across 48 western Canadian feedlots and found that toe tip necrosis syndrome occurred sporadically but clustered within specific lots and feedlots. Only 4% of lots had at least one case, and 26% of these occurred in a single feedlot, suggesting that facility-level factors may influence disease occurrence. The condition was observed throughout the year and affected calves, yearlings, steers, and heifers. No consistent relationship was found between animal source and the timing of euthanasia or death due to toe tip necrosis syndrome. Among 702 affected cattle, the median time to diagnosis was 19 days on feed, and the median time to death or euthanasia was 27 days. Erickson (2023) also reported that most cases occurred early in the feeding period, with a mean of just 9 days on feed until

diagnosis. Given this early onset, Erickson et al. (2024a) proposed that the disease may be linked to stressors, such as transport and feedlot processing.

To explore potential nutritional risk factors, Jelinski et al. (2018) investigated whether mineral concentrations differed between cattle with toe tip necrosis and healthy controls. Hoof samples were collected from 183 cattle across 16 feedlots and analyzed for 8 minerals in the hoof wall and solar horn. Magnesium concentrations were significantly lower in claws from affected animals. For every 10 ppm decrease in magnesium, the odds of toe tip necrosis syndrome increased by 1.13 times in the hoof wall and 1.21 times in the solar horn, suggesting that magnesium deficiency may impair horn quality and predispose cattle to disease.

#### 3.2.3.4 Joint Infections

Despite how commonly they occur, joint infections in feedlot cattle remain poorly understood, particularly with respect to underlying risk factors. A specific and severe form of joint infection is septic arthritis. Warr (2024) analyzed the microbial composition of 66 synovial fluid samples, selected from an initial 137 cases of septic arthritis collected across 11 commercial feedlots. *Mycoplasmosis* accounted for 94.8% of genus-level abundance in septic joints, with significantly higher abundance and lower microbial diversity observed in joints affected by septic arthritis and in postmortem samples. Contrary to prior assumptions, *Histophilus* was not among the top 15 genera detected, and members of the Pasteurellaceae family accounted for only 1% of amplicon sequence variants. Species-level identification revealed *Mycoplasma alkalescens* and *Mycoplasma wenyonii* in a small subset of samples. These findings suggest that *Mycoplasma*, rather than *Histophilus*, are the predominant organism in septic joints of feedlot cattle.

In an analysis of risk factors, Davis-Unger et al. (2019) reported that fall-placed calves had significantly higher odds of joint infections compared to yearlings, suggesting increased susceptibility in younger animals. Sex differences were also noted, with steers less likely to be diagnosed with joint infections than heifers. Importantly, joint infections accounted for nearly half of all lameness-associated deaths in the study, highlighting their clinical severity and need for targeted intervention.

#### 3.2.3.5 Diagnosis of Lameness

Lameness is a painful condition in cattle that alters mobility and posture. Affected animals often exhibit signs such as head bobbing, arched backs, and shortened or uneven stride length due to discomfort while walking or standing (Coetzee et al., 2017). Evaluation of these visual indicators can aid in the detection of lameness and provide insights into underlying hoof pathologies.

Thomas et al. (2022b) explored the relationship between digital dermatitis, locomotion scores, and specific gait traits in 480 feedlot cattle. Animals were assessed while walking for signs of arched back, asymmetric gait, head bobbing, reluctance to bear weight, and tracking up (e.g., hind hooves failing to land in or near the position of the fore hooves). Hind feet were then examined for digital dermatitis and classified by lesion stage. Cattle with digital dermatitis had significantly higher locomotion scores, with the highest odds of lameness seen in those with active lesions (i.e., those that were ulcerative). Among the gait traits, asymmetric gait and

reluctance to bear weight were most strongly associated with digital dermatitis. Although sensitivity was low for individual traits, locomotion score and asymmetric gait were the most predictive, supporting their use in diagnosing digital dermatitis in feedlot cattle, although additional refinements to improve sensitivity are warranted.

Other hoof-related conditions produce distinct clinical signs. Chamorro et al. (2019) focused on clinical signs associated with septic arthritis of the distal interphalangeal joint in beef cattle. In a study of 39 animals presenting with single-limb lameness, diagnosis of septic arthritis was confirmed using radiographic changes and synovial fluid analysis. Two clinical signs were particularly diagnostic, with asymmetric swelling at the coronary band and a lameness score of 4 out of 5 or higher being associated with septic arthritis. Specifically, these indicators increased the odds of diagnosing septic arthritis by 63- and 120-fold, respectively, highlighting their value during on-farm evaluation.

Despite the utility of gait assessment, observer agreement can be inconsistent. Fitzsimmonds et al. (2024) evaluated the reliability of a four-point mobility scoring system using 40 video clips scored by 39 beef farmers and 42 veterinarians. Agreement across all respondents was fair (Fleiss kappa = 0.34), with veterinarians showing higher inter-observer reliability than farmers (0.38 vs. 0.29). Intra-observer agreement varied widely, ranging from slight to almost perfect. These findings indicate that variability in scoring may reduce the reliability of visual lameness detection in beef cattle, underscoring the need for consistent training and standardized assessment practices.

To overcome the limitations of gait scoring, technology-based approaches may offer more accurate and consistent methods for diagnosing lameness. Thomas et al. (2021) evaluated whether behavioural monitoring could aid in early diagnosis of digital dermatitis. Using ear-mounted accelerometers, they tracked rumination, feeding, activity, and inactivity in 120 heifers throughout the feeding period. Of the 114 animals with complete data, 45% were diagnosed with digital dermatitis. In the 5 to 2 days prior to diagnosis, affected heifers ruminated less and were more inactive than unaffected cattle. These results suggest that digital dermatitis influences behaviour prior to clinical detection and that automated behaviour monitoring could aid in early identification. It is important to note that while visual gait scoring and behavioural monitoring are useful for identifying lameness, accurately determining the underlying cause typically requires lifting the feet to examine for specific lesions or signs of joint involvement. Additional studies exploring the use of advanced technologies to improve the diagnosis of lameness and its various causes are needed.

### ***3.2.4 Nutritional Diseases Associated with High Concentrate Feeding***

#### ***3.2.4.1 Ruminal Acidosis***

Ruminal acidosis is a common metabolic disturbance in feedlot cattle, particularly during and after transitions to high-concentrate diets. Castillo-Lopez et al. (2014) monitored 250 steers, including 28 fitted with indwelling rumen pH sensors, to evaluate the incidence and severity of acidosis across backgrounding, transition, and finishing phases. As cattle advanced to a finishing diet containing more than 80% barley grain, mean ruminal pH declined, with the lowest values observed during the latter half of the finishing period. Time spent below a pH of 5.5, which was

used to define ruminal acidosis, exceeded 3 hours per day in many steers. By the end of the feeding period, 38% of cattle were affected with ruminal acidosis. Higher dry matter intake and days on feed were strongly associated with both the likelihood and severity of acidosis. In a commercial setting, Wiese et al. (2017) found similar trends during a 40-day transition to a high-concentrate diet. Reticuloruminal pH decreased with each step up in dietary concentrate, and by the end of the transition, 83% of cattle had experienced at least one episode of low pH lasting more than 180 minutes. These findings highlight the increased risk of ruminal acidosis as cattle move toward finishing rations, particularly when forage content declines and grain inclusion rises.

The strong association between high-grain diets and subacute ruminal acidosis has prompted investigations into how forage inclusion and physical form influence rumen pH and acidosis risk. Chibisa et al. (2016) compared a high-starch, low-forage diet (30% forage, 45.3% starch) to a high-forage diet (70% forage, 30.9% starch) and found that cattle fed the low-forage diet spent an average of 2.5 hours per day with ruminal pH below 5.5, compared to only 0.09 hours in the high-forage group. The low-forage diet also reduced eating and resting salivation, contributing to reduced buffering capacity. In a follow-up study, Chibisa et al. (2020) fed finishing diets containing 0%, 4%, 8%, or 12% barley silage (dry matter basis) with barley grain as the primary concentrate. Increasing silage inclusion increased ruminal pH and reduced the duration and severity of acidotic episodes, though acidosis was not completely prevented even at 12% inclusion. Koenig et al. (2020) similarly evaluated barley silage inclusion at 0%, 4%, 8%, and 12% of dietary dry matter in barley-based finishing diets. While dry matter intake increased with greater silage inclusion and average daily gain was unaffected, feed efficiency declined linearly, indicating poorer conversion of feed to gain as silage levels rose. Rumen pH was not directly measured, but cattle fed higher silage levels had lower eating rates, which typically prevents sudden pH drops in the rumen. However, liver abscess prevalence did not differ, and carcass traits were largely unchanged. Pickinpaugh et al. (2022) examined roughage levels of 10–16% in wheat-based diets containing 30% modified distillers grains and found that increasing roughage elevated ruminal pH and shifted fermentation patterns toward greater acetate and butyrate production. Feedlot performance was unaffected; however, marbling tended to decline with more roughage.

Other studies have examined the role of dietary adaptation. Tomczak et al. (2019) evaluated steers fed a high-energy finishing diet from arrival, either alone, with intermittent hay supplementation, or following a lower-energy starter diet (beginning at low concentrate levels and gradually increasing). Despite no differences in growth performance, cattle that received the gradual starter diet ruminated more and maintained higher ruminal pH early in the study, highlighting the stabilizing effects of higher forage content and slower adaptation. Crawford et al. (2022) similarly compared high-risk feedlot cattle fed either a high-energy finishing diet from arrival or a lower-energy receiving diet followed by transition to the finishing diet. Cattle on the finishing diet had lower dry matter intake during the first 74 days but showed greater average daily gain, better feed efficiency, and higher ruminal pH early in the study, despite ruminating less. No statistical differences were detected in health outcomes or liver abscess rates. Final carcass weight was higher in the finishing group, while other carcass traits were similar. Collectively, these studies show that higher forage inclusion and gradual dietary adaptation

consistently support rumen pH stability, although the effects on growth performance and carcass quality remain variable.

Beyond forage inclusion level, the physical form of fiber can also influence rumen environment. Addah et al. (2015) evaluated how chop length and bacterial inoculation of barley silage affected rumen pH and feeding behaviour in finishing steers. Barley silage was chopped to either 1 cm (short chop) or 2 cm (long chop) and included in finishing diets. While average daily gain and feed efficiency did not differ among treatments, steers fed the 2 cm long-chop silage consumed more dry matter and spent more time eating at a slower rate, behaviours that enhance rumen buffering. Inoculating the silage with an esterase-producing bacterial strain reduced the duration and severity of low ruminal pH in steers fed long-chop silage, but it worsened ruminal pH outcomes in those fed short-chop silage. Similarly, Arbaoui et al. (2025) compared long-form straw with ground and pelleted straw and found no benefit of pelleting for growth, intake, digestibility, or emissions. However, steers fed pelleted straw had lower rumen pH and tended to have reduced protozoal counts, suggesting increased acidosis risk. These findings highlight that coarser forage particles may help support rumen health, even when diet composition remains constant.

While dietary fiber and forage management are important for maintaining rumen function, grain type and processing characteristics are also critical determinants of acidosis risk. Ream and Chibisa (2021) evaluated the impact of replacing corn with 20% or 40% wheat grain. Inclusion of wheat grain reduced mean and minimum ruminal pH and increased the time pH remained below 5.8, indicating a greater risk of subacute acidosis. Similarly, He et al. (2015) substituted wheat for barley in finishing diets processed to a consistent index and found that, although nutrient digestibility and volatile fatty acid profiles were unaffected, increasing wheat levels led to longer durations with rumen pH below 5.8. Supporting these findings, Yang et al. (2014) reported that substituting barley with either soft or hard wheat resulted in lower mean ruminal pH and longer periods below pH 5.8 and 5.5, despite similar digestibility. Moya et al. (2015) also found differences in behaviours of cattle fed wheat or barley. Specifically, wheat-fed cattle showed shorter meals, fewer feeding visits, and tended to have lower intake and feeding time than those fed barley. Further, stress indicators such as flight speed and hair cortisol were also lower in barley-fed cattle. These findings suggest that wheat may increase acidosis risk and result in behavioural change, even when processed similarly.

The rolling method used for grain processing also influences rumen pH and may contribute to acidosis risk. Pereira et al. (2022) compared dry-rolling and temper-rolling of hybrid rye and found that cattle fed dry-rolled rye spent more time with ruminal pH below 5.5, despite greater digestibility of dry matter and crude protein. In contrast, temper-rolled rye maintained higher ruminal pH and supported similar starch digestibility. Similarly, Meadows et al. (2023) assessed ruminal pH responses in cattle fed dry-rolled versus temper-rolled high and low protein wheat. Ruminal pH was lower in steers fed high-protein, dry-rolled wheat compared to those fed high-protein, temper-rolled wheat. These findings indicate that tempering may help mitigate the pH depressions associated with fine particle size and high fermentability, potentially lowering the risk of subacute acidosis during dietary transitions.

Grain processing index also plays a role in modulating rumen environment and performance. Moya et al. (2015) compared barley- and wheat-based diets processed to either a high (75%) or

low (85%) processing index. A lower processing index increased dry matter intake but reduced feed efficiency and carcass yield. Similarly, Ribeiro et al. (2016) found that low processing index (processing index of 75% vs. 85%) lead to higher dry matter intake but reduced starch digestibility, feed efficiency, and net energy gain, without negatively affecting rumen pH. Ran et al. (2021) examined the interaction between barley processing index and dietary undigested neutral detergent fiber (NDF) levels. While reducing the processing index did not affect rumen pH or fermentation, increasing dietary undigested NDF improved ruminal pH and chewing activity, with cattle spending more time eating and less time below the acidosis threshold. Together, these findings suggest that although processing index affects nutrient utilization and performance, dietary fiber content may have a more direct and consistent role in stabilizing rumen pH and mitigating acidosis in high concentrate finishing diets.

#### 3.2.4.2 *Liver Abscess*

Liver abscesses are a common and economically significant issue in feedlot cattle. Grimes et al. (2024) analyzed more than 1.5 million carcasses and reported abscesses across a range of severities: approximately 7% had 1 to 2 small abscesses or scars, 3–5% had 1 or 2 large abscesses or multiple small ones, 2–5% had multiple large abscesses, 4–6% had abscesses with adhesions, 1–2% had open abscesses, and about 1% had both open and adhered abscesses. Herrick et al. (2022) conducted audits at 11 beef processing facilities on 130,845 fed-beef and 30,646 cull-beef cattle. They found liver abscess prevalence averaged 20% in fed-beef cattle and 18% in cull cattle, with fed Holsteins showing the highest prevalence (25%) compared to fed-beef steers (18%) and heifers (19%).

The economic impact of liver abscesses is substantial. Grimes et al. (2024) found that severe abscesses were associated with reductions in hot carcass weight (up to 13 kg), decreased longissimus muscle area, and lower subcutaneous fat compared to carcasses with normal livers. Severe lesions also increased the chance of carcasses being removed from the production line and significantly reduced overall carcass value. Similarly, Herrick et al. (2024) reported that Holstein carcasses with both adhered and open abscesses weighed 25 kg less (a 7% reduction) and required more carcass trim (up to 4 kg) compared to those without abscesses. These carcasses also generated \$94 to \$121 USD less in gross revenue, with offal value losses ranging from 20% to 84% depending on severity.

Several risk factors have been associated with liver abscess development. Champagne et al. (2025) evaluated 900 feedlot mortalities across 6 U.S. feedyards and identified greater odds of liver abscesses in steers, dairy-influenced breeds, and cattle with more than 100 days on feed. Peritoneal adhesions were also more common among affected animals. Histologically, cattle with abscesses showed wider rumen papillae with thinner keratin layers and signs of small intestinal damage. These gastrointestinal tract alterations, particularly damage to the ruminal epithelium and intestinal mucosa, may facilitate bacterial translocation and contribute to liver abscess formation, with both ruminal acidosis and pathogen exposure playing key roles in pathogenesis.

Liver abscess development in feedlot cattle is multifactorial, with ruminal acidosis and bacterial translocation playing key roles. Theurer et al. (2021) demonstrated that steers with more severe liver abscesses spent significantly more time with ruminal pH below 5.6 and 5.2, thresholds for

subacute and acute acidosis, especially during the first transition to a higher-energy diet. These findings suggest that periods of low ruminal pH may facilitate mucosal damage and bacterial passage from the rumen. Herrick et al. (2022) provided supporting microbiological evidence, reporting that *Fusobacterium necrophorum* was isolated from 80% of liver abscesses and *Salmonella enterica* from up to 28% of samples in fed-beef cattle, implicating both pathogens in abscess formation.

Experimental studies have further clarified these relationships. McDaniel et al. (2024a) showed that an acidotic diet alone induced ruminal acidosis but did not result in liver abscesses unless cattle were also inoculated with *F. necrophorum* or *F. necrophorum* and *S. enterica*. Liver abscess prevalence reached 40–50% in the inoculated groups, validating the importance of bacterial presence. Similarly, Childress et al. (2025) found that bacterial inoculation with *F. necrophorum* and *S. enterica* could induce liver abscesses even in cattle fed a high-forage diet, indicating that acidosis is not a prerequisite for abscess formation. In that study, steers with liver abscesses had more severe rumenitis, reinforcing that both mucosal injury and pathogen exposure contribute to pathogenesis. Together, these findings underscore that while acidosis may increase risk, bacterial colonization, particularly with *F. necrophorum*, plays a central role in liver abscess development.

To reduce the risk of liver abscesses, tylosin, a macrolide antimicrobial, is commonly included in feedlot diets during the finishing period. As previously reviewed in the Review of Scientific Research on Priority Issues (Schwartzkopf-Genswein et al., 2012), Wileman et al. (2009) conducted a meta-analysis of 6 studies and reported that, while tylosin did not consistently improve average daily gain or feed efficiency, it significantly reduced liver abscess prevalence from 30% in control cattle to 8% in treated cattle. However, concerns have been raised about the long-term use of tylosin and its impact on antimicrobial resistance. Cazer et al. (2020) conducted a systematic review and meta-analysis and found that extended tylosin use, particularly beyond 100 days of supplementation, consistently increased the prevalence of macrolide-resistant *Enterococcus* species in the gastrointestinal tract. The effects on *Escherichia coli*, *Salmonella*, and *Campylobacter* were mixed or unclear, in part due to inconsistent reporting of tylosin administration.

Several studies have evaluated whether tylosin can be administered more strategically to reduce antimicrobial use while still limiting liver abscesses in feedlot cattle. Linneen et al. (2023) assessed tylosin phosphate fed during different portions of the feeding period in large groups of steers and heifers. In steers, liver abscess prevalence was lowest when tylosin was fed for the first 75% of the feeding period or continuously, and highest when it was provided only during the last 50% or not at all. In heifers, the lowest abscess rates occurred when tylosin was fed during the last 83% or continuously, while earlier withdrawal or no tylosin increased both prevalence and severity. Davedow et al. (2020) compared continuous tylosin administration with use only during the first 125 days or the last 121 days in over 7,500 yearlings. Although overall liver abscess prevalence, growth, and carcass traits were not statistically different, cattle that received tylosin for the first 125 days had more severe abscesses, and a similar trend was observed in cattle receiving tylosin during the final 121 days. Further, antimicrobial resistance in *Enterococci* was found to increase over time, but resistance levels were not significantly different among treatment groups. Feitoza et al. (2025) evaluated tylosin given during the first 30 or 60 days of the finishing period, compared to a control group that received no tylosin. Tylosin-

fed steers had greater body weight at day 30 or 60, but final performance and carcass traits were not different by treatment. These findings suggest that targeted tylosin use, especially during high-risk transition periods or later in the feeding phase, may help reduce abscess severity while limiting overall antimicrobial exposure.

Several studies have explored whether increasing dietary fiber can help reduce liver abscess prevalence in feedlot cattle, particularly as an alternative or complement to in-feed antimicrobials like tylosin. Paterson et al. (2024) investigated how different forage inclusion strategies affected growth performance and liver abscess outcomes. In this study, beef steers were assigned to 1 of 4 treatments: a conventional finishing diet with tylosin, the same diet without tylosin, or diets without tylosin that either decreased or increased in forage concentration over time. While growth performance was greatest in the tylosin group, steers on the decreasing-forage diet had a similar prevalence of minor liver abscesses as those receiving tylosin (52% in both groups), and both were lower than in the control and increasing-forage groups (62% and 64%, respectively). Word et al. (2024) also examined the role of roughage in liver abscess prevention, focusing on corn stalk inclusion levels. Steers were fed diets with either 7% corn stalks with or without tylosin, or higher roughage levels of 13% or 19% without tylosin. As roughage increased, dry matter intake rose, but average daily gain, gain-to-feed ratio, and hot carcass weight declined. Tylosin reduced liver abscess prevalence by 32% and lowered the number of adhered livers. While increasing roughage inclusion also reduced abscess prevalence, it did not affect severity. McDaniel et al. (2024b) further refined the relationship between fiber and liver health by evaluating the effects of increasing NDF from alfalfa hay and the bulk density of steam-flaked corn. In a  $2 \times 3$  factorial study, cattle were fed diets containing 3%, 4.5%, or 6% roughage NDF, along with either low- or high-density steam-flaked corn. Liver abscess prevalence, including severe abscesses, declined as roughage NDF increased. Additionally, cattle fed higher-density steam-flaked corn (412 grams per liter) had nearly 14 percentage points fewer abscesses than those fed lower-density corn, without any negative effects on growth. Together, these studies suggest that strategic use of dietary fiber, particularly when provided early in the feeding period or through increased NDF levels, can help reduce liver abscess prevalence, although trade-offs in growth performance may occur depending on the roughage source and inclusion rate.

In addition to fiber content, dietary starch concentration has also been implicated in liver abscess risk. Schneid et al. (2024) evaluated how starch level and feeding consistency influenced liver abscess prevalence and performance outcomes in finishing steers. In this  $2 \times 2$  factorial study, cattle fed a high-starch diet (64.4%) had a markedly greater prevalence of liver abscesses (55.1%) compared to those fed a lower-starch diet (49.1%, 33.4%). High-starch diets also resulted in reduced final body weight, average daily gain, dry matter intake, hot carcass weight, and marbling score. Interestingly, variation in feeding schedule, whether consistent or erratic, did not affect liver abscess prevalence or growth performance. These findings highlight dietary starch concentration, rather than timing or quantity variability, as a key driver of liver abscess risk in feedlot cattle.

Overall, the literature demonstrates that liver abscesses remain a prevalent and economically significant condition in feedlot cattle, driven by a combination of dietary, microbial, and host factors. While ruminal acidosis can facilitate bacterial translocation through mucosal injury, bacterial exposure, particularly to *Fusobacterium necrophorum*, is essential for abscess

formation. Tylosin continues to be an effective preventive tool, especially when used strategically during high-risk periods, but its contribution to antimicrobial resistance and its status as a World Health Organization (WHO) critically important antimicrobial has prompted efforts to identify alternative or complementary strategies. Research suggests that dietary interventions, such as increasing fiber inclusion early in the feeding period or adjusting starch concentration, can reduce abscess prevalence. These strategies likely work by stabilizing the rumen environment, thereby reducing the frequency and severity of acidotic episodes that promote mucosal damage and enable bacterial entry. Although liver abscesses can still occur in the presence of *Fusobacterium necrophorum* even without acidosis, limiting epithelial injury through diet appears to reduce risk by limiting pathogen invasion. However, nutritional approaches may carry trade-offs in terms of growth performance and carcass quality, depending on the source and amount of fiber or starch used.

#### 3.2.4.3 *Behavioural Adaptations to Nutritional Diseases*

Beyond the well-documented physiological markers described above (e.g., rumen pH, liver abscess biopsies), recent research has begun to explore how these conditions also drive motivational and behavioural changes, which can be used to infer affective state and overall well-being. Cattle that experienced low rumen pH showed behavioural adaptations that would help attenuate the effects of acidosis, by either sorting their ration to consume a greater proportion of long, fibrous particles (DeVries et al., 2014a, 2014b) or changing the feeding pattern to have more frequent and smaller meals throughout the day (Moya et al., 2011, 2014). Van Os et al. (2018) showed that cattle fed a high-energy, low-roughage diet were more motivated to obtain forage compared to those fed a high-roughage diet. Similarly, Coon and Tucker (2024) determined that the motivation of feedlot cattle to access forage increased as rumen pH depression became more severe. Nevertheless, the same study, and Coon and Tucker (2023), showed that despite a prolonged reticulorumen pH depression, feedlot cattle were still more motivated to access a high-grain total mixed ration (TMR) than to access additional forage. The results of these studies suggest that the caloric density, palatability, and previous experiences with the TMR may be driving a strong motivation to ingest high-concentrate rations despite the potential negative digestive consequences. This poor association between acidotic diets and its post-ingestive consequences can lead to the chronicity of digestive upsets, with a demonstrated impact on cattle health and welfare. Moya et al. (2015) showed how a wheat-based diet resulted in a greater concentration of cortisol in hair and cattle with more excitable temperaments upon being handled, likely a reflection of the stress and discomfort caused by liver pathology. These behavioural indicators provide valuable insights into the negative consequences of acidosis and liver abscesses of feedlot cattle and highlight the importance of dietary management to promote animal welfare. Further research is needed to determine how these behavioural adaptations are connected with cattle affective states, as a key component of animal well-being.

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## 4 End-of-Life Management

### Conclusions:

1. **Euthanasia decisions regarding livestock are complex and influenced by factors such as the likelihood of recovery, animal pain and distress, transport feasibility, and economic considerations. Clear decision-making guidelines, including timelines, are essential to ensure humane treatment and prevent unnecessary suffering.**
2. **Training and education are critical to improve euthanasia practices, including accurate shot placement, proper equipment maintenance, and decision-making skills. Consideration should also be given to supporting caretakers with resources and training to alleviate emotional stress related to euthanasia practices.**
3. **Captive bolt paired with a secondary step (i.e., a second captive bolt shot, pithing, exsanguination, or intravenous injection of salt solutions) and gunshot (given appropriate firearm choices are made and close range can safely be achieved) are effective methods for euthanasia.**
4. **Non-penetrating captive bolts and smaller caliber bullets (0.22 long rifle (LR)) are only suitable for euthanizing calves (2–3 months and 4 months, respectively).**
5. **Confirmation of death is critical to ensure humane outcomes and requires checking for cessation of breathing, heartbeat, and reflexes.**
6. **Further research is needed to develop improved tools, training programs, and decision-making guidelines tailored to beef cattle, with a strong emphasis on enhancing human and animal safety while enhancing overall welfare during euthanasia practices.**

### 4.1 Decision-Making Surrounding Euthanasia

Ending the life of an animal in order to reduce or eliminate distress and/or suffering is referred to as euthanasia (Shearer, 2018). The decision to euthanize livestock is complex and influenced by both practical and emotional factors. Moggy et al. (2017) surveyed cow–calf producers in western Canada and found that the primary considerations for on-farm euthanasia were the likelihood of recovery (73%) and the animal’s pain and distress (64%). Qualitative interviews revealed that producers often viewed euthanasia as a difficult and emotional decision, frequently consulting veterinarians for advice but ultimately feeling personally responsible for the decision. Other influencing factors included the animal’s ability to access feed and water, transport feasibility, and meat salvage quality, with minimizing suffering consistently prioritized. It is important to note that 13% of respondents also reported that cattle were not euthanized on farm, which suggests they were either transported off site or died without assistance, either of which might lead to prolonged suffering. Indeed, the criteria for deciding when to euthanize is critical

to minimize suffering, particularly with respect to when an animal is not responding to treatment and/or has a poor prognosis and is unlikely to recover.

Difficulty in making euthanasia decisions may also explain findings by Goldhawk et al. (2015), who reported that half of the cull beef cow shipments in Canada contained at least one compromised cow, suggesting producers may struggle with timely euthanasia or assessing fitness for transport. Windeyer et al. (in preparation) evaluated 9,643 cattle from 8 auction markets, 11 provincial abattoirs, and 1 federally inspected abattoir across Alberta and found that, 95% of cattle were considered fit for transport upon arrival. However, that study elucidated additional details that suggest there is room for improvement regarding on-farm decision-making about end-of-life care. Specifically, 0.4% (16 of 4,461) of cattle arriving at auction markets, 2% (26 of 1,069) at provincial abattoirs, and 0.1% (5 of 4,013) at federal abattoirs were considered unfit for transport. However, it is important to note that the arrival condition may not accurately represent the animal's status on the farm and may instead reflect issues arising during transport or delays in decision-making to address compromised conditions. Furthermore, 4% (197/4,561) of cattle arriving at auction markets and 2% (73/4,013) arriving at federal abattoirs were considered compromised, which is likely not appropriate given that such animals may only be locally transported with special provisions to receive care be euthanized or humanely slaughtered (Government of Canada, 2019). These findings underscore the importance of support and training to improve euthanasia decision-making on farms.

Decision-making surrounding euthanasia in the dairy industry has also been found to be complex and emotionally challenging. Wagner et al. (2020) emphasized the lack of clear guidelines for determining euthanasia timelines for cattle with injuries or illnesses who are unlikely to recover. A survey of 307 dairy producers revealed significant variability in euthanasia practices, with 6% and 12% of respondents indicating they would never euthanize a non-ambulatory cow or calf, respectively. Focus groups highlighted three key themes influencing decision-making: animal welfare, human psychology, and farm operations, with participants emphasizing the need to minimize animal suffering while grappling with the emotional burden of euthanasia decisions. Merenda et al. (2023a) further explored dairy workers' attitudes toward euthanasia, identifying three clusters: confident but uncomfortable, confident and comfortable, and unconfident with limited knowledge. Workers on medium-sized farms and those with less experience were more likely to lack confidence and knowledge, underscoring the need for targeted training. Similarly, Denis-Robichaud et al. (2023) reported that 17% of Canadian dairy farmers felt discomfort with the responsibility of performing euthanasia and 19% observed unease among others on the farm. Half of the participants noted that those performing euthanasia experienced at least one painful emotion or source of anxiety, highlighting the emotional complexities inherent in euthanasia decision-making. Collectively, these findings underscore the importance of clear guidelines, targeted training, and emotional support to enhance euthanasia decision-making and improve both human and animal welfare.

## 4.2 Current Methods and Practices

Humane euthanasia may entail a single step that causes immediate death or may be achieved using two steps: an initial stunning step that causes loss of consciousness followed quickly by a secondary step that causes death while the animal is insensible (Terlouw et al., 2016).

Euthanasia practices in cattle production vary depending on operation type and region. Lee et al. (2015) surveyed 23 consulting feedlot veterinarians in the US and Canada and found that 91% identified gunshot as the most commonly used method for humane euthanasia on the feedlots they served, consistent with 87% in 2009. In comparison, captive bolt was reported by only 9% of participants, compared to 13% in 2009. A survey of 109 cow-calf producers in western Canada documented on-farm euthanasia practices (Moggy et al., 2017). The most common method for euthanasia was gunshot, with 94%, 88%, 82%, and 96% of respondents reporting it as the main method of euthanasia for preweaned calves, weaned calves, adult cows, and adult bulls, respectively. These findings highlight the prevalence of gunshot as the primary method of euthanasia across different cattle production systems.

### 4.2.1 Appropriate Methods of Euthanasia

#### 4.2.1.1 Firearm

**Rifles and handguns.** Baker and Scrimgeour (1995) isolated cadaver heads from adult steers and heifers and tested various firearms and ammunition. Firearms included the Ruger Mini-14 with .223 FMJ and Core-Shot pre-fragmented rounds, the Ruger 10/22 with .22 LR standard and high-velocity rounds, and a .30-06 rifle with soft-nose rounds, among others. The Ruger Mini-14 with Core-Shot pre-fragmented rounds demonstrated superior performance, causing extensive brain damage without overpenetration, whereas the Ruger 10/22 with .22 LR standard and high-velocity rounds proved inadequate for penetration. Thomson et al. (2013) assessed euthanasia methods for feedlot cattle by using computed-tomography imaging to analyze cranial penetration and brain tissue disruption in cadaveric steer heads. Rifle-fired .22-caliber solid-point rounds, pistol-fired .45-caliber ACP rounds, and carbine-fired .223-caliber rounds were highly effective, while rifle-fired .22-caliber hollow-point rounds and pistol-fired 9-mm rounds were less reliable due to insufficient brainstem damage. Shearer (2018) attributed these limitations to bullet fragmentation, which reduced penetration, and the shorter barrel length of pistols, which decreases muzzle velocity, as rounds like 9 mm and .45 caliber require barrels longer than 16 inches for optimal performance.

Based on these studies and expert opinion, the American Veterinary Medical Association (AVMA, 2020), Canadian Veterinary Medical Association (CVMA, 2021), and American Association of Bovine Practitioners (AABP, 2023) have established guidelines for euthanasia in cattle. A .22 LR is commonly used to euthanize cattle in North America and consistently delivers bullets at a velocity of 1,200 feet/s with a muzzle energy (ME) in the range of 120 to 130 foot-pounds (AVMA, 2020). ME is the kinetic energy of a bullet and is a measure of its destructive potential. Heavier bullets with greater velocity have higher ME and capacity for destruction. The AVMA (2020) indicates the ME requirements needed to penetrate and traverse the skulls of cattle for the purpose of euthanasia has been poorly understood, and prior recommendations of a minimum ME of 300 foot-pounds for animals up to 400 lb and as much as 1,000 foot pounds for

animals over 400 lb have been deemed excessive (AVMA, 2020). A study by Blackmore (1985) found 94 foot-pounds was adequate to penetrate the frontal bone of a 3-year-old Angus cow and sufficient for humane slaughter or euthanasia of mature cattle.

The AVMA emphasizes that .22 caliber long rifle ammunition should only be used with a rifle (though this specification regarding rifles may not be relevant in Canada due to differing gun laws), equipped with a solid point bullet, fired from close range (30–90 cm [1–3 feet]), and aimed at the correct anatomic placement on the skull. Further, the AABP's current recommendations (AABP, 2023) suggest that a .22 caliber handgun or rifle loaded with a long rifle solid point bullet is sufficient only for calves less than four months of age. In cattle over four months of age, it is necessary to use .22 Magnum or higher calibers for consistently effective euthanasia.

**Shotgun.** Baker and Scrimgeour (1995) evaluated three shotguns for euthanasia using isolated cadaver heads from adult steers and heifers. The .410-gauge shotgun with #4 and #6 birdshot caused sufficient brain damage but required close range to prevent shot dispersion and needed reloading after every shot, offering little advantage over a captive bolt gun. The 12-gauge Remington 870 with a rifled slug was powerful but lacked accuracy at 25 metres, with excessive recoil making it unsuitable for repeated use, though the impact likely induced unconsciousness. When loaded with #7 1/2 game shot, the same shotgun achieved total brain destruction but was excessively powerful and offered limited benefits compared to a captive bolt gun at close range. Thomson et al. (2013) similarly found that shotguns loaded with birdshot or slugs were effective for euthanasia of feedlot cattle based on a simulation study using feedlot steer cadaver heads shot from a distance of 3 metres.

The AABP (2023) emphasizes that shotguns are highly effective for euthanasia at close range (less than 90 cm or 3 feet), recommending 12-, 16-, and 20-gauge shotguns for adult cattle and 28- or .410-gauge shotguns for calves. Using shot shells at close distances ensures the projectiles strike the skull as a compact mass, enhancing consistency and effectiveness. Similarly, the AVMA (2020) recommends shotguns loaded with birdshot (#6 or larger) or slugs for cattle euthanasia at short ranges (91–183 cm [1–2 yards]). At these distances, birdshot impacts the skull as a compact mass, effectively penetrating and causing extensive brain tissue destruction, leading to immediate unconsciousness and rapid death. It is important to note that the use of shotguns is only appropriate at close range, which means that appropriate restraint and immobilization of the animal is necessary for both animal and human safety.

**Human safety.** Although not extensively detailed in the literature, human safety is paramount when using firearms for euthanasia. Bottleneck centrefire rifle cartridges pose a significant risk of ricochet and over-penetration, as their high energy can cause the projectile to pass through the animal and travel considerable distances, potentially endangering people or property. For safer alternatives, shotgun slugs or rifles chambered for pistol ammunition, such as .357 Magnum or .44 Magnum, are recommended, as they offer sufficient stopping power while minimizing the risk of ricochet and over-penetration. As mentioned previously, proper restraint and immobilization as well as consideration of the surrounding environment (e.g., the risk of ricochet within the confines of a trailer) are also critical considerations for maintaining both animal and human safety. Sedation, such as the use of xylazine prior to euthanasia, has been shown to improve animal immobilization, enhance handler safety, and facilitate a more practical and

efficient process, particularly in large-scale depopulation scenarios (Hanthorn & Sanderson, 2019).

#### 4.2.1.2 *Captive Bolt*

***Non-penetrating versus penetrating captive bolt.*** Finnie (1995) assessed non-penetrating percussive captive bolt stunning in 12 cattle, finding it caused immediate unconsciousness with a 3 cm depressed frontal bone fracture and extensive subarachnoid hemorrhage over the brainstem, temporal, and frontal lobes. Microscopic examination revealed petechial hemorrhages in the thalamus and basal ganglia, linked to concussive forces and brain acceleration within the skull. However, larger studies highlight the limitations of non-penetrating captive bolts for adult cattle. Gibson et al. (2019) evaluated 31 approximately 30-month-old Zebu × Hereford crossbred bulls, finding all bulls stunned with a penetrating captive bolt exhibited electroencephalogram patterns (e.g., measures of electrical activity in the brain) consistent with unconsciousness, while only 82% of those stunned with a non-penetrating bolt showed unconsciousness and two non-penetrating stuns resulted in incomplete unconsciousness. Similarly, Oliveira et al. (2018) examined 455 Zebu and Zebu-cross cattle and found penetrating captive bolts outperformed non-penetrating bolts in velocity, momentum, and energy, with fewer repeat shots required (12% vs. 29%). Penetrating bolts achieved higher rates of immediate collapse (99% vs. 91%) and fewer signs of distress, such as rhythmic respiration and reflexive movements, indicating superior welfare outcomes. Supratikno et al. (2024) further reported a success rate of only 74% for non-penetrating pre-slaughter stunning in Brahman-cross cattle, highlighting its limitations for adult cattle. Cumulatively, these studies suggest that non-penetrative captive bolts are not effective on adult cattle. However, it should be noted that non-penetrative captive bolts, when used properly, may be used for humane slaughter if followed immediately with a secondary method such as exsanguination (Musk & Johnson, 2024). It is important that the “stun-to-stick” interval is short, ideally less than 60 s and no more than 90 s (Jerlström et al., 2025).

In contrast, Collins et al. (2020) found non-penetrating captive bolts effective for younger animals, demonstrating immediate and sustained unconsciousness in sedated 4- to 5-month-old Holstein steers, with only minor differences in cessation of respiration and convulsions between penetrating and non-penetrating captive bolts.

Reflecting these findings, the AVMA (2020) and CVMA (2021) recommend that solely penetrating captive bolts should be used for humane euthanasia of older cattle, with non-penetrating captive bolts used only in calves. Similarly, the AABP (2023) guidelines for humane euthanasia of cattle suggest non-penetrating captive bolt can be used for the euthanasia of neonates and calves less than 2 to 3 months of age

***Type of penetrating captive bolt.*** Baker and Scrimgeour (1995) evaluated euthanasia methods for cattle during foreign animal disease outbreaks and found that two .25-caliber penetrating captive bolt stunners from Accles and Shelvoke, including the Magnum stunner, effectively induced immediate unconsciousness in adult cattle at abattoirs. Kaluza et al. (2022) compared pneumatically powered and cartridge-fired captive-bolt stunners in cattle, reporting superior outcomes with pneumatic stunning. This method required fewer repeat shots (6% vs. 18%) and had fewer deviations in shot placement (25% vs. 34%) and direction (10% vs. 47%), particularly in bulls, indicating greater efficacy and reliability with pneumatic systems. Finally, Frazer et al.

(2023) compared three penetrating captive bolt devices, the Blitz-Kerner, Jarvis BABOOM, and Matador SS3000, using ballistic gelatin and cadaver heads from male and female cattle of varying ages. The Matador SS3000 demonstrated the greatest penetration depth, followed by the Jarvis BABOOM and the Blitz-Kerner, with significant differences between the devices. Additionally, the Blitz-Kerner exhibited the lowest kinetic energy.

The length of the penetrating captive bolt is also an important consideration. Kline et al. (2019) evaluated the impact of three captive bolt lengths (15.2 cm, 16.5 cm, and 17.8 cm) on tissue damage and hind limb kicking in properly stunned fed-beef cattle and Holstein steers and heifers using a pneumatic stunner. All 45 cattle were rendered unconscious with a single shot. Visual examination indicated that the shortest bolt caused the least brain damage, with intact brainstems observed across all treatments. The findings confirm that cattle can be stunned without visible brainstem disruption, regardless of bolt length, which is desirable when attempting to diagnose neurologic diseases, including BSE surveillance. In a similar study, Anderson et al. (2025) reported that a penetrating depth of approximately 35–52 mm would be needed to reach the brain of most mature Holstein cows when using most recommended frontal positions, and 96.3 mm penetration depth would be needed to reach the hypothalamus when using an ideal frontal position. They also stated that most commercial penetrating captive bolts are not of adequate length to be used for the poll position in mature cattle. Importantly, they also mention the dimensions measured for the cadaver heads used in their study were not substantially different than what is reported in the literature for mature cattle of beef breeds. As such, their findings are likely also relevant for mature beef cattle.

***Secondary steps for euthanasia with captive bolts.*** Death is not always assured when captive bolts are used alone, emphasizing the importance of adjunctive steps. Grandin (2002) evaluated penetrating captive bolt stunning in 21 U.S. beef slaughter plants, observing over 2,500 cattle, including steers, heifers, cows, and bulls. While 81% of plants rendered all cattle insensible before hoisting onto the bleed rail, 0.2% of fed steers and heifers and 1.2% of bulls and cows showed signs of returning to sensibility. Gilliam et al. (2018) further demonstrated the need for secondary steps, as the CASH Euthanizer captive bolt system failed to euthanize 9.7% of adults, 10.5% of young animals, and up to 20% of neonates with penetrating shots. Failures were associated with the return of respiration or prolonged time until cardiac arrest. Similarly, Dewell et al. (2015b) evaluated penetrating captive bolt use in 22 feedlot calves, finding that cardiac death (i.e., ventricular standstill) occurred an average of 8 minutes and 34 seconds after stunning. Clinical cardiac death, defined as the absence of an audible heartbeat, occurred earlier, with only 70% of calves presumed deceased based on clinical parameters prior to ventricular standstill.

These findings support AVMA (2020), AABP (2023), and CVMA (2021) guidelines, which emphasize that captive bolts should be paired with an adjunctive step to ensure complete euthanasia.

***Second shot.*** Robbins et al. (2021) evaluated the efficacy of frontal sinus and poll locations as secondary shot sites for cattle euthanized with a penetrating captive bolt. Clinical assessments showed no signs of sensibility after the initial frontal sinus shot in this study, regardless of the secondary shot location. While poll shots resulted in fewer animals with a heartbeat 5 minutes post-shot, pathology revealed limited brainstem damage, indicating that such damage may not be required for irreversible insensibility and death. Both locations were found to be similarly

effective as secondary shot sites. A follow-up study by Robbins et al. (2023) confirmed these findings in mature Jersey × Holstein dairy crosses, showing minimal signs of consciousness after an initial frontal sinus shot. The time to the last heartbeat and gross brain trauma scores did not differ significantly between frontal sinus and poll shots, suggesting that either location is an effective secondary method.

***Intravenous administration of salts.*** Intravenous administration of potassium chloride or magnesium sulfate following the use of a captive bolt disrupts the heart muscle's electrical conductivity to ensure death. The AVMA (2020) notes that potassium chloride typically induces death more rapidly than magnesium sulfate, but the CVMA (2021) highlights that magnesium sulfate may result in fewer violent neuromuscular reactions. Stanger et al. (2019) supports this, finding both methods humane based on measures of pain perception in sheep; however, potassium chloride caused severe reflex movements during infusion, while magnesium sulfate did not.

***Exsanguination.*** Exsanguination is typically performed by making an incision on the ventral side of the throat or neck, cutting through the skin, muscle, trachea, esophagus, carotid arteries, jugular veins, and numerous sensory and motor nerves, along with other vessels. The AVMA (2020) and AABP (2023) state this procedure must not be used as a standalone method of euthanasia but is acceptable for use as an adjunctive method.

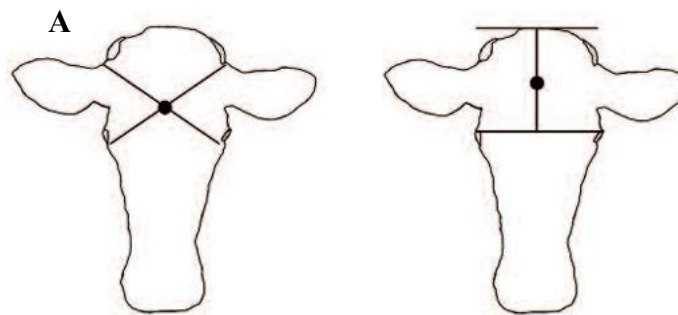
***Pithing.*** Pithing involves inserting a rod through the skull's entry site created by a penetrating captive bolt to destroy the brainstem and spinal cord. Appelt and Sperry (2007) compared stunning alone to stunning followed by pithing, primarily in cull dairy cows. They found that none of the pithed animals regained consciousness, whereas 5 of 12 animals that were not pithed exhibited signs of returning to consciousness, underscoring the effectiveness of pithing. However, Leach and Wilkins (1985) noted that pithing after captive bolt stunning in Hereford × Holstein crosses at slaughter induced violent muscular activity, which could pose challenges during implementation.

***Single step with captive bolt.*** Derscheid et al. (2016) assessed a penetrating captive bolt device with an integrated air-channel pithing mechanism as a one-step euthanasia method for feedlot cattle. Among 66 steers and heifers, 94% were euthanized with a single shot, while 6% required additional shots due to placement errors. All shots penetrating the cranial vault rendered cattle unconscious with no return to sensibility.

In a study using a penetrating captive bolt with an extended bolt, Dewell et al. (2024) euthanized 17 cattle of various ages and breeds by positioning the device flush against the parietal bone behind the poll and aiming toward the base of the tongue. Properly placed shots resulted in immediate loss of consciousness without return to sensibility, followed by clinical death, with only one animal requiring a second shot due to an improper angle. Postmortem assessments confirmed sufficient brain trauma, supporting the poll shot as an effective euthanasia method when executed correctly.

While these studies demonstrated varying success with different bolt devices and shot positions, a secondary step is still recommended, as neither study achieved 100% success in all animals with a single shot.

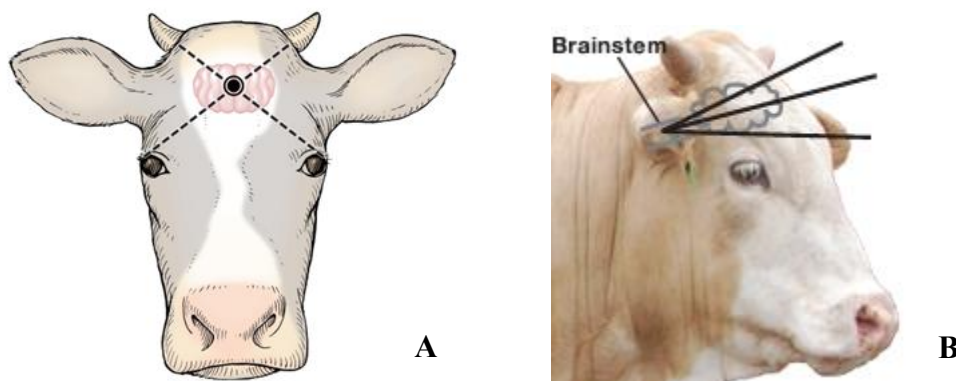
**Placement of captive bolt or firearm shot.** The positioning of the captive bolt or the firearm shot on the head of the cattle is critical, with Schiffer et al. (2017) finding accurate shot placement was more critical than the choice of firearm caliber. This was further emphasized by Gilliam et al. (2016), who randomly assigned intact cadaver h **B** ; of beef and dairy cattle to a high or low single shot of a penetrating captive bolt. The low group used the standard landmark (intersection of lines from the medial canthus of the eye to the top of the opposite ear; Figure 1A), while the high group used a modified landmark (midline halfway between the top of the poll and an imaginary line connecting each lateral canthus of the eye; Figure 1B). Results showed greater brainstem disruption in the high group for adult cattle (16/18 high vs. 7/14 low) and young cattle (13/16 high vs. 11/19 low), with both landmarks performing equally well in neonates (11/11 high and 14/14 low). These findings suggest that the higher shot placement improves the likelihood of brainstem disruption in adult cattle, potentially reducing the risk of regaining sensibility.



**Figure 1.** Figure from Gilliam et al. (2016)

**A** demonstrates the position of the shot used in the low group (intersection of lines from the medial canthus to the top of the opposite ear), while **B** demonstrates the position of the shot used for the high group (midline halfway between the top of the poll and an imaginary line connecting each lateral canthus).

Based on this, the AVMA (2020), AABP (2023), and CVMA (2021) recommend the shot should be placed at the intersection of two lines drawn from the lateral canthus (outer corner) of each eye to the centre of the base of the opposite horn (or the area where the horn would be) as shown in Figure 2A. The angle of the shot must be perpendicular to the front of the skull (Figure 2B).



**Figure 2.** *Appropriate landmarks for shot placement for euthanasia of cattle.*

**A)** Figure from AVMA (2020): demonstrates the position of the shot placed at the intersection of two lines drawn from the lateral canthus (outer corner) of each eye to the centre of the base of the opposite horn (or the area where the horn would be). **B)** Figure from AABP (2023): the trajectory of the shot is along the midline between the base of the ears at the level of the external ear canal, directing it perpendicular or slightly downward (no more than 45 degrees). The angle can be adjusted, as illustrated in Figure 2B, to accommodate the position of the animal and caretaker, particularly when using a firearm. Penetrating captive bolts should be discharged with the device held flush and perpendicular to the frontal bone.

More recently, the commonly recommended positions for captive bolt placement were assessed by Anderson et al. (2025). They not only assessed the potential from brain contact, but also contact with the thalamus, the major area of the brain responsible for consciousness. Based on this, the ideal placement was in fact 1cm above the intersection described above (Figure 2A), which achieved thalamus contact in 100% of the mature Holstein cow cadaver heads. However, both the placement in Figure 2A and the placement in Figure 1B also made 100% contact with the brain but only 94% and 0% contact with the thalamus, respectively.

**Barbiturates and barbituric acid derivatives.** Barbiturates lead to rapid transition from consciousness to unconsciousness and death when administered at the appropriate dosage intravenously (AVMA, 2020). However, there are drawbacks stated by the AVMA (2020) and AABP (2023), including the cost, need for adequate animal restraint, administration by registered personnel (i.e., veterinarians), and limited options for carcass disposal. Further, AABP (2023) highlights that there are risks of ingestion by wildlife and rendered material consumed by domestic pets and as such recommend it as a last resort for euthanasia, unless appropriate carcass disposal can be carried out. However, this method of euthanasia is perhaps preferable for neurological conditions or suspected cases of bovine spongiform encephalopathy, where it is essential to preserve the brain, particularly the brainstem, intact.

**Confirmation of death.** Confirming the success of a euthanasia method is essential to ensure humane treatment and prevent unnecessary suffering. Moggy et al. (2017) found that among western Canadian cow–calf respondents who euthanized cattle, the most common method of confirming death was checking for breathing (68%), followed by absence of the corneal reflex (62%), heartbeat (47%), limb movement (38%), and bellowing or vocalization (15%). However, of concern, 8% of respondents who performed on-farm euthanasia did not confirm death at all. Since surveys often capture responses from more engaged producers, the proportion is likely higher in the general population.

The CVMA (2021) guidelines state the last step of euthanasia is to confirm death by ensuring all of the following indicators: immediate and permanent cessation of rhythmic breathing, absence of vocalization, absence of eye reflexes, a glazed or glassy appearance of the eyes, eyes remaining open and facing straight forward, and absence of a detectable heartbeat. The AABP (2023) guidelines also state that confirmation of death following a euthanasia procedure is absolutely essential, with lack of heartbeat and respiration for 3 to 5 minutes used to confirm death.

### 4.3 Training to Improve Euthanasia Practices

Training is essential for ensuring the success of any euthanasia method. Setijanto et al. (2024) highlighted that improper shot placement and shooting distances significantly reduced the success rates of penetrating captive bolt use. Similarly, Grandin (2002) identified factors contributing to the return of sensibility after captive bolt stunning, including damp cartridge storage, poor stunner maintenance, and operator inexperience. Schiffer et al. (2017) found shot location was more critical than the choice of firearm caliber when testing five firearm and bullet combinations, further emphasized the importance of accurate shot placement.

Effective training programs are critical for improving the skills, including placement, equipment, and confirmation, and confidence of individuals responsible for euthanasia of livestock. Dewell et al. (2015a) evaluated an interactive workshop for beef cattle handlers and found that participants reported moderate improvements in their ability to identify the optimal point of entry for firearms and captive bolts, demonstrating the value of training. In dairy cattle, Merenda et al. (2023b) assessed an interactive, case-based euthanasia training program aimed at improving decision-making and awareness of timely euthanasia. Participants reported increased confidence in identifying compromised animals, determining when euthanasia is necessary, and recognizing its importance, with younger and less-experienced workers benefiting the most. These findings highlight the effectiveness of such programs in enhancing euthanasia decision-making. Reflecting this need, the AABP (2023) recommends that owners, facility employees, or non-veterinarian third parties performing euthanasia receive annual training and certification.

### 4.4 Future Research

Studies are needed to evaluate the effectiveness and reliability of different euthanasia tools and techniques under real-world conditions across diverse cattle production systems. Additionally, euthanasia recommendations for captive bolts and firearms may need to account for breed-specific differences, as variations in skull morphometric characteristics have been observed between dairy and beef breeds (Çakar et al., 2024). Research should also focus on developing improved decision-making frameworks that integrate practical, emotional, and welfare considerations, enabling producers to make timely and humane euthanasia decisions. Furthermore, designing and implementing training programs tailored to different experience levels and farm sizes could significantly enhance confidence and precision in euthanasia practices. For firearms, requiring appropriate licensing and training is critical to ensure both safety and the humane application of euthanasia practices. An additional research priority is monitoring the prevalence of appropriately versus inappropriately euthanized animals arriving at diagnostic laboratories, within feedlots, and/or by veterinarians performing field necropsies, particularly as an outcome measure to assess the effectiveness of training programs.

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## 5 Weaning Practices and Pre- and Post-Weaning Management

### 5.1 Introduction, Scope, and Main Principles

Weaning is considered a necessary management practice in most modern beef cattle systems, where the dam and calf are separated to facilitate cows regaining body condition, support the next pregnancy, and allow the specialized feeding of the calves. While necessary, the process of weaning is widely recognized as a source of stress for both the cow and the calf. This stress can have short-term and long-term implications for welfare, health, and performance.

The 2012 Review of Scientific Research on Priority Issues (Schwartzkopf-Genswein et al., 2012) summarized the evidence available at that time, highlighting the behavioural and physiological responses to weaning and describing several weaning methods. Since then, additional research has expanded our understanding of how weaning practices influence the welfare of both beef cows and calves and has introduced refinements to pre- and post-weaning management aimed at mitigating negative outcomes.

This updated review highlights the scientific literature on weaning in beef cattle from 2012 onwards. It focuses on four key areas: (1) the welfare impacts of weaning on both the cow and the calf, (2) common and emerging weaning procedures and practices, (3) management strategies that may influence weaning outcomes, and (4) future research priorities. This review focuses exclusively on studies conducted in beef cattle or those applicable to Canadian beef production systems.

### 5.2 The Welfare Impacts of Weaning on Both the Cow and the Calf

#### Conclusions:

- 1. Weaning is a significant welfare challenge for both cows and calves, consistently associated with behavioural and physiological indicators of distress, which last for several days, reinforcing conclusions from earlier scientific reviews.**
- 2. Individual and management-level factors influence the welfare impacts of weaning. While some characteristics, like cow parity, are not easily modified, evidence clearly supports that weaning younger calves or using abrupt methods results in greater distress, and that combining weaning with other stressors (e.g., transport) can further compromise welfare.**

The 2012 Review of Scientific Research on Priority Issues (Schwartzkopf-Genswein et al., 2012) concluded that weaning causes distress to both the cow and the calf, as evidenced by behavioural changes and increased morbidity (Since then, research has continued to document the behavioural, physiological, and health-related consequences of weaning, reinforcing the conclusion that imposing weaning is a significant welfare challenge.

A key strength of a study by Ungerfeld et al. (2014) was the inclusion of a non-weaned control group, allowing for a direct comparison of behavioural and physiological outcomes in cows

subjected to weaning with those allowed to maintain the cow–calf bond. Cows that had calves weaned using either abrupt or nose-flap methods exhibited increased behavioural signs of distress, such as vocalization and pacing, compared to cows of non-weaned calves. Although the nose-flap method reduced behavioural signs of distress compared to abrupt separation, cows in the control group showed minimal signs of stress and maintained higher milk production throughout.

There is also individual variation that occurs in the response to weaning. Stěhulová et al. (2017) evaluated how cow and calf characteristics influence behavioural outcomes following abrupt separation at 151 to 274 days of age. Cows vocalized more if their calves were younger at weaning or had higher growth rates or if the cows were not pregnant, while younger cows moved more. Among calves, vocalization and movement were greater in females and in those with higher weight gain. Behavioural responses also differed in cows and calves over time, with cow vocalizations peaking 6 to 8 hours post-separation before declining, while calf vocalization frequency continued to rise for 24 hours after separation. De Paula et al. (2023) also examined the effect of cow parity on their stress response following abrupt weaning with remote separation in Nellore cattle. While both primiparous and multiparous cows displayed behavioural and physiological responses, multiparous cows showed greater increases in cortisol, red blood cell counts, hematocrit, and hemoglobin. These data suggest that older, multiparous cows may experience a more intense physiological stress response, perhaps due to a more strongly established maternal bond.

The negative welfare implications of weaning extend beyond behavioural changes. Hodgson et al. (2012) investigated how maternal separation at the time of a viral infection impacts susceptibility to secondary bacterial pneumonia. Calves abruptly weaned with remote separation and transported at the time of a primary bovine herpesvirus type-1 infection were twice as likely to die following challenge with *Mannheimia haemolytica* compared to calves pre-adapted to weaning (i.e., separated from their dams, housed separately on the ranch, and fed hay and grain for 2 weeks prior to transport and challenge). Although viral shedding did not differ, abruptly weaned calves mounted an exaggerated immune response, elevated interferon- $\gamma$ , acute-phase proteins, CD14, and TNF- $\alpha$ . This work underscores that the stress of weaning may exacerbate disease severity in the face of respiratory co-infections and highlights the critical importance of management strategies that reduce cumulative stressors during the weaning period.

### 5.3 Common and Emerging Weaning Practices

#### Conclusions:

- 1. Weaning method significantly influences calf and cow welfare, with gradual strategies, such as fence-line separation and nose-flap use (i.e., two-stage weaning), reducing behavioural signs of stress in calves compared to abrupt weaning with remote separation.**

- 2. Two-stage weaning using nose flaps reduces distress in both cows and calves, with variable impacts on immune status but has inconsistent impacts on performance, immune status, and physiological indicators of stress.**
- 3. A proportion (~30%) of nose-flap devices can be lost, and a high percentage (86–100%) of calves fitted with the device had nasal lesions, which raise welfare concerns that must be weighed against their other benefits.**
- 4. Fence-line weaning improves early post-weaning growth and reduces calf distress but may prolong stress-related behaviours in cows compared to abrupt weaning. Long-term performance benefits are inconsistent throughout different production stages.**

The method used for weaning plays a central role in determining both immediate and longer-term outcomes for calf welfare, growth, and health. A growing body of research demonstrates that weaning strategies not only influence behavioural and physiological stress responses in calves, but also that they can affect post-weaning performance, and, in some cases, the degree of stress experienced by the cow. Gradual weaning approaches, such as fence-line separation and two-stage weaning using nose flaps, reduce distress and promote a smoother transition. Despite the availability of lower-stress alternatives, abrupt weaning remains a common practice among Canadian cow–calf producers. A 2015 survey of 109 producers in western Canada found that 70% used abrupt weaning, often citing cost, logistics, and pasture availability as key constraints to implementing more gradual weaning approaches (Moggy et al., 2017). More recent data from the 2023 Canadian Cow–Calf Survey, which included 600 respondents, indicate that the use of abrupt weaning has declined to 51%. Among those using this method, the main reasons cited for continuing to use abrupt weaning were selling calves immediately after weaning (59%), limited time, labour, or infrastructure (21%), and no perceived financial benefit to alternative approaches (12%) (BCRC, 2024).

### ***5.3.1 Nose-Flap versus Abrupt Weaning***

Two-stage weaning using a nose flap device is often proposed as a lower-stress alternative to abrupt weaning. This method allows calves to remain in contact with their dams while preventing nursing for a short period of time prior to physical separation. Use of two-stage weaning among Canadian cow–calf producers appears to be increasing, with 4% of respondents reporting its use in a 2015 western Canadian survey (Moggy et al., 2017) compared to 12% in a national survey conducted in 2023 (BCRC, 2024).

Behavioural studies consistently report that nose-flap weaning reduces signs of distress in both cows and calves. For example, Lambertz et al. (2014) found that cows vocalized significantly more when calves were abruptly weaned with remote separation (19.2 times/hour) compared to when calves were fitted with nose flaps 7 days prior to separation (3.7 times/hour). Calves in both groups increased walking behaviour post-weaning, but the increase was lower in those fitted with nose flaps. Similarly, Alvez et al. (2015) reported that calves abruptly weaned with remote separation vocalized, walked, and paced more frequently, and showed reduced standing and grazing after weaning compared to those weaned using a two-stage method with nose flaps. These behavioural indicators of stress were substantially lower in calves fitted with nose flaps for

either 7 or 21 days prior to separation, with minimal differences between the two durations. Further, Freeman et al. (2021) found that nose-flap-weaned calves vocalized less and were less active than abruptly weaned calves during the first few days post-separation, indicating a muted behavioural stress response. Wiese et al. (2016) evaluated how weaning method and timing influence calf behaviour and intake during weaning, transport, and a two-week simulated receiving period. Calves were assigned to 1 of 3 treatments: abrupt weaning with remote separation 5 days before transport, two-stage weaning using nose flaps applied 5 days before transport, or abrupt weaning on the day of transport. In the days leading up to transport, calves fitted with nose flaps were less active than those abruptly weaned early but were more active than calves that had not yet been weaned. Calves abruptly weaned early also spent more time lying in the first 2 days post-weaning. After transport, calves weaned on the day of shipping showed the highest levels of behavioural stress, with increased movement and reduced lying time.

Studies have also examined the effects of nose-flap weaning on cow behaviour. Ungerfeld et al. (2014) compared the behavioural and production responses of beef cows whose calves, averaging 184 days of age, were weaned either abruptly with remote separation or through a two-step method involving nose flap placement 14 days before separation. Cows in the abrupt group vocalized and paced more after separation from their calves than cows in the nose flap group, indicating a stronger behavioural stress response. Milk yield declined in both groups after weaning, as expected; however, cows in the nose flap group lost less body weight than those in the abrupt group, suggesting they experienced less physiological stress or maintained better energy balance during the transition. In a follow-up study, Ungerfeld et al. (2016) evaluated two-stage weaning in early-weaned calves, around 2 months of age, using nose flaps placed 6 days prior to separation. Cows in the nose flap group exhibited fewer stress-related behaviours, such as pacing, vocalizing, and reduced grazing, compared to cows whose calves were abruptly weaned with remote separation. This suggests that the two-stage method can lessen maternal distress even when the cow-calf bond is expected to be particularly strong, such as when calves are still quite young. Mijar (2025) also reported that cows whose calves were fitted with nose flaps showed fewer behavioural signs of distress after weaning, including reduced pacing and vocalizing, and had lower salivary cortisol concentrations compared to cows whose calves were weaned abruptly or by fence line. Cows of abruptly weaned calves exhibited the most vocalization, pacing, and activity on the first day after weaning, but also spent more time eating and ruminating that same day.

The performance outcomes of two-stage weaning are mixed. Lambertz et al. (2014) did not detect statistically significant differences in weight gain between nose-flap and abruptly weaned calves, whereas Freeman et al. (2021) found that calves fitted with nose flaps for 7 days prior to separation had lower average daily gain over a 42-day period post-weaning than abruptly weaned calves. Similarly, Taylor et al. (2020) studied 288 beef calves aged 7 to 8 months and reported that calves fitted with nose flaps 6 days prior to weaning had reduced weight gain in the 13 days before weaning and from 13 days before to 7 days after weaning compared to calves abruptly weaned with remote separation. However, calves in the nose flap group showed higher growth from 13 days before to 28 days after weaning compared to those abruptly weaned and immediately shipped, suggesting that the nose flap group had some compensatory gains after weaning. Lippolis et al. (2016a) also observed lower average daily gain in nose-flap calves

during the 21-day period prior to separation, compared to calves that remained with their dams and were abruptly weaned without nose flaps. It is important to note that reduced growth found prior to separation in nose-flap calves likely reflects their limited diet, as they are prevented from nursing and must rely solely on forage intake, whereas calves that continue to suckle receive both milk and forage, and abruptly weaned calves are typically offered hay or a forage-based total mixed ration.

Lippolis et al. (2016a) further explored the impact of weaning method on immune response. Compared to calves that were abruptly weaned, calves fitted with nose flaps showed reduced humoral immune responses after weaning, including lower antibody titers to bovine viral diarrhea virus type-1 and bovine herpesvirus type-1, a lower percentage seroconverting for bovine viral diarrhea virus type-1, and reduced ovalbumin-specific IgM levels. These differences occurred despite similar post-weaning feed intake, feed efficiency, and morbidity between groups. In contrast, Browning (2023) found that, although body weights and cortisol levels did not differ between groups, calves in their nose flap group mounted a stronger immune response to vaccination compared to those weaned abruptly or by fence-line separation. Griebel et al. (2014) examined how the combination of weaning method and transport timing influenced immune responses in calves following a bovine herpesvirus type-1 challenge. Abrupt weaning combined with transport heightened systemic inflammation, increasing haptoglobin and TNF- $\alpha$ . In contrast, calves fitted with nose flaps 4 days prior to transport showed reduced inflammatory responses, suggesting that both the nature and timing of weaning-related stressors shape immune function and disease vulnerability.

Despite the utility of nose flap devices, concern has been raised about their physical effects. Lambertz et al. (2014) reported that over 95% of calves exhibited nasal abrasions at device removal after 7 days, with 30% showing heavy bleeding and 10% sustaining more severe injuries. Further, 1 week following removal, 45% of calves still showed signs of nasal irritation. Valente et al. (2022) similarly found that despite 27% of calves losing their nose flaps before removal, all calves, regardless of device retention, developed ulcerative nasal lesions that were not present at device placement. Kirk and Tucker (2023) reported that 32% of calves lost their flaps prematurely, while 86% of those that retained the flap for 7 days showed visible bleeding immediately after removal. Six days later, all calves still had tissue damage, although healing had begun. Freeman et al. (2021) also noted similar issues with device retention and nasal injuries.

In summary, nose-flap weaning reduced several behavioural indicators of stress in calves and cows and some physiological indicators of stress in cows, indicative of improved health and welfare compared to abrupt separation. Some studies have observed reduced average daily gain in nose-flap-weaned calves compared to abruptly weaned calves, particularly during the pre-separation period when nursing access is restricted, that often preceded compensatory gains, while other studies did not detect significant differences. Findings regarding immune function are variable, with some studies indicating reduced humoral immune responses, while others report no negative effects or even improved vaccine responses or reduced inflammatory responses to a viral challenge. However, the risk of nasal injury associated with the device, the need for two handling events, and the added labour or stress these may impose remain important considerations.

### 5.3.2 *Fence-Line versus Abrupt Weaning*

Fence-line weaning, which allows visual and auditory contact between cows and calves while preventing nursing, is considered a less stressful alternative to abrupt separation. Among western Canadian cow–calf producers surveyed in 2015, 19% reported using fence-line weaning (Moggy et al., 2017), while a 2023 national survey of 600 producers found that 32% used this approach (BCRC, 2024). Several studies have compared abrupt and fence-line weaning, identifying differences in calf behaviour, performance, and physiological responses.

Behaviourally, fence-line weaning appears to reduce signs of distress in calves compared to abrupt weaning. In a 14-day study by Mac et al. (2024), calves weaned with fence-line contact exhibited more rest and rumination and reduced activity than abruptly weaned calves. Cows in the fence-line group also rested more and were less active in the first few days post-separation than abruptly weaned cows, who showed earlier and higher activity. However, fence-line cows demonstrated reduced eating and rumination for several days after complete separation, which contributed to their lower average daily gain compared to abruptly weaned cows. Similarly, Mijar (2025) reported that cows in the fence-line weaning group exhibited more persistent stress-related behaviours, such as vocalizing, walking, and pacing, from the time of weaning through to 7 days post-separation, compared to abruptly weaned cows. In contrast, abruptly weaned cows showed the highest levels of these behaviours only on day 1 post-weaning and also spent more time eating and ruminating that same day.

With respect to production parameters, most studies report that fence-line weaning, compared to abrupt weaning, has a positive effect on early post-weaning weight gain. In a field trial involving 288 calves, Taylor et al. (2020) found that calves weaned by fence-line contact for 7 days had higher weight gains compared to those weaned abruptly, using nose flaps, or by intermittent separation (i.e., removal from dams for 24-hour intervals on days 13 and 6 prior to weaning, followed by fence-line contact for 7 days post-weaning). Similarly, Gubbels et al. (2023) reported that calves provided fence-line contact for 7 days prior to weaning had the highest average daily gain from weaning to 7 days post-weaning compared to abruptly weaned calves, while the latter gained more between 7 and 26 days post-weaning. Final body weights and carcass traits did not differ among treatments, suggesting that early growth advantages of fence-line weaning may not persist through the finishing period. Silva et al. (2023) found that calves weaned with fence-line contact for 7 days had higher average daily gain and greater body weights up to 82 days post-weaning compared to abruptly weaned calves, with no differences observed in physiological stress markers, such as cortisol. Browning (2023) reported similar results, where fence-line calves gained more post-weaning than abruptly weaned calves, despite no treatment differences in cortisol. Bailey et al. (2016) found that abruptly weaned calves with remote separation in a drylot had greater average daily gain during the 28-day period after weaning and first 60 days following arrival to a feedlot compared to pasture-weaned calves managed with fence-line contact. However, drylot calves tended to have higher morbidity. Drylot-weaned calves also adapted more quickly to feed, approaching the bunk sooner and exhibiting higher feed intake and feed efficiency than pasture-weaned calves without supplemental feed. Interestingly, pasture-weaned calves without supplements demonstrated superior feed efficiency during the finishing phase, suggesting that the performance benefits of different weaning strategies may vary across production stages.

In summary, fence-line weaning reduces calf stress-related behaviours and supports greater early post-weaning growth compared to abrupt, remote separation. However, these benefits may not persist throughout the feeding period, and cows may exhibit more prolonged behavioural stress with fence-line methods. Further research is needed to clarify the long-term effects of fence-line weaning, particularly on dam welfare.

### ***5.3.3 Nose-Flaps with either Fence-Line or Abrupt Weaning***

Campistol et al. (2013) investigated the combined effects of two-stage weaning using a nose flap device for 7 days, followed by either fence-line contact or remote separation, on the growth and physiological responses of beef steers. Among calves fitted with nose flaps, remotely separated calves gained more weight and had lower cortisol concentrations than those that had fence-line contact. Nose-flap use was also associated with increased hematocrit prior to weaning, a higher neutrophil-to-lymphocyte ratio, and reduced lymphocyte percentages from day 0 to 7 post-weaning, indicating a greater physiological stress response regardless of separation method. Overall, while nose flaps may elicit a measurable physiological response due to stress or tissue damage, their impact on growth appears to depend on how calves are separated from their dams.

## **5.4 Management Strategies that may Influence Weaning Outcomes**

### **Conclusions:**

- 1. Weaning age strongly influences calf welfare and performance, with early weaning (under 3 months) leading to heightened behavioural and physiological stress, while delayed weaning (beyond 180 days of age) results in less distress and supports improved growth, assuming cow condition and forage availability are adequate.**
- 2. Nutritional strategies, such as creep feeding, preweaning supplementation, or targeted post-weaning concentrate diets, buffer stress responses and support growth, particularly when early weaning is implemented.**
- 3. Temporary cow–calf separation before weaning, delaying transport after weaning, carefully timing vaccinations relative to weaning, or a combination of these and other management strategies under a preconditioning program may improve resilience, calf behaviour, and health outcomes in the feedlot.**
- 4. Effects of preconditioning are highly dependent on the individual management practices it consists of. Preconditioning did not consistently enhance growth performance in the early feedlot period; however, behavioural adaptation was improved and, in some cases, disease risk and use of antimicrobials reduced.**
- 5. Novel tools, such as bovine appeasing substances, show some promise but need to be examined more thoroughly to assess their practical impact on stress during the weaning transition.**

A range of management strategies has been studied in an attempt to mitigate the welfare and productivity impacts of weaning in beef calves. These potential strategies span decisions around the timing of weaning, the nutritional and social environment pre- and post-weaning, and the use of supportive tools or interventions, such as temporary separation, pheromone therapy, or preconditioning programs.

#### **5.4.1 Weaning Age**

The age at which calves are weaned plays a critical role in shaping both their immediate stress response and longer-term productivity. Studies consistently show that early weaning is associated with greater behavioural and physiological distress. For example, de Souza Teixeira et al. (2021a) compared 36 beef calves, weaned at 30, 75, or 180 days of age (12 calves per group), and found that calves weaned at 30 days exhibited more stress behaviours, including increased vocalization, walking, and cross-sucking, as well as elevated cortisol levels and respiratory rates. These stress responses were consistent in a follow-up study by de Souza Teixeira et al. (2021b), which demonstrated that calves weaned at 30 and 75 days had higher and more prolonged inflammatory and stress markers, including higher cortisol, plasma fibrinogen, and neutrophil-to-lymphocyte ratios, than those weaned at 180 days of age. Together, these findings suggest that early weaning, particularly under 3 months of age, may compromise calf welfare and resilience.

In addition, delaying weaning beyond traditional timelines may offer advantages. Freeman et al. (2021) assessed calves that remained with their dams for an additional 49 days beyond the typical 7-month weaning age. Although both groups of calves were abruptly weaned, those with delayed weaning showed higher average daily gain in the 42 days post-separation compared to their earlier-weaned counterparts. Despite this performance advantage, delayed-weaned calves were just as vocal and active immediately after weaning, suggesting similar levels of behavioural distress. Ultimately, both groups performed comparably through finishing, indicating that delayed weaning can enhance early growth, provided cow condition and forage availability are adequate. Lambertz et al. (2014), who compared calves weaned at 6 versus 8 months of age, found that calves abruptly weaned and remotely separated at 6 months vocalized more, stood or walked longer, and laid down less in the days following separation than those weaned at 8 months, indicating a stronger behavioural stress response. Although post-weaning average daily gain did not differ, calves weaned at 8 months had greater growth between 6 and 8 months, further supporting the potential production benefits of weaning at a later age.

Lambertz et al. (2015) evaluated how the age at weaning and timing of Burdizzo castration relative to abrupt weaning affected the behaviour, physiology, and performance of beef calves aged 6 to 7 months. In a  $2 \times 2$  factorial design, calves were either castrated and weaned concurrently at week 0, castrated at week 0 and weaned 4 weeks later, or left intact and weaned at either week 0 or week 4. On day 1 after weaning, vocalizations were significantly higher in calves weaned at week 0 compared to those weaned at week 4. Further, calves weaned at week 0 also spent less time lying down and more time standing and walking, indicating heightened behavioural stress. Average daily gain was greater during the first 3 weeks post-weaning in early-weaned calves but declined in weeks 4 to 7, becoming lower than in calves weaned later. Haptoglobin concentrations declined over time in all groups, with no effect of castration or weaning timing. The study found no additional behavioural or physiological impacts when castration and weaning were performed concurrently. These findings suggest that weaning had a

stronger influence on calf behaviour and performance than Burdizzo castration, and that performing both procedures at the same time did not exacerbate stress responses.

Together, these studies provide evidence that earlier weaning may increase behavioural and physiological indicators of distress, while delayed weaning may support growth and ease the transition to solid feed.

#### ***5.4.2 Feed Supplementation Prior to Weaning***

Nutritional strategies before weaning can influence productivity and physiological responses to the stress of maternal separation. Campistol et al. (2016) evaluated whether providing a high-fiber supplement for 7 days prior to weaning would affect the physiological stress response and growth of steers managed with either fence-line or total separation. Although all steers gained weight and showed reduced interferon- $\gamma$  levels by the day of weaning, those receiving the supplement exhibited higher neutrophil-to-lymphocyte ratios and tended to have elevated cortisol and ceruloplasmin concentrations, indicating a more pronounced acute-phase response. After weaning, abruptly weaned unsupplemented steers experienced weight loss and higher cortisol levels compared to their supplemented counterparts. Further, from days 14 to 35 post-weaning, unsupplemented steers weaned by fence-line contact gained less weight than all other groups. These results suggest that short-term supplementation prior to weaning may help buffer calves against the negative effects of maternal separation. Reis et al. (2015) explored whether providing creep feed to heifer calves during the nursing phase would influence long-term growth and reproductive development. Heifers that had ad libitum access to a corn-based supplement for 50 days while still suckling had greater average daily gain and higher plasma IGF-I and glucose concentrations at the end of the supplementation period. They also showed differences in liver and adipose gene expression associated with growth and metabolism. However, these early physiological advantages did not result in differences in final body weight, age at puberty, or reproductive outcomes.

Where cow-calf pairs are kept and their nutritional management prior to weaning can also influence both short- and longer-term outcomes for cows and calves. Myerscough et al. (2022) housed cow-calf pairs in either drylots feeding a corn silage-based TMR or on rotationally grazed-pastures from 81 days postpartum through to fence-line weaning at 110 days to assess how housing environment influenced cow condition and calf performance. Cows managed and fed in drylots had greater body weight, body condition score, and milk production at the time of weaning compared to those managed on pasture. Their calves were also heavier and had higher average daily gain prior to weaning. Further, at weaning and during the period after arrival to the feedlot, pasture calves vocalized and walked more, indicating greater behavioural stress, while drylot calves were more active before weaning and vocalized more after transport. Although pasture calves exhibited greater average daily gain and tended to be more feed efficient in the 42-day period following weaning, they remained lighter than drylot calves. Reproductive performance of the cows did not differ between housing environments.

#### ***5.4.3 Nutritional Management After Weaning***

The nutrition provided post-weaning can significantly affect cow and calf performance depending on the timing of weaning. Jaeger et al. (2022) compared early (153 days of age) and

conventional (209 days) weaning strategies in cow–calf pairs managed either in confinement with a concentrate-based diet or on pasture without supplementation. Calves that remained with their dams and received concentrate in confinement had the highest average daily gain over the study period, followed by weaned calves fed concentrate in confinement. In contrast, weaned calves managed on pasture had the lowest gains, while calves that remained with their dams on pasture exhibited intermediate growth. Cow outcomes also varied, with cows in the early weaned group that were kept on pasture losing less body weight and preserving more rump fat, while cows of early-weaned calves housed in confinement lost the most body condition. Moriel et al. (2014) examined early weaning at 72 days of age in Brahman × British crossbred heifers under three post-weaning strategies: (1) fed concentrate until 180 days, (2) fed concentrate until 90 days then grazed, or (3) grazed until 180 days. These were compared to conventionally weaned heifers left with their dams until 180 days. Heifers fed concentrate to 180 days were the heaviest throughout the study, while those fed concentrate and transitioned to pasture at 90 days reached similar body weights to conventionally weaned heifers by day 180. Early-weaned heifers on concentrate diets also had greater average daily gain and higher expression of insulin-like growth factor-1 in the liver, and reached puberty earlier. This indicates that supplementing early-weaned calves with concentrates enhances growth and reproductive development compared to conventional pasture-managed calves, although information on the mid- to long-term effects of these nutrition strategies on health and welfare is limited.

#### **5.4.4 Temporary Cow–Calf Separation and Handling Before Weaning**

The suckling stimulus and even the physical presence of the calf are influential factors prolonging postpartum anestrus in beef cows. Temporary weaning, involving short periods of separation or the use of nose flaps, has been evaluated both as a strategy to improve reproductive efficiency and as a means of reducing the stress of weaning. Pérez-Torres et al. (2016) assessed the behavioural and physiological responses of calves and cows to temporary separation of 24, 48, or 72 hours at 25 and 45 days postpartum. As the duration of separation increased, calves vocalized less, spent less time near the fence, and had lower cortisol concentrations and weight loss. Calves also appeared to have a lower stress response when separated at 45 days compared to 25 days. While cows exhibited fewer behavioural responses overall, cortisol concentrations were highest in cows whose calves were separated for 72 hours at 25 days postpartum compared to those separated for 24 or 48 hours at the same age, suggesting that prolonged separation at an early stage may heighten physiological stress in the dam. In terms of weaning stress, Hötzel et al. (2012) explored whether previous experience with temporary weaning improved calf responses to two-step weaning with nose flaps. Calves either temporarily wore a nose flap for 13 days at around 10 weeks of age or were allowed to continue suckling. Later, all calves were weaned using a two-step process involving nose flaps followed by permanent separation. Calves with prior nose-flap experience adapted more quickly during the nose-flap application period at weaning and showed fewer signs of distress following separation, including reduced vocalization and a faster return to grazing. Notably, prior nose-flap use did not appear to cause aversion when reapplied, despite concerns about nasal injury, indicating calves tolerated repeated exposure to the device. These results suggest that familiarity with temporary weaning methods might improve behavioural adaptation during final weaning. Similar findings were reported by Pérez et al. (2017), who evaluated the effects of separating *Bos indicus* cow–calf pairs for 24, 48, or 72 hours at both 25 and 45 days postpartum. Compared to continuously suckled calves, those

subjected to maternal deprivation displayed fewer signs of distress around the time of final weaning at 150 days of age. These calves vocalized less, spent more time grazing, and had lower cortisol concentrations in the days following weaning. By 270 days, calves previously separated for 48 or 72 hours were heavier than control calves, suggesting improved post-weaning growth. All these results suggest that the inclusion of temporary maternal separation strategies could reduce the signs of behavioural distress during the final weaning.

#### ***5.4.5 Time from Weaning Until Shipping***

The interval between weaning and transport can significantly influence calf health, behaviour, and performance. Taylor et al. (2020) showed that 7- to 8-month-old calves shipped at the time of weaning or within seven days afterward had the poorest average daily gain and the highest rates of morbidity, regardless of the weaning method, compared to delaying transport by 28 days post-weaning. Wiese et al. (2016) also investigated how the timing of weaning relative to transport impacts behavioural stress responses and feed intake. Calves weaned abruptly on the day of transport displayed the highest behavioural signs of stress after arrival at the feedlot, including increased locomotion and reduced lying time, compared to calves weaned 5 days prior, either abruptly or via a two-stage method. Despite these behavioural differences, dry matter intake during the period after feedlot arrival did not differ between groups. This evidence indicates that separating weaning from transport causes a significant improvement in calves' welfare.

#### ***5.4.6 Vaccination Timing***

The timing of vaccination relative to weaning can affect both immune responses and calf performance. Schumaker et al. (2019) compared 3 vaccination strategies in calves preconditioned for 30 days, each involving 2 doses of vaccine against BRD administered 30 days apart: at weaning and again at feedlot arrival, 15 days before both weaning and feedlot entry, or 15 days after each event. Calves vaccinated before weaning and before feedlot entry mounted stronger antibody responses to all measured respiratory pathogens and had a lower incidence of respiratory disease. Body weight and carcass traits did not differ among groups. In a similar study, Lippolis et al. (2016b) evaluated the same 3 vaccination strategies and found that calves vaccinated 15 days before both weaning and feedlot entry had higher antibody concentrations at feedlot arrival. Although these calves gained less weight before weaning, they had greater average daily gain after feedlot arrival compared to those vaccinated at weaning or 15 days after each event, likely reflecting compensatory growth. Overall body weight, feed intake, and health outcomes after arrival did not differ among groups. Silva et al. (2018) further explored how vaccination timing interacts with nutritional management. In their 2 × 2 factorial study, calves were vaccinated either before weaning (14 days before and at weaning) or after weaning (7 and 21 days post-weaning) and then provided a concentrate supplement either daily or 3 times weekly. Calves vaccinated before weaning and supplemented 3 times per week had the lowest average daily gain, while those vaccinated after weaning and fed daily had the highest. Pre-weaning vaccination increased plasma cortisol and haptoglobin concentrations and reduced serum antibody titers to parainfluenza-3 virus, indicating a stronger inflammatory and weaker humoral immune response. Infrequent supplementation was also associated with elevated cortisol and lower antibody titers to bovine viral diarrhoea virus type-1. Collectively, these studies suggest that vaccinating calves before weaning can enhance immune responses and may reduce

disease risk, but could impair growth unless paired with consistent, high-quality nutritional support.

#### **5.4.7 Preconditioning**

Preconditioning programs, typically involving a range of the management strategies mentioned so far, such as weaning calves several weeks before transport, combined with vaccination, deworming, and transition to feedlot-style diets, are designed to improve health and performance outcomes. However, their effectiveness can also be influenced by management practices, housing, and post-arrival conditions.

Vanbergue et al. (2024) evaluated a preconditioning protocol in 9 commercial herds where young bulls were weaned indoors 50 days before transport, vaccinated twice with a respiratory vaccine, dewormed, and transitioned to a concentrate-based diet. Control calves remained on pasture with their dams until transport and received no interventions. Preconditioned calves experienced higher morbidity and respiratory disease scores during the preconditioning period, likely due to indoor housing and increased pathogen exposure, and no health differences were observed after arrival at the feedlot. Further, preconditioned calves, having had earlier exposure and adaptation to a concentrate-based diet, showed higher average daily gain during the 50-day preconditioning phase. Long-term outcomes, such as final body weight, carcass weight, and days on feed, however, did not differ between groups, suggesting there might have been compensatory gain. In a study evaluating the first 40 days in a feedlot, Mijar et al. (2023) assessed health and performance in feedlot pens containing different proportions of preconditioned and auction-derived calves. Morbidity was lowest in pens with only preconditioned calves, and preconditioned animals were less likely to develop and be treated for BRD than pre-sorted, auction-derived calves. Auction-derived calves gained more weight over the 40-day trial period, regardless of pen composition, likely due to this group starting with a lower body weight and being more prone to compensatory gains. Interestingly, calves in pens with only 25% preconditioned animals showed both the highest morbidity and the highest average daily gain, with the authors suggesting interactions between use of antimicrobials and improved performance outcomes.

Preconditioning has been shown to support a more favourable behavioural time budget after arrival to the feedlot. Hodder et al. (2023) found that preconditioned calves spent more time eating and less time inactive in the first 7 days after feedlot arrival compared to both auction-derived and ranch-sourced calves. These patterns were partially maintained even when preconditioned calves were commingled with auction-derived calves, although feeding time declined slightly as the proportion of auction calves increased. Further, rumination behaviour did not differ among groups. Mijar et al. (2024) used behavioural sensors and hair cortisol analysis to evaluate stress and adaptation in the same groups of preconditioned and pre-sorted, auction-derived steers (Mijar et al., 2023) over 6 weeks in the feedlot. Preconditioned steers consistently spent more time eating, ruminating, and being active and less time inactive during the first 3 weeks, regardless of commingling status. These behavioural patterns indicate more rapid acclimation, although hair cortisol levels, disease incidence, and growth did not differ between groups.

Together, these studies suggest that a preconditioning program is only as good as the individual management practices included in it. While preconditioning may not consistently enhance growth performance in the early feedlot period, it improves behavioural adaptation and, in some cases, reduces disease risk and use of antimicrobials.

#### 5.4.8 *Pheromone*

Pheromone-based products, such as bovine appeasing substances, have been explored as a non-invasive approach to mitigate stress and support adaptation during the weaning and preconditioning period. These synthetic analogs mimic natural maternal pheromones and may influence behaviour, immune function, and growth. Schubach et al. (2020) evaluated the application of a bovine appeasing substance at weaning and monitored stress, behaviour, and performance in abruptly weaned beef calves over a 42-day preconditioning period. Treated calves had greater average daily gain during the first 28 days and higher feed intake during the first week after weaning. Further, treated calves showed more feeding, social, and play behaviours. They also had lower haptoglobin and hair cortisol concentrations, slower chute exit velocity, and stronger vaccine-induced antibody responses compared to untreated controls. Similarly, Vieira et al. (2023) studied the use of a bovine appeasing substance in abruptly weaned Nellore calves. Treated animals, compared those given saline, exhibited fewer behavioural and physiological signs of stress, including lower chute exit velocity, reduced vocalizations, and lower serum cortisol concentrations. They also spent more time grazing, eating, walking, ruminating, and playing, and had higher serum titer concentrations of parainfluenza-3 virus and bovine viral diarrhoea virus type 1. Finally, Kvamme et al. (2024) evaluated the effects of repeated bovine appeasing substance applications during a 42-day preconditioning program followed by transport to a feedlot. While average daily gain, final body weight, and feed efficiency did not differ between treatment groups, treated calves had lower plasma haptoglobin concentrations on days 3 and 7 relative to arrival at the feedlot, reduced non-esterified fatty acid levels on day 3, and lower exit velocity across multiple time points compared to calves administered a placebo.

More research has examined the use of bovine appeasing substances administered at the time of feedlot entry. Pickett et al. (2024) found that applying bovine appeasing substance to newly weaned, high-risk calves at feedlot arrival and at day 14 after arrival reduced hair cortisol levels, lowered *Mycoplasma* abundance in the nasal microbiota, and decreased respiratory disease-related mortality compared to the placebo. Although BRD incidence was similar across groups, pheromone-treated calves were more likely to recover with a single antibiotic treatment and had greater total pen-based weight gain. Cooke et al. (2025) reported that administering bovine appeasing substance during initial processing and at reimplant improved growth, final body weight, hot carcass weight, and feed intake compared to a placebo. Further, treated animals also had reduced morbidity and mortality due to respiratory disease in one of the experiments.

Collectively, these studies suggest that bovine appeasing substances could reduce behavioural and physiological indicators of stress, enhance immune responsiveness, and support positive adaptation during the weaning and preconditioning period. Further research is needed to validate these results with different commercially available or experimental products under Canadian conditions, and to assess the cost-benefit of such products.

#### **5.4.9 *Addition of Social Facilitator Cow***

Nickles et al. (2020) investigated whether placing a social facilitator cow with abruptly weaned calves on pasture could reduce walking behaviour and prevent weight loss. Heifer calves were randomly assigned within each replicate to either a group with a social facilitator cow or a control group without one, with multiple replicates conducted across two locations. Although calves with a social facilitator tended to spend less time walking and covered shorter distances on the day of weaning, no differences were observed in body weight or average daily gain between groups. These findings suggest that simply introducing an unrelated adult cow is not sufficient to meaningfully influence calf behaviour or performance, likely because the maternal bond is key to moderating the stress response.

### **5.5 Future Research**

While significant progress has been made in understanding the welfare and performance impacts of weaning, several knowledge gaps remain. Future research should explore how combinations of weaning methods and management strategies interact to influence long-term outcomes, including immune competence, feedlot performance, and carcass quality. It is also important to recognize that good performance, such as high average daily gain, does not always indicate better welfare or resilience. Studies should continue to assess behavioural and physiological indicators alongside production metrics. There is a need for field-based studies that evaluate the economic feasibility and practicality of low-stress weaning methods across diverse production systems. Finally, research should assess the potential benefits and limitations of novel strategies, such as pheromone use, in commercial settings and determine how these tools can be effectively incorporated into broader health and welfare programs.

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# CODE OF PRACTICE FOR THE CARE AND HANDLING OF BEEF CATTLE: REVIEW OF SCIENTIFIC RESEARCH ON PRIORITY ISSUES

## Beef Code of Practice Scientific Committee Report October 2025

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## 1 Introduction

### 1.1 Purpose and Objectives

The purpose of this report is to review and summarize the scientific research on priority welfare issues for the Canadian beef industry. The specific topics and scope of this report were collectively identified by the Code Development Committee and the Scientific Committee. A prioritization exercise between these committees was undertaken, where members were asked to identify priority topics with the following criteria:

- Is the topic related to animal welfare and is it particularly important for the welfare of the species in question?
- Is there sufficient research to do a review?
- Is it a topic that would particularly benefit from a rigorous review of the research by a committee with diverse areas of expertise?
- Is it within the scope of the Code (on-farm, an issue for which producers have control)?
- Are there already established protocols that can be relied upon instead?

The mandate of the Scientific Committee was to address the implications of the scientific research for beef cattle welfare within the priority issues identified by the aforementioned committees, as outlined in the [NFAACC Code Development process](#). The Code Development Committee for which this report was prepared represents considerable expertise in these areas and is tasked with considering such factors in its discussions.

The present report reflects a narrative review of the literature on the topics listed below. For each priority topic, we identified published review articles (e.g., systematic reviews, scoping reviews, meta-analyses, and relevant narrative reviews) that addressed the primary headings and subheadings listed as being of interest to the Code Development Committee. The search for scientific literature focused on review articles, followed by primary studies, and was conducted in the following journal databases: Google Scholar, PubMed, and Web of Science. Our key search terms, joined using Boolean operators, were comprised of the key words found in the list of priority topics below and were used to identify papers. We focused on including papers published since the Review of Scientific Research on Priority Issues was completed in 2012, with a preference for work conducted in North America. Articles focused on geographies in Africa, Asia, and Oceania were excluded, as were articles written in a language other than English.

Where possible, systematic literature reviews and meta-analyses have been leveraged to rely on higher strength of evidence. However, the existing research on many of these topics lacks a sufficient number of comparable randomized controlled trials to enable meaningful meta-analyses. In the absence of existing reviews that synthesize the science and offer insight into quality and strength of evidence, the original literature has been reviewed and summarized. The synthesis presented herein represents a summary of the significant findings, key conclusions, and reported outcomes of the existing body of peer-reviewed literature. It was, however, out of scope to conduct a more systematic assessment of study design, statistical power, and limitations that may have influenced study outcomes. This report provides a comprehensive review of the

current evidence on beef cattle welfare practices, incorporating high levels of evidence where feasible, to provide reasonable evidence-based conclusions from the reviewed science.

The specific priority issues discussed within this report include:

- Pain control for painful procedures
  - Main principles
  - Necessity for painful procedures and evidence for alternative management strategies
  - Assisted calving
  - Disbudding and dehorning
  - Castration
  - Branding
- Weaning
  - Welfare impacts of weaning on both the cow and the calf
  - Weaning procedures/practices
  - Pre- and post-weaning management
- Health conditions at different stages of production
  - Main principles
  - Neonatal calf diarrhea
  - Bovine respiratory disease (BRD) in cow–calf and feedlot production
  - Lameness in cow–calf and feedlot production
  - Nutritional diseases associated with high concentrate feeding (acidosis, liver abscesses, laminitis)
- End-of-life management
  - Current euthanasia method(s) and practices
  - Decision-making, especially for vulnerable animals

The Scientific Committee wishes to also highlight that, though out of scope for this review, a number of other topics are important to discuss when evaluating health and welfare in the Canadian beef sector. These include:

- Climate change and disease patterns
- Environmental conditions (e.g., heat and cold stress, drought)
- Housing conditions (pen stocking density, shade, resource availability)
- Stockmanship and low-stress handling
- Managing pregnancy in the feedlot
- Dairy-beef cross cattle in feedlots: tolerance to high-grain rations/liver abscesses, lameness, impact and prevalence of BRD, dark cutters, etc.
- Health protocols and record keeping for disease monitoring.

Some of these items were not included due to insufficient research or scientific evidence to summarize. Despite this paucity of evidence, it is imperative that these topics be acknowledged, and stress and pain mitigated when possible.

## **2 Pain Control for Pain and Painful Procedures**

### **2.1 Introduction, Scope, and Main Principles**

Before delving into the science behind pain and painful procedures in beef cattle, it is important to address several overarching principles and considerations. This section serves as a foundation, outlining key themes that set the stage for a deeper exploration of current research on these practices.

### **2.2 Beef and Dairy Cattle Comparisons**

In the sections on dehorning, castration, branding, and health conditions, this report aims to focus only on the scientific literature relating to beef cattle. However, much relevant research has been conducted on dairy cattle and/or under dairy management conditions. This distinction is important when evaluating research findings for two reasons. First, beef cattle and dairy cattle differ genetically and behaviourally (Haskell et al., 2014), and second, the handling and management systems for beef production are markedly different from dairy production (Endres & Schwartzkopf-Genswein, 2018). Researchers studying pain in domestic animals have cautioned against the extrapolation of behavioural and physiological pain related responses between and within a species due to breed, age, and sex differences (Anil et al., 2002, 2005). Despite these differences, there is little reason to suspect that dehorning, castration, branding, and health conditions do not cause similar pain and distress in beef cattle regardless of breed. However, the differences between beef and dairy cattle and between the production systems mean that care is required in interpreting how specific research findings in dairy cattle relate to beef cattle. Nonetheless, these comparisons are useful to assist in identifying gaps in scientific knowledge and future research needs for beef cattle.

#### ***2.2.1 Prevention of Painful Conditions and Procedures***

A useful practice for addressing pain in cattle, whether caused by procedures or painful health conditions, is to prevent it whenever possible. In some cases, alternatives to certain painful practices (e.g., disbudding vs. polled genetics) are becoming more commonplace. For example, a recent producer survey indicated that in 2022, 80.6% of Canadian beef producers reported having > 75% polled calves (BCRC, 2022). In other cases, improved pain control methods are being developed that may provide more effective pain mitigation (aimed at controlling both procedural and post-operative pain) compared to conventional approaches (Rudd et al., 2025; Ross et al., 2024; Lauder et al., 2020; Meléndez et al., 2018a, 2018b). It is therefore essential to consider the necessity of each procedure or intervention, recognizing that it will cause some level of pain or discomfort, and to select the least painful methods while ensuring appropriate pain control is provided for any painful condition or procedure.

#### ***2.2.2 Managing Pain in Cattle***

Managing pain in cattle is a critical aspect of ensuring animal welfare and optimizing outcomes in livestock production (Steagall et al., 2021). This section provides an overview of the key

pharmacological strategies used to address pain, aiming to establish a common understanding of their mechanisms and applications.

Effective pain management (mitigation of procedural, acute, and longer-term pain) in cattle often requires a combination of pharmacological approaches, including local anesthetics, non-steroidal anti-inflammatory drugs (NSAIDs), or sedatives, each addressing different aspects of pain and stress (Zoltick et al., 2024). Local anesthetics such as lidocaine block sodium channels in nerve cells, preventing the initiation and transmission of pain signals to the central nervous system (Zoltick et al., 2024) and are particularly effective for providing acute pain relief during and immediately after procedures such as castration or dehorning.

Often complementing local anesthetics, NSAIDs like meloxicam and flunixin meglumine function in part by reducing prostaglandin production through the inhibition of cyclooxygenase enzymes (COX-1 and COX-2; Zoltick et al., 2024). This lowers inflammation and pain by decreasing nociceptor sensitivity and pain signaling (Stock & Coetzee, 2015). COX-1 contributes to immediate inflammatory responses and COX-2 is involved in prolonged inflammation. Targeting both isoenzymes enhances pain relief; however, COX-1 inhibition can lead to adverse renal and gastrointestinal effects (Mushtaq et al., 2025). Although limited studies have been conducted in cattle, selective COX-2 inhibitors, such as meloxicam, may therefore be preferred for minimizing these side effects (Mushtaq et al., 2025). The dual analgesic and anti-inflammatory effects of NSAIDs make them valuable for managing both acute and chronic pain (Stock & Coetzee, 2015).

Sedatives such as xylazine complement anesthesia and analgesia by targeting stress and facilitating muscle relaxation, especially during invasive procedures (Stock & Coetzee, 2015). As an alpha-2 adrenergic agonist, xylazine decreases norepinephrine and dopamine release, resulting in sedation, mild analgesia, and muscle relaxation (Ball et al., 2022). Sedatives, particularly alpha-2 agonists, have an inhibitory peripheral effect on pain transmission pathways and help reduce the perception of pain, which may improve welfare during handling or procedures (Stock & Coetzee, 2015).

Together, these pharmacological tools provide a multifaceted strategy for managing pain and stress in cattle. The choice of therapy should be tailored to the specific type, severity, and duration of pain to ensure optimal welfare outcomes. A scientific review of pain control strategies for specific procedures—including dehorning or disbudding, castration, branding, dystocia and assisted calvings, spaying of female cattle, and painful health conditions—are addressed below. Our ability to mitigate pain in cattle is influenced by many factors, including the drugs' availability and duration of action. For example, NSAIDs, sedatives, and local anesthetics provide limited duration or relief compared to duration of pain experienced by cattle following common procedures (Meléndez et al., 2025).

### ***2.2.3 Working with a Veterinary Advisor***

Tools and strategies are available to manage short- and long-term pain associated with many of the procedures and conditions outlined below. As detailed in the following sections, evidence-informed protocols and drugs have been developed to mitigate pain, but their implementation and widespread adoption remain areas for improvement within the Canadian beef industry

(BCRC, 2024). Veterinary involvement is crucial in ensuring the appropriate use of these tools and protocols, providing expertise in pain management strategies and promoting animal welfare practices. This is particularly important to ensure the use of registered products for food-producing species that are labeled for the indication.

#### **2.2.4 Scope**

A review of the science on painful practices was included in the Code of Practice for the Care & Handling of Beef Cattle: Review of Scientific Research on Priority Issues (Schwartzkopf-Genswein et al., 2012), with a focus on dehorning, castration, and branding. As such, this review focuses on updates to the science since 2012 when referring to those specific conditions while also introducing new sections on dystocia and assisted calvings, spaying of female cattle, and painful health conditions.

### **2.3 Dystocia and Assisted Calvings**

#### **Conclusions:**

- 1. Dystocia causes pain and soft tissue trauma in cows, often leading to musculoskeletal injuries, nerve damage, and an increased risk of uterine infections.**
- 2. In calves, dystocia also causes pain and soft tissue trauma, manifesting in reduced vigour, delayed ability to stand, musculoskeletal injuries, hypoxia, and increased risks of illness and mortality.**
- 3. Administration of certain NSAIDs after calving can improve cow comfort, milk production, and reproductive performance, with meloxicam showing consistent benefits; however, flunixin meglumine is associated with negative outcomes, such as retained placenta and reduced milk yield.**
- 4. Pain relief for calves after birth, particularly with NSAIDs like meloxicam and ketoprofen, improves welfare indicators such as activity and play behaviour, but effects on long-term growth and health are inconsistent and perhaps should not be expected.**
- 5. Future research should prioritize optimizing the timing and dosage of NSAIDs for both cows and calves, evaluating the efficacy of different types of NSAIDs, exploring their long-term impacts on productivity, and assessing various pain mitigation strategies under commercial cow–calf conditions.**

Dystocia, defined as calving difficulty resulting from prolonged spontaneous calving or prolonged/severe assisted extraction (Mee, 2004), differs from assisted calving, which refers to any calving where assistance is provided, even if dystocia is not present (Mee, 2008). Both conditions are prevalent in the Canadian beef industry. In a study of 203 cow–calf herds during the 2002 calving season, 8.9% of calvings required assistance, and 3.7% were classified as severe dystocia (Waldner, 2014). More recent data from a survey of 97 cow–calf producers in

western Canada reported an average herd-level incidence of assisted calvings at 4.9%, with 13.5% in heifers and 3.2% in cows (Pearson et al., 2019a). Caesarean sections were uncommon, occurring at a rate of 0.2% (0.7% in heifers, 0.15% in cows). Additionally, in the same survey, most producers reported assisting at least 1 heifer (95.7%; 89/93) or cow (89.6%; 86/96) during the 2016 calving year. Data from 562 herd records collected in western and eastern Canada between 2019 and 2022 show that 7.4% of calvings required assistance, with easy pulls, hard pulls, and caesarean sections accounting for 4.7%, 2.8%, and 0.2% of cases, respectively (Waldner et al., 2024). Collectively, these studies highlight the frequent occurrence of both assisted calvings and dystocia in Canadian beef herds.

Dystocia and assisted calvings significantly affect the health and welfare of both cows and calves. Calves born from difficult or prolonged deliveries often exhibit lower vigour, delayed standing and walking, prolonged hypoxia, acidemia, and skeletal injuries (Barrier et al., 2012a; Murray et al., 2016; Pearson et al., 2019d; Homerosky et al., 2017a). These issues can hinder colostrum intake and transfer of passive immunity (Homerosky et al., 2017b), increasing the risk of illness and death (Barrier et al., 2013; Murray et al., 2016; Pearson et al., 2019d). Elevated creatine kinase, reflecting soft tissue trauma, can also be measured in calves born under these conditions (Pearson et al., 2019d). Injuries such as rib fractures, reported in 6% of preweaned dairy calves in one study, are frequently linked to challenging births (Ollivett et al., 2018).

For cows, dystocia causes considerable pain and trauma, often resulting in musculoskeletal injuries, nerve damage, and a higher likelihood of uterine infections such as metritis (Mee, 2008). This can often lead to a higher risk of culling, as demonstrated by Sewalem et al. (2008), who found that Holstein cows requiring a hard pull or surgery during calving were 1.27 and 1.92 times more likely to be culled, respectively, compared to cows with unassisted calvings. Lucio et al. (2024a) found that assisted calving reduced the expected profit by \$151.32 CAD in heifers compared to unassisted heifers, while in cows, assisted calving reduced the expected profit by \$187.18 CAD compared to unassisted cows. Additionally, cows in pain after calving may show behavioural changes, such as reduced activity, abnormal lying positions, and less grooming (Barrier et al., 2012b). These challenges are likely due to the force required to extract calves, with Pearson et al. (2020) reporting that for mechanical deliveries 380.6 kg minutes of force was used. Canadian producers also identify dystocia as painful, with 89% of surveyed western Canadian cow-calf producers agreeing it was painful if no pain control was provided (Moggy et al., 2017). Cumulatively, these findings highlight the trauma and pain associated with dystocia and assisted calvings.

### ***2.3.1 Pain Mitigation Strategies for Dystocia and Assisted Calvings***

There are a variety of different options to manage pain associated with calving. Administration of a local anesthetic is used to reduce sensation of a specific area and is mainly used to provide pain relief during surgical procedures, such as a caesarian section (Stock & Coetzee, 2015). It may also be provided as an epidural, though its effects during dystocia are not well studied. NSAIDs are commonly used and studied as a method to reduce pain caused by inflammation associated with calving.

A survey of western Canadian cow-calf producers found that 44.8% and 44.7% of respondents administered an NSAID to the majority of cows and calves, respectively, after a difficult calving

(Pearson et al., 2019a). A lidocaine epidural was rarely used with 2.1% of respondents administering it in the case of a difficult calving. Further, a 2014 survey of 109 cow–calf producers in western Canada found that the prevalence of pain mitigation strategies used for dystocia and caesarean section by respondents were 46% and 100%, respectively (Moggy et al., 2017).

### *2.3.1.1 Pain Mitigation Following Calving in Cows*

Research into pain mitigation in cows has highlighted the benefits of administering NSAIDs like meloxicam, ketoprofen, and acetylsalicylic acid after calving to improve comfort, milk production, and reproductive performance.

**Beef cows.** Research on pain control following calving in beef cows is limited. Lucio et al. (2024b) studied 23 cows assisted at birth and found no behavioural differences between those treated with meloxicam and placebo. However, studies on caesarean sections in beef cows have found that meloxicam administration can help reduce indicators of pain. Barrier et al. (2014) observed that meloxicam-treated cows spent more time lying and had more frequent lying bouts within 24 hours post-surgery, indicating improved comfort. Mauffré et al. (2021) also reported positive benefits, including higher pregnancy rates, shorter calving intervals, and a trend toward lower culling rates in Charolais heifers undergoing caesareans treated with pre-operative meloxicam. Finally, Guatteo et al. (2022) found that meloxicam administered prior to caesareans enhanced passive immunity transfer in calves, especially in multiparous cows, without affecting colostrum quality or time to first suckling, highlighting potential benefits for calf survival.

**Dairy cows.** In dairy cattle, NSAIDs have been widely studied for their impact on postpartum welfare and production, with meloxicam being primarily evaluated. Newby et al. (2013) found that meloxicam administered 24 hours after assisted calving increased feeding time and bunk visits but did not affect milk production or health outcomes. Similarly, Mainau et al. (2014) showed increased post-calving activity in meloxicam-treated heifers, suggesting improved comfort. Production increases have also been observed where Swartz et al. (2018) found that meloxicam given before calving increased milk yield in unassisted cows and improved milk fat, protein, and lactose production regardless of calving difficulty. Shock et al. (2018) also demonstrated improved productivity, where they evaluated 2,653 cows across 20 Canadian herds and found that meloxicam-treated cows had increased milk yield, reduced subclinical mastitis, and lower culling rates within 60 days postpartum. Similar results were found in Carpenter et al. (2016) which compared sodium salicylate, meloxicam, and placebo at calving. With either NSAID, whole-lactation milk and protein yields improved, with additional metabolic benefits, including decreased beta-hydroxybutyric acid, in sodium salicylate-treated cows and higher glucose levels in meloxicam-treated cows.

Other NSAIDs have also been studied. Gladden et al. (2021) administered ketoprofen within 3 hours of calving in 72 Holstein cows and found reduced lateral recumbency and more behaviours associated with greater comfort. Similarly, Stilwell et al. (2014) reported that carprofen given within 6 hours of calving improved early feed intake and increased 305-day milk yield in first-lactation cows, although it delayed conception and reduced pregnancy rates at 220 days postpartum. Barragan et al. (2020) evaluated the impact of post-calving oral acetylsalicylic acid treatment on inflammatory, nociceptive, and stress biomarkers (haptoglobin, substance P, and

cortisol) in 152 dairy cows across 3 organic herds. The key finding was that treatment with acetylsalicylic acid reduced haptoglobin levels in multiparous cows, but calving difficulty and parity had a stronger influence on biomarker levels regardless of treatment.

Unlike other NSAIDs, flunixin meglumine has shown disadvantages. Newby et al. (2017) reported that pre-calving administration increased stillbirth risk, while post-calving treatment raised the likelihood of retained placenta, high rectal temperature, decreased milk production, and metritis, leading to recommendations against its use within 24 hours of parturition. Importantly, meloxicam administration within 1 hour of calving has not shown such negative effects (Newby et al., 2014).

A single study evaluated dexamethasone in cows with dystocia (Swartz et al., 2023). Treated cows exhibited reduced activity, less restlessness, and increased lying times, suggesting reduced discomfort. However, these cows produced 2.7 kg/day less milk during the first month postpartum, highlighting potential drawbacks in milk production.

While NSAIDs such as meloxicam demonstrate consistent benefits for postpartum comfort, milk production, and reproductive performance, the timing of administration and choice of drug are critical. Negative outcomes observed with flunixin meglumine and the production trade-offs associated with dexamethasone warrant careful consideration.

### *2.3.1.2 Pain Mitigation Following Calving in Calves*

Studies on pain relief in calves have highlighted potential advantages of using NSAIDs such as meloxicam and ketoprofen after calving.

**Beef calves.** Pearson et al. (2019b) investigated the effects of meloxicam in 33 beef calves requiring assistance at birth. Meloxicam-treated calves exhibited a higher average daily gain (+0.3 kg/day) during the first 7 to 10 days of life compared to placebo-treated calves. However, meloxicam had no significant effect on physiological pain and inflammation markers, standing and nursing behaviour within 1-hour, passive immunity, overall health outcomes, or average daily gain to weaning. Similarly, Lucio et al. (2024b) studied 23 assisted beef calves administered meloxicam or a placebo. Although meloxicam did not influence cow–calf bonding, treated calves showed increased activity and play behaviour, indicating improved welfare through reduced discomfort. In a larger cohort, Pearson et al. (2019c) enrolled 230 assisted beef calves but found no significant effects of meloxicam on serum IgG concentrations, growth, disease treatment risk, or mortality.

**Dairy calves.** In Holstein dairy calves, Murray et al. (2016) conducted a randomized double-blind trial to assess the effects of meloxicam administered shortly after newborn calves were discovered on calf vigour, health, and growth. The study revealed that meloxicam improved calf vigour, suckling reflex, milk intake, and health during the pre-weaning period. Similarly, Kovács et al. (2022) explored the effect of meloxicam administration immediately after birth on the standing behaviour of 180 Holstein calves born to eutocic or dystocic dams. The study found that meloxicam improved the duration and frequency of standing as well as the longest standing bout in low-vitality calves, but it did not affect calves with normal vitality. Clark et al. (2020) also investigated the effects of meloxicam on calves unassisted and assisted in delivery; however, it

was administered in pill form prior to colostrum feeding or mixed in solution with colostrum replacer. Few differences were noted between groups with respect to IgG concentrations; however, calves treated with meloxicam tended to consume more starter feed and had higher ketone levels, suggesting improved rumen development, compared to the control group. Further, those receiving meloxicam in pill form tended to gain weight at a faster rate and had lower glucose levels compared to meloxicam offered in colostrum. With regard to ketoprofen, Gladden et al. (2019) evaluated its administration to 75 Holstein calves at birth. Regardless of whether calves required assistance during birth, ketoprofen increased play behaviour during the 48 hours after birth, suggesting it alleviated neonatal discomfort.

These studies collectively indicate that NSAID administration can improve specific welfare metrics such as activity and play behaviour in calves after calving. However, effects on health outcomes and long-term growth appear inconsistent, although the latter perhaps should not be the primary outcome of interest for such studies. There remains a need for further research to optimize pain management strategies in newborn calves.

### **2.3.2 Future Research**

Future research in beef cattle should focus on optimizing the timing and dosage of anesthetic and analgesic administration, particularly around assisted births, to improve cow comfort, reproductive performance, and calf health, welfare, survival, and productivity. Further, there is a need to develop novel routes of administration that could make pain control use more practical for producers as well as veterinarians. Additional studies that explore the long-term effects of pain mitigation on herd productivity and economics might be beneficial to increase the uptake of pain mitigation among producers and veterinarians who are not currently using it. Comparative evaluations of different products and their impacts on both dams and calves under beef production conditions are also essential to guide practical, evidence-informed recommendations.

## **2.4 Spaying of Female Cattle**

### **Conclusions:**

- 1. Spaying, regardless of the method used, causes significant pain and stress in cattle, with flank laparotomy having more prolonged adverse effects compared to the Willis dropped ovary technique.**
- 2. Pain management strategies, such as NSAIDs like meloxicam in combination with an anesthetic or other NSAIDs, reduce pain behaviours and physiological stress following spaying, improving cattle welfare.**
- 3. Alternatives to spaying, such as improved reproductive management, are available to avoid the need for the procedure altogether.**

Some female cattle that are not required for breeding are spayed to prevent unwanted pregnancies and mitigate potential negative consequences associated with pregnancy in fed

heifers when alternative strategies are deemed impossible; such is the case with range cattle where mating may be harder to control. In these circumstances, spaying can help mitigate the risk of having pregnant heifers calving in the feedlot, which has the potential to create an even larger welfare issue. However, scientific evidence suggests that spaying offers limited economic advantages in many cases. Spayed heifers not implanted with growth-promoting hormones have a lower average daily gain compared to intact heifers not implanted with growth-promoting hormones (as reviewed by Pinner, 2006), and when implanted, spayed heifers perform similarly to implanted intact heifers (Cain et al., 1986; Popp et al., 1997). Given the painful nature of spaying and the lack of clear performance benefits, its use warrants critical evaluation, particularly in light of alternative management strategies that may mitigate the risks of pregnancy without causing significant welfare concerns.

Spaying methods include flank laparotomy and transvaginal ovariectomy (Pinner, 2006). Although limited, research consistently demonstrates that spaying, regardless of the technique, is associated with significant pain and stress in cattle. McCosker et al. (2010) investigated morbidity and mortality in yearling Brahman heifers spayed using either a form of transvaginal ovariectomy called the Willis dropped ovary technique (WDOT) or ovariectomy via flank incision compared to control unsplayed heifers under commercial conditions. Spayed heifers exhibited acute pain-related behaviours within the first 6 hours post-procedure. Body weight and weight gain were significantly lower in spayed heifers compared to controls at 21 and 42 days, with 5% of flank wounds remaining unhealed at 42 days. Mortality rates were 0% for the control group, 1.5% for WDOT, and 2.5% for flank-spayed heifers, with WDOT deaths occurring later after the procedure. Petherick et al. (2011) compared the WDOT and flank laparotomy methods and found elevated cortisol concentrations in spayed heifers compared to controls subjected only to crush restraint. Flank-spayed heifers also had elevated haptoglobin levels until day 4 post-procedure. Petherick et al. (2013) evaluated the welfare outcomes of cattle spayed using WDOT or flank laparotomy, comparing these methods to control procedures such as physical restraint or mock artificial insemination. Plasma cortisol concentrations were significantly higher in cattle spayed using either method during the 8 hours following procedures compared to animals subjected to physical restraint or mock insemination. Flank laparotomy was also associated with elevated creatine kinase and aspartate aminotransferase levels, indicating greater tissue damage. Inflammatory responses, as measured by haptoglobin levels, were more pronounced and longer lasting in cattle spayed via flank laparotomy. Behaviourally, cattle spayed by either method spent more time standing with their heads down and less time feeding immediately after the procedure than controls, with these effects persisting longer in those spayed via flank laparotomy. Body weight changes were not significantly different across treatments. From these studies, it can be concluded that spaying causes significant pain and stress in cattle, with flank laparotomy having more prolonged adverse effects compared to WDOT. These findings highlight the need for improved pain management strategies and welfare considerations for spaying procedures, as well as exploration of potential alternatives.

#### ***2.4.1 Pain Mitigation Strategies for Spaying Female Cattle***

Regarding pain management, Lauder et al. (2020) investigated the effectiveness of pain management in cattle undergoing WDOT. Heifers treated with a combination of butorphanol, xylazine, and ketamine (an anesthesia protocol administered exclusively by a veterinarian) prior to spaying, along with oral meloxicam at the time of the procedure, exhibited significantly lower

salivary cortisol levels within 2 hours post-spaying and reduced haptoglobin levels at 2-, 4-, and 7-days post-procedure compared to untreated spayed heifers. Similarly, Yu et al. (2020) evaluated the impact of meloxicam administered post-procedure and a topical anesthetic applied before piercing the vaginal wall immediately before ovary excision during the WDOT procedure. Pain-related behaviours such as head tucking and tail stiffness were observed in all spay groups but were least pronounced in heifers treated with analgesia and anesthesia. Treated heifers also spent more time ruminating and eating and less time standing with an arched back or lying down, indicating a reduction in negative welfare outcomes. Together, these studies highlight the effectiveness of multimodal analgesia in reducing but not eliminating pain associated with WDOT.

#### **2.4.2 Future Research**

Future research should focus on optimizing multimodal pain management strategies for spaying procedures, including the timing, dosage, and combination of NSAIDs, anesthetics, and other analgesics. However, given the clear evidence of significant pain associated with spaying and the limited practical and effective strategies currently available to mitigate that pain, the necessity of the procedure itself warrants critical evaluation. Exploring and encouraging alternative management strategies to prevent unwanted pregnancies or reduce the need for spaying should also be prioritized, particularly in light of welfare concerns and the minimal evidence of long-term productivity benefits under commercial conditions.

## **2.5 Disbudding and Dehorning**

### **Conclusions:**

- 1. Disbudding and dehorning are painful procedures that cause a range of stress and behavioural changes in calves, with animals facing greater health and welfare risks when dehorning is performed at an older age.**
- 2. Pain mitigation strategies, such as combining local anesthetics and NSAIDs, effectively reduce but do not eliminate acute and post-procedure pain in cattle of any age.**
- 3. Additional pain management, beyond the initial doses of local anesthetics and NSAIDs, are needed for effective management of chronic pain and inflammation.**
- 4. Sedation with xylazine could aid in reducing immediate stress during disbudding in addition to having analgesic effects.**
- 5. Research specific to beef calves is needed to evaluate methods, optimize pain control, particularly for chronic pain, and inform best practices for disbudding and dehorning in beef production.**
- 6. Breeding for polled genetics is a viable alternative to disbudding and dehorning, with no observed negative effects on productivity.**

Disbudding is the removal of horn-forming tissue before its attachment to the skull, whereas dehorning is the removal of the horn after this occurs at approximately 2 to 3 months of age (CVMA, 2022). These procedures are done as horned cattle are perceived to pose a risk of injury to people as well as other animals (Stock et al., 2013). Further, Lutz et al. (2019) found that horned dairy cattle exhibited more non-contact aggression and successful head butts than dehorned cattle, highlighting the potential for increased conflict and injury in horned cattle. While some researchers suggest that horns have some benefits and pose a risk only when cattle are housed in confined spaces where competition for resources is increased (Knierim et al., 2015; Algra et al., 2023), others acknowledge the economic and practical challenges of widespread housing adaptations needed to manage horned cattle in intensive production systems (Drwencke et al., 2025b).

As concluded in the previous Review of Scientific Research on Priority Issues (Schwartzkopf-Genswein et al., 2012), disbudding or dehorning causes pain and distress at any age. Specifically, animals that have been disbudded or dehorned have increased levels of cortisol, have higher heart and respiratory rates, seek physical and visual isolation, exhibit behavioural indicators of pain (e.g., tail flicking, head shaking, ear flicking, vocalization), and have increased sensitivity in the area of the wound (as reviewed by Reedman et al., 2022a). Although both are painful, disbudding is recommended over dehorning as it is less invasive and painful (Stafford & Mellor, 2005a, 2011).

More recent research in dairy calves has also highlighted long-term consequences associated with disbudding or dehorning. Specifically, Adcock et al. (2023) found that cautery disbudding in calves resulted in increased inactivity and lower rumination for up to 11 days post-procedure, as well as more head-down sleeping throughout the three-week study and increased lying on day 17. Further, Adcock and Tucker (2018), in young dairy calves, found that indicators of pain remained for 62 days following cautery disbudding. Hence, despite the use of pain relief, evidence from dairy calves raises concerns about long-term welfare implications.

### ***2.5.1 Use of Polled Genetics***

The use of polled genetics is common in the Canadian beef industry, with 56% of surveyed western Canadian cow-calf producers reporting that more than 90% of their calf crop is polled (Moggy et al., 2017). The 2024 cow-calf survey reported that the majority (80.6%) of survey respondents had more than 75% of their calves born polled (BCRC, 2024). Initially, it was feared that polled genetics would lead to lower levels of production; however, most studies point to no difference between polled and horned beef breeds (Schwartzkopf-Genswein et al., 2012). Randhawa et al. (2021) compared estimated breeding values for 12 production and carcass traits between 2.5 million horned and polled cattle. Prior to the year 2000, polled animals had lower genetic merit for traits like live and carcass weights, milk, and meat quality. However, between 2000 and 2018, significant genetic gains were achieved, with polled animals improving for most traits and showing advantageous estimated breeding values for live and carcass weights, despite slightly lower birth weights in some breeds. Therefore, recent selection for polled genotypes has not negatively impacted genetic merit, addressing concerns about reduced productivity in polled animals.

### **2.5.2 *Age of Animal***

As a calf ages, the size and degree of attachment of the horn increases, thereby changing the procedure from disbudding to dehorning, and the method used is adjusted accordingly (see section 2.5.3). The previous Review of Scientific Research on Priority Issues (Schwartzkopf-Genswein et al., 2012) highlighted the limited research that has been conducted on the impact of age at dehorning or disbudding; however, from the few studies it was clear that disbudding conducted in young calves (< 7 months of age) typically resulted in faster wound healing compared to older calves. Since then, few studies have explored this topic, and those that have primarily focused on dairy calves under 35 days of age. Adcock and Tucker (2018) compared cautery disbudding in calves at 3 and 35 days of age, reporting no differences in wound healing time or weight gain between the groups. However, calves disbudded at 3 days exhibited greater generalized pain sensitivity at 28, 42, and 56 days after disbudding, suggesting heightened long-term pain responses with earlier disbudding. Mirra et al. (2018) found that cautery disbudding at either 1 or 4 weeks of age caused comparable increases in pain and tactile sensitivity scores, with both groups experiencing acute pain and peripheral sensitization. Notably, calves disbudded at 4 weeks had lower pressure pain thresholds, indicating more intense localized pain than those disbudded at 1 week, despite no differences in physiological or behavioural measures. These findings highlight the complexities of timing for disbudding, as earlier procedures may reduce certain pain responses but still cause significant pain and sensitization, suggesting that even early disbudding carries welfare concerns.

### **2.5.3 *Method Used for Disbudding and Dehorning***

There are multiple methods that can be used to disbud or dehorn cattle. In 109 western Canadian cow-calf operations, most (51%) calves were disbudded with caustic paste at < 1 week, followed by 23% using cautery disbudding at 1 week to 3 months, and 14% using gouge or scoop disbudding at 1 week to 3 months (Moggy et al., 2017). In the most recent industry cow-calf survey, dehorning paste was the most common dehorning method used by producers at 34%, followed by electric disbudgers at 25.6%, while spoons, saws, wires, keys, or guillotines were used by 26.3% of producers and 13.7% used other methods including hot iron, gouge and burn, or knife for dehorning. Only 0.4% of producers surveyed reported not dehorning their calves (BCRC, 2024). It is important to note, very few studies have completed direct comparisons between methods, with the overwhelming majority of studies conducted in dairy calves. Nevertheless, disbudding is preferred over dehorning (CVMA, 2022), as it causes less tissue trauma and lower risk of sinusitis, uncontrolled bleeding, fly infestation, and infection (Stafford & Mellor, 2011)

#### **2.5.3.1 *Caustic Paste versus Cautery Disbudding***

Newby et al. (2016) compared the behaviour and outcomes of three disbudding methods in dairy calves aged 1 to 15 days: caustic paste, caustic stick, and hot iron with a cornual nerve block lidocaine. Calves that had caustic paste disbudding were quicker to approach a person on days 1 and 7 post-disbudding. Cautery disbudding resulted in smaller scars but had higher odds of showing signs of infection (e.g., redness, purulent discharge, and crust formation) 3 weeks later compared to caustic methods. Weight gain and horn regrowth at 6 weeks and 6 months were similar across all methods. It should be noted that the rates of infection resulting from caustic

compared to cautery disbudding reported by Newby et al. 2016 were very low and therefore conclusions and recommendations based on this comparison cannot be made. In addition, a study evaluating the efficacy of novel disbudding methods in dairy calves found that the likelihood of infection was not the same for all methods of cautery disbudding evaluated. For example, leaving the bud in resulted in double the percentage of buds infected compared to removing them, suggesting that technique is also important for managing infection (Sutherland et al., 2019). Drwencke et al. (2023) found that caustic paste disbudding in 3-day-old Jersey and Holstein calves resulted in prolonged wound healing, averaging 18.8 weeks compared to the 7 to 9 weeks typical for cautery disbudding. Wounds were also more sensitive than intact horn buds for at least 6 weeks, highlighting the extended healing time and sensitivity associated with the use of caustic paste. Similarly, Drwencke et al. (2025b) reported that wound size and depth were larger with paste compared to hot iron disbudding, and wounds took at least twice as long to heal (i.e., 17–18 weeks paste compared to 10 weeks for hot iron). Cui et al. (2024) also compared caustic paste and hot iron and found both groups of calves showed an increase in pain behaviour after the procedures, but the paste group had higher frequency of these behaviours than the hot iron group. Further, calves in the dehorning cream group had higher blood haptoglobin concentrations, a biomarker for inflammation, compared to their hot iron counterparts at 48 hours post-disbudding.

Whether the area is shaved before application and the dose of paste applied both impact calf behaviour, wound healing, and success of the procedure. When the horn bud area was shaved before application, calves were more likely to rub, thereby disrupting the paste, compared to unshaved calves, and 30% of all calves had paste on their body or surrounding environment (Drwencke et al., 2025a). In that study, a smaller dose (0.2 ml) on unshaved buds re-epithelialized faster than a larger dose (0.3 ml) on shaved buds; however, the risk of regrowth was highest in the 0.2 ml dose unshaved group (8%) compared to the 0.2 ml dose shaved (0%), 0.3 ml dose unshaved (0%), and 0.3 ml dose shaved (2%) groups.

These studies highlight the potential trade-offs between caustic paste and cautery disbudding methods, with caustic paste delaying wound healing and causing higher pain sensitivity over a prolonged period, while cautery disbudding may carry a higher risk of infection despite faster wound resolution.

### 2.5.3.2 *Hot Iron Type*

Adcock et al. (2019) compared wound healing in 4- to 10-day-old calves disbudded with a Rhinehart X50A electric disbudder and a Portasol gas disbudder. Although wounds from both irons took 7 to 8 weeks to heal, Rhinehart wounds exhibited more days with detached necrotic tissue and fewer days with granulation tissue, likely due to the larger surface area of the Rhinehart iron creating a more severe burn. Despite these differences, re-epithelialization times were similar between irons. Building on this, Thomsen et al. (2021) explored how iron size and timing of anesthesia impact pain-related behaviours in 1- to 15-day-old dairy calves during cautery disbudding. It was found that calves disbudded with a large iron were 2.3 times more likely to react behaviourally (i.e., getting up, kicking, or lifting head) compared to those disbudded with a small iron. The interval from administration of local anesthesia to disbudding (ranging from 2 to 35 minutes) did not influence behavioural responses. The size of the horn bud of beef breed calves averaged between 13.8 mm and 15.1 mm and was significantly larger in

calves 4–8 weeks old compared to calves 2–4 weeks old, and in male calves compared to female calves (Marquette et al., 2021). However, age was a poor predictor of horn bud size, so the authors caution against using age as the sole factor in deciding the size of iron to use. The goal should be to create a wound that does not cause excessive damage and targets only the horn growing tissue (Dewencke et al., 2025b). Together, these studies illustrate the significant impact of iron size on calf responses during disbudding, suggesting that smaller irons reduce behavioural indicators of pain and improve wound healing.

#### *2.5.3.3 Dehorning Method in Older Cattle*

One study evaluated the use of different dehorning methods in cattle arriving to a feedlot (Neely et al., 2014). They evaluated pain, behaviour, and wound healing in 40 feedlot cattle dehorned using high-tension banding, mechanical removal using a Keystone dehorner, or removal of the horn tip by using a hand saw to cut perpendicular to the horn's longitudinal axis at a diameter of 3.17 cm. Mechanical dehorning caused the most vocalizations, indicating severe pain, while banding elicited prolonged discomfort and delayed recovery, with higher scores for posture, lying, and wound healing. Removing the horn tip caused fewer signs of distress, compared to other methods of dehorning. The study concluded that while mechanical dehorning causes acute pain and banding leads to extended discomfort and slower healing, removal of the horn tip resulted in fewer signs of distress. However, removal of the horn tip is a less permanent solution as it does not fully remove the horn-producing cells, which could regrow and require additional intervention.

#### **2.5.4 Pain Mitigation Strategies for Disbudding and Dehorning**

As highlighted above, dehorning and disbudding are painful. Western Canadian cow–calf producers also agree that it is a painful practice with 84% agreeing that dehorning was painful if pain mitigation was not used; however, less than 15% of respondents that dehorned their calves used pain mitigation (Moggy et al., 2017). The use of pain control among producers has increased since 2017, according to the 2023 Canadian Cow-Calf Survey (BCRC, 2024), which gathered data from 600 producers across 9 provinces. The survey found that among those who disbudded or dehorned calves, 47.3% consistently used pain mitigation, while 22.9% used it depending on the age of the calf and the method employed. Further, veterinarians acknowledge disbudding and dehorning as painful, with a position statement by the Canadian Veterinary Medical Association (CVMA, 2022) stating that cattle that are disbudded or dehorned should receive a local anesthetic and peri-operative analgesia.

##### *2.5.4.1 Combination of Local Anesthesia and Non-Steroidal Anti-Inflammatory Drugs*

There is clear scientific evidence that a combination of a local anesthetic and NSAID at the time of disbudding or dehorning will mitigate procedural pain as well as some post-operative pain. Specifically, Winder et al. (2018) conducted a systematic review and meta-analysis of 21 studies to evaluate the impact of local anesthesia and NSAIDs on managing pain from cautery disbudding in dairy and beef calves under 12 weeks of age. The review concluded that local anesthesia provides effective short-term pain relief, significantly reducing plasma cortisol concentrations for up to 2 hours post-disbudding, although cortisol levels rise again by 4 hours. Administering NSAIDs in conjunction with local anesthesia extended pain relief, mitigating the

delayed rise in cortisol, reducing pressure sensitivity, and decreasing pain behaviours between 3 and 6 hours post-procedure. Despite variability in study designs, the findings strongly support the combined use of local anesthesia and NSAIDs as best practice for managing pain associated with cauterly disbudding.

After the publication of the meta-analysis, other studies have also found that this mitigation strategy is effective at reducing pain associated with disbudding or dehorning, irrespective of age and method. In 1–9-day-old Holstein calves undergoing caustic paste disbudding, the concurrent use of local lidocaine anesthesia and systemic meloxicam analgesia effectively reduced serum cortisol concentrations, early pressure sensitivity, and inflammation compared to using either treatment alone or no pain control (Reedman et al., 2020). In addition, cortisol concentrations in the combined treatment group were comparable to sham controls, and haptoglobin concentrations tended to be lower 3 to 4 days post-disbudding, underscoring the benefits of this multimodal approach for pain management in young calves. In 6-week-old to 6-month-old Holstein calves, Qi et al. (2024) found that using meloxicam alongside lidocaine for amputation dehorning significantly reduced pain behaviours, physiological stress responses, and inflammatory markers while increasing mechanical nociceptive thresholds compared to lidocaine alone. In 7-month-old cattle, Park et al. (2020) examined the effects of lidocaine and flunixin meglumine on stress, inflammation, and behaviour during surgical dehorning with a gouge dehorner. Calves treated with lidocaine and flunixin meglumine displayed reduced head-shaking frequency, indicating alleviation of pain-related behaviours, though cortisol and haptoglobin levels were unaffected by the treatment.

Collectively, these findings provide robust evidence that a multimodal approach combining local anesthesia (e.g., lidocaine) with systemic analgesia (e.g., NSAIDs, such as meloxicam or flunixin meglumine) is required to effectively mitigate both procedural and post-operative pain associated with disbudding and dehorning across various ages and methods.

#### *2.5.4.2 Types of Non-Steroidal Anti-Inflammatory Drugs*

Several studies have assessed the efficacy of different NSAIDs alongside local anesthesia for pain management during dehorning and disbudding. Glynn et al. (2013) compared local anesthesia paired with oral meloxicam, oral gabapentin, a combination of meloxicam and gabapentin, intravenous flunixin, or a placebo in 6-month-old calves. While all analgesics improved average daily gain and reduced plasma substance P concentrations, only flunixin reduced serum cortisol, and meloxicam increased mechanical nociceptive thresholds, indicating localized pain relief. Gaab et al. (2022) evaluated lidocaine with transdermal flunixin meglumine, lidocaine with oral meloxicam, and lidocaine alone in calves undergoing disbudding. Although behavioural and cortisol responses increased post-disbudding, no significant differences were observed among treatments. Stock et al. (2021) compared four NSAIDs—meloxicam, flunixin meglumine, firocoxib, and carprofen—administered orally to 50-day-old calves during cauterly dehorning, with all calves also receiving a local anesthetic prior to dehorning. Placebo-treated calves, which received only a local anesthetic, produced approximately 25% greater cortisol concentrations over the first 24 hours compared to flunixin meglumine, meloxicam, and firocoxib-treated calves. Flunixin-treated calves also had lower cortisol concentrations at 4 and 8 hours after dehorning compared to placebo-treated calves. Meloxicam reduced heart rates and marginally affected nociceptive thresholds, while carprofen

was less effective, increasing cortisol and wound temperatures. Another study by Ede et al. (2019) examined the emotional impact of pain using calves disbudded with either meloxicam or ketoprofen in addition to local anesthesia. Calves treated with meloxicam showed a less aversive reaction to the location where the disbudding procedure took place than ketoprofen-treated calves, potentially because ketoprofen has a shorter duration of action. Lastly, Prior et al. (2023) compared a single injection of subcutaneous meloxicam and 3 days of oral sodium salicylate in 35-day-old calves undergoing cautery disbudding. Behavioural and growth performance outcomes showed no significant differences, indicating comparable effects between these two NSAIDs. Together, these studies demonstrate that while there are some differences in NSAID efficacy, the majority found that providing any NSAID yielded significant benefits compared to no pain relief, underscoring the importance of incorporating NSAIDs into pain management protocols for disbudding and dehorning. A more detailed systematic review is available by Wagner et al. (2021), although no general conclusions could be made from that analysis beyond that additional research is needed.

#### *2.5.4.3 Sedation*

The use of xylazine, a sedative with analgesic properties, has also been explored in beef and dairy calves. Caray et al. (2015) evaluated the impacts of cautery disbudding in 1- and 4-week-old dairy and beef calves and tested xylazine sedation combined with ketoprofen but without local anesthesia. Xylazine with ketoprofen reduced immediate stress responses such as salivary cortisol and heart rate, but pain responses persisted beyond 2 hours post-disbudding, with vocalizations continuing up to 7 hours after the procedure regardless of treatment group. Reedman et al. (2021) further explored xylazine use in Holstein calves alongside lidocaine and meloxicam. Sedated calves struggled less during disbudding, showed reduced pain sensitivity immediately after the procedure, and were more likely to play 24 hours later. However, sedation slowed milk drinking for up to 48 hours and reduced play in the first 3 hours. Both studies highlight that xylazine may mitigate immediate stress and pain sensitivity but has limited impact on long-term pain.

#### *2.5.4.4 Extending Pain Relief After Disbudding and Dehorning*

To address the prolonged pain associated with disbudding and dehorning, studies have explored additional doses of local anesthetic or NSAIDs. Reedman et al. (2022b) evaluated administering a second dose of meloxicam to 18- to 25-day-old Holstein calves 3 days after disbudding, following an initial lidocaine nerve block and meloxicam dose at the time of the procedure. While calves receiving 2 doses exhibited delayed wound healing, with larger wound diameters and slower re-epithelialization compared to those receiving 1 dose, they tended to show reduced mechanical nociception sensitivity at 7, 10, and 17 days and spent less time lying in the week following disbudding, suggesting improved pain relief. Adcock et al. (2020) examined the effects of lidocaine administered 11 days after disbudding on behavioural responses. Calves treated with lidocaine displayed fewer head shakes and ear flicks, indicating reduced pain, and increased head rubbing, suggesting diminished wound-protective behaviour. As the anesthetic wore off, head shaking and scratching increased, highlighting the return of wound sensation. Recently, a novel formulation of meloxicam-medicated pellet (120 mg of meloxicam/kg of pellet, fed at 1 kg of pellets per calf per day, resulting in a dose of at least 1 mg/kg, from the day before until 6 days after disbudding) explored the potential for provision of more sustained

NSAID delivery (Scerri et al., 2025). Calves receiving prolonged oral meloxicam via pellet had less wound inflammation and expressed fewer pain behaviours and more social behaviours compared to untreated calves; calves given a single dose of injectable meloxicam appeared to have similar short-term pain mitigation but poorer long-term mitigation. The findings of these studies together demonstrate that additional doses of analgesics may provide extended pain relief.

### **2.5.5 Future Research**

Future research should prioritize beef-specific strategies to improve outcomes in disbudding and dehorning practices, while also defining clear metrics to evaluate pain and welfare outcomes. Comparisons between methods, such as caustic paste and cautery, may be valuable given the number of beef producers using these techniques, enabling them to select the method that minimizes pain in calves. Additionally, few studies have compared dehorning methods across different calf ages, leaving gaps in understanding how age and method interact to influence pain and welfare. Pain mitigation strategies require further exploration, not only regarding the optimal timing and dosing of NSAIDs but also in terms of drug onset, half-life, and method of delivery (e.g., oral, injectable, or transdermal). Furthermore, understanding the combined effect of the pain mitigation strategy and the specific dehorning method is essential, as certain strategies may be more effective depending on the type of tissue damage caused and the length of healing time. The impact of greater handling stress in beef calves compared to dairy calves should also be considered in such studies. Finally, research should be directed towards identifying barriers to the uptake of pain mitigation strategies by producers, as this is critical for translating research findings into improved welfare outcomes on-farm.

## **2.6 Castration**

### **Conclusions:**

- 1. Castration causes significant short- and long-term pain, with sensitivity and behavioural indicators persisting for weeks or months after the procedure regardless of the age and method used, as evidenced by physiological and behavioural indicators.**
- 2. Younger calves heal more quickly and experience less overall pain and distress compared to older calves.**
- 3. Band castration causes less immediate pain but results in prolonged swelling and delayed healing, while surgical castration leads to greater acute pain but faster recovery.**
- 4. Combining local anesthetics and NSAIDs provides the most effective pain relief, addressing both immediate and prolonged discomfort at all ages of cattle assessed.**

- 5. The effect of pain control in castrated neonates is inconsistent and few studies have been conducted. Inconsistencies may be due to altered physiological and behavioural profiles in very young calves (0 to 7 days of age) associated with recent parturition or immature endocrine, digestive, and immune systems.**
- 6. Pain associated with knife-castration is more likely to be alleviated than band-castration since currently available pain control drugs are relatively short-acting.**

Castration is performed to prevent unwanted pregnancies, reduce aggression and mounting behaviour, and improve handling, ultimately leading to fewer injuries and reduced dark-cutting (Stafford & Mellor, 2005b; Marquette et al., 2023). Further, steers have higher quality meat, being more tender and marbled. Despite the benefits of castration, it is clear that all methods of castration cause pain as reviewed in the previous Review of Scientific Research on Priority Issues (Schwartzkopf-Genswein et al., 2012) and more recently by Coetzee (2013) and Marquette et al. (2023). Specifically, castration is associated with physiological stress markers, such as elevated plasma cortisol and increased heart rate, and behavioural responses, including avoidance, vocalizations, and changes in posture. Further, increased scrotal swelling and prolonged wound healing also occur as a result of castration. It is also important to note that most (72%) western Canadian beef producers agreed that castration was painful if a pain mitigation strategy was not used (Moggy et al., 2017); although only 10% of respondents reported using pain mitigation for castration. More recent estimates suggest that pain control is being more commonly implemented for castration. Specifically, in a survey of 600 producers across 9 provinces, 26.2% of producers reported always using pain mitigation during castration, and 20.4% used it depending on the age and method used (BCRC, 2024). The Canadian Cow-Calf Survey (BCRC, 2024) shows that 84.5% of calves are castrated at less than 3 months old and only 6.3% of producers typically castrate bull calves older than 6 months of age. A comprehensive review on this topic was recently published by Meléndez et al. (2025).

### ***2.6.1 Age of Animal***

The age at which calves are castrated influences their physiological, behavioural, and production responses. In the previous Review of Scientific Research on Priority Issues (Schwartzkopf-Genswein et al., 2012), it was concluded that the trauma caused by castration increases as the testes grow bigger, so castration at a younger age results in quicker healing and causes less pain and distress overall. Further, animals castrated at younger ages show lower declines in post-procedural growth rate. In more recent literature, similar findings have been noted.

Norring et al. (2017) observed faster wound healing in surgically castrated 0- to 8-day-old beef calves compared to those castrated at 69 to 80 days, with wounds closing in a median of 39 days versus 61 days. Further, younger calves recovered their daily weight gain quicker; however, they also experienced greater swelling and localized pain early in the healing process. Bergamasco et al. (2021) also found improvements in young Holstein calves, where those castrated at < 6 weeks old exhibited lower cortisol concentrations and faster recovery to baseline after surgical castration compared to 6-month-old calves. Younger calves also showed reduced autonomic nervous system activity, lower eye temperatures, and less stress overall, highlighting the benefits of early castration in mitigating physiological stress responses.

When evaluating Burdizzo castration, Marquette et al. (2021) reported that castration of 2.5-month-old beef calves was associated with lower cortisol concentrations and fewer pain-related behaviours compared to castration at 5 months. In band castrated beef calves, similar results were found, with calves castrated at 3 months of age healing faster and showing better liveweight gain over 45 days after castration compared to those castrated at 6 months of age (Petherick et al., 2015). It is important to note, however, that growth performance effects after castration are often masked over longer periods of time due to compensatory growths, so they should always be interpreted with caution when used as an indicator of pain and discomfort.

With respect to performance and carcass characteristics, Marti et al. (2017) found no differences in final body weight, average daily gain, or feed efficiency between Holstein calves castrated at 3 or 8 months, although earlier castration resulted in greater intramuscular fat and higher dressing percentages. Prado et al. (2014) similarly reported no differences in performance or carcass weight between Friesian calves castrated at 15 days or 5 months, though late castration altered muscle composition, increasing moisture and polyunsaturated fatty acids.

Based on these studies, younger calves generally exhibit faster healing, lower cortisol responses, and better growth recovery post-castration compared to older calves. While early castration may result in increased short-term swelling, it minimizes the duration of physiological and behavioural stress, suggesting it may be the preferred option for welfare and production outcomes.

### **2.6.2 Castration Method**

The main methods used for castration in Canada are banding and surgical castration. Moggy et al. (2017) surveyed 109 producers in western Canada and reported that among the 10,893 calves included, 53% were band castrated at less than 1 week of age, 26% were surgically castrated between 1 week and 3 months of age, and 15% were band castrated within the same age range. The Canadian Cow-Calf Survey (BCRC, 2024) indicated that 80.2% of calves were castrated using rubber bands, 18.3 % were castrated using surgical methods (e.g., blade or scalpel) and 1.2% used clamp or Burdizzo methods.

Differences between knife and band castration have been evaluated with these methods differing significantly in their acute and chronic effects, with distinct patterns of pain, stress, and recovery.

Meléndez et al. (2017a) examined acute pain in beef calves castrated using different methods at 1 week, 2 months, and 4 months of age. Knife castration caused the greatest immediate pain responses, with 1-week-old calves showing increased tail flicking 2 to 4 hours post-castration compared to banded calves. In 2-month-old calves, knife castration resulted in elevated cortisol, reduced lying and eating, and increased standing and walking, while band castration caused less immediate discomfort. In 4-month-old calves, band castration produced the highest cortisol concentrations, indicating prolonged stress compared to the intermediate responses observed with knife castration. Marti et al. (2017), following the same cohort of calves, found no differences in chronic markers of pain; however, swelling and inflammation were prolonged in band-castrated calves, particularly older animals.

Further studies corroborated these findings. Meléndez et al. (2018a) demonstrated that knife castration in 1-week-old beef calves caused more acute pain, with significantly higher cortisol and serum amyloid A (SAA) concentrations compared to band castration. Marti et al. (2018), who followed the same cohort, reported faster wound healing in knife-castrated calves with swelling resolving sooner, whereas band castration resulted in prolonged swelling. Knife-castrated calves also exhibited lower serum amyloid A concentrations from days 7 to 35 compared to band-castrated calves, indicating a reduced inflammatory response. When evaluating the impact of medicating calves with a subcutaneous injection of meloxicam as part of the castration procedure, they observed that hair cortisol concentrations were highest at day 56 in non-medicated band-castrated calves compared to medicated band-castrated calves and both medicated and unmedicated knife-castrated groups. Similarly, in 2-month-old beef calves, Gellatly et al. (2021) found knife castration caused intense acute pain, with increased standing, walking, tail flicking, and foot stamping during the first 11 hours post-castration. Knife castration also resulted in pain sensitivity lasting through days 6 to 34, while band castration led to prolonged sensitivity until day 62, with swelling persisting until day 34.

In older calves, similar patterns have been observed. Nordi et al. (2019) reported prolonged cortisol elevation and higher pain scores in knife-castrated compared to band castrated 6-month-old beef calves. Knife castration also resulted in longer meal durations and higher scrotal temperatures, indicating greater discomfort, while band castration caused moderate stress responses with cortisol peaking earlier and resolving more quickly. In 7-month-old beef calves, Moya et al. (2014) found that surgical castration led to more acute pain, characterized by elevated cortisol levels, higher visual analog pain scores, and significant reductions in average daily gain during the first week post-castration. Band castration, on the other hand, caused prolonged inflammation, with scrotal temperatures peaking around week 4 and persistent reductions in average daily gain during weeks 2, 3, 6, and 7. Finally, Roberts et al. (2015) examined feedlot cattle (approximately 8 months old) undergoing surgical and band castration. Surgical castration resulted in greater acute inflammation, as indicated by elevated haptoglobin levels and increased standing times immediately after the procedure. In contrast, band castration led to prolonged lying bouts and higher step counts, suggesting extended discomfort. Although surgically castrated cattle experienced reduced average daily gain during the first week, they recovered more quickly, with improved average daily gain from day 14 onward compared to band-castrated cattle.

Gonadotropin-releasing hormone (GnRH)-immunocastration offers a non-surgical alternative to castration in bulls, with evidence supporting that it suppresses testicular function reducing the negative effects of testosterone caused during the male reproductive development (Marti et al., 2015). However, Wang et al. (2023) have also described immunization failures due to insensitivity to antigens in some individuals, causing failure to elicit an immune response or a shorter duration of immune effect. These, along with the risk of accidental self-injection by farm workers (Weese & Jack, 2008) and uncertainty regarding consumer attitudes toward meat from pharmacologically castrated animals (Font-i-Furnols et al., 2022), has prevented immunocastration from being considered a real alternative to invasive castration procedures.

These studies highlight that castration methods differ significantly in their acute and chronic effects, with distinct patterns of pain, stress, and recovery observed across various ages. Knife castration consistently results in greater acute pain and stress, particularly in younger calves, but

allows for faster recovery, with inflammation and swelling resolving more quickly. In contrast, band castration causes less immediate discomfort but leads to delayed and prolonged inflammatory responses, with swelling and stress indicators persisting for weeks, particularly in older calves. These findings highlight the trade-offs between methods, emphasizing the need to balance welfare concerns with practical considerations when selecting a castration method. Importantly, the timing and duration of pain also influence pain management strategies, as acute pain is often easier to mitigate than chronic pain, particularly in beef cattle where frequent handling for repeated treatment may not be practical.

### ***2.6.3 Pain Mitigation for Castration***

The scientific literature about pain control for castration of cattle has recently been reviewed by Nogues et al. (2025). The results of their meta-analysis concluded that local anesthesia in combination with an NSAID was most effective in lowering serum cortisol in calves compared to control untreated calves for the first 4 hours after surgical castration. There was inadequate available information to assess any other types of pain mitigation, methods of castration, or outcome measures.

#### ***2.6.3.1 Local Anesthetic Alone***

The previous Review of Scientific Research on Priority Issues (Schwartzkopf-Genswein et al., 2012) concluded that local anesthesia reduces immediate pain from castration but neither eliminates it nor alleviates longer-term post-operative pain. Recent studies support this conclusion. Webster et al. (2013) found that Holstein × Friesian calves treated with local anesthesia 20 minutes prior to surgical castration exhibited transient cortisol increases, including a second spike 120 minutes after injection. These calves also displayed more pain-related behaviours such as head turning, statue-like standing, and postural changes compared to a sham group, indicating that local anesthesia alone does not fully mitigate the pain of castration. Meléndez et al. (2018b) found that lidocaine administered 30 minutes prior to surgical castration mitigated the signs of pain expressed by 7- to 8-month-old beef calves. Specifically, it reduced salivary cortisol concentrations within an hour of castration, resulted in fewer pain-related behaviours, including reduced visual analog scale scores (a measure of pain intensity), leg and head movements, and escape attempts, and lower serum amyloid A levels on days 1, 3, 21, and 28 compared to the control calves castrated without lidocaine. However, lidocaine had no impact on average daily gain, weight, or feeding behaviour. Together, these findings suggest that while lidocaine may be effective at reducing acute pain and stress responses during castration, it does not address longer-term discomfort or improve overall performance outcomes.

Recent studies highlight the potential benefits of lidocaine-impregnated castration bands as a method for pain mitigation during band castration. Saville et al. (2020) demonstrated that lidocaine-impregnated bands release lidocaine rapidly within the first 30 minutes, followed by sustained delivery for at least 48 hours. The sensitivity of the skin immediately above where the lidocaine-impregnated band was allocated was the same as that provided by injected lidocaine for up to 48 hours post-application, as measured via electrostimulation in 3- to 4-week-old and 5-month-old calves. Seven days after band application, calves with lidocaine-impregnated bands showed reduced sensitivity to electrostimulation and higher lidocaine concentrations in scrotal tissue compared to those receiving injectable lidocaine. No differences were observed between

groups in growth, tail flicks, or average heart rate. Similarly, Ross et al. (2024) compared the effectiveness of injectable lidocaine and lidocaine-impregnated castration bands for pain management during castration. Injectable lidocaine provided short-term anesthesia lasting up to 60 minutes, as indicated by response scores to electrocutaneous stimulation, but these scores returned to baseline by 90 minutes. Tissue concentrations of lidocaine also declined rapidly, with minimal levels detected at 240 minutes post-administration. In contrast, lidocaine-impregnated castration bands achieved effective tissue concentrations at 2 and 72 hours and sustained them above effective tissue concentration thresholds for at least 28 days. A study by Moya et al. (2024) found that injectable lidocaine provided pain relief for up to 60 minutes, while lidocaine-impregnated bands achieved effective tissue concentrations by 2 hours, peaked at 72 hours, and remained above effective levels for 28 days. Mancke et al. (2025) compared lidocaine-impregnated to non-medicated bands in dairy-beef cross calves under 2 weeks of age and found that the medicated bands improved ADG and feed efficiency and reduced behavioural signs of pain (increased lying and reduced wound licking) over a 49-day period post-castration. These results suggest that lidocaine-impregnated castration bands may offer some potential for prolonged pain mitigation as an alternative to injectable anesthetics, though further research is needed to evaluate their effectiveness, particularly when combined with NSAIDs.

#### 2.6.3.2 *Non-Steroidal Anti-Inflammatory Drugs Alone*

NSAIDs are the most frequently used option when pain control is applied for castration (Moggy et al., 2017). This section reviews the effectiveness of NSAIDs in managing castration pain, focusing on meloxicam, ketoprofen, flunixin, and their comparative efficacy. Studies explore variations based on timing, administration methods, and type of NSAID used. This topic has also been reviewed thoroughly by Wagner et al., 2021.

**Meloxicam.** Meloxicam has been widely studied for its effectiveness in reducing pain associated with castration. Crevier et al. (2024) reported significantly fewer pain behaviours, such as licking and tail flicking, in newborn Angus calves treated with either oral or injectable meloxicam during band castration, compared to calves band castrated without pain control, though weight gain was unaffected. Similarly, Meléndez et al. (2018a) found lower markers of acute pain, including substance P and tail flicks, in 1-week-old Angus calves treated with meloxicam compared to those without pain control during knife or band castration, though no improvements were observed in eating or standing behaviours. In contrast, a study by Brown et al. (2015) in knife-castrated beef calves found that surgical castration performed near birth, with or without oral administration of meloxicam, had no effect on growth and little effect on behaviour or inflammation, so the impact of meloxicam on pain mitigation could not be demonstrated in neonate bulls. Chronic pain evaluations by Marti et al. (2018) showed that a single dose of subcutaneous administration meloxicam at the time of band castration reduced hair cortisol in 1-week-old calves at 56 days post-castration but did not improve wound healing or inflammation compared to no pain control. It should be noted that there is a lack of understanding of pain in very young calves (0- to 7-days-of-age) due to the fact that physiological profiles of calves at this age may be confounded by recent parturition as well as immature endocrine, digestive, and immune systems (Hulbert & Moisés, 2016). Similarly, the behavioural response to pain in neonates is poorly understood, and the absence of significant findings in observable pain expression may not fully reflect what the animal is experiencing, highlighting that assessments conducted in calves under 1 week of age require careful interpretation (Meléndez et al., 2025).

In older calves, Gellatly et al. (2021) observed limited effects of meloxicam in 2-month-old beef calves undergoing band or knife castration. Although meloxicam-treated calves exhibited increased suckling behaviour, there were no differences in acute or chronic pain markers compared to calves without pain control. Daniel et al. (2020) assessed the effects of oral meloxicam compared to no pain control in 3-month-old beef calves undergoing band castration. While no differences were found on average daily gain, fibrinogen, or haptoglobin, meloxicam-treated calves exhibited fewer steps and more lying bouts during the second week post-castration, indicating potential improvements in comfort. In 4- to 5-month-old Holstein calves, Olson et al. (2016) demonstrated that meloxicam reduced pain and inflammation following band castration, with treated calves showing lower heart rates, cortisol concentrations, and scrotal swelling compared to untreated calves. In feedlot cattle, Roberts et al. (2018) reported improved performance in those band or surgically castrated with meloxicam, including reduced inflammation and increased average daily gain and backfat thickness compared to untreated cattle. Brown et al. (2015) found that oral meloxicam reduced serum haptoglobin and improved ADG in weaned, knife-castrated calves.

Regarding the type of meloxicam to use, Meléndez et al. (2019) compared oral and subcutaneous meloxicam in knife-castrated calves and found minor pharmacokinetic differences, with oral administration showing faster drug clearance, potentially leading to a shorter duration of therapeutic effects compared to the subcutaneous route. Despite these differences, both routes provided comparable practical efficacy for pain management. With respect to timing of meloxicam administration, Meléndez et al. (2017b) found that administering meloxicam immediately before knife castration in 7- to 8-month-old calves was most effective, reducing substance P, scrotal temperature, and pain-related behaviours compared to those that received meloxicam 3 and 6 hours after the procedure.

Recent literature has explored other approaches for the oral administration of meloxicam, highlighting the need for extended analgesia beyond the typical 48-hour window provided by injections. Rudd et al. (2025) tested the ad libitum oral self-administration of meloxicam via molasses lick blocks in surgically castrated calves. Results showed that calves consuming the lick blocks had higher plasma meloxicam concentrations at most timepoints than those with a subcutaneous meloxicam injection, although with great individual variability leading to inconsistent plasma levels. Despite this, calves in the lick block group showed improved wound healing and reduced pain-related behaviours. The lick block method, therefore, offers a non-invasive, practical, and potentially long-acting route for pain relief, but dose control remains a challenge.

***Ketoprofen.*** Moya et al. (2014) evaluated the effects of single and multiple intramuscular injections of ketoprofen (administered 30 minutes before castration and at 1, 2, 4, 5, and 6 days post-castration) in beef calves undergoing either surgical or band castration. The study compared calves receiving ketoprofen to untreated calves (i.e., no pain control) for both castration methods. Ketoprofen showed limited efficacy, with minimal effects on scrotal temperature, salivary cortisol, white blood cell counts, and behavioural responses associated with pain. Additionally, reductions in average daily gain and feed intake observed in untreated castrated calves were not mitigated by ketoprofen treatment.

**Flunixin.** Kleinhenz et al. (2018) evaluated transdermal flunixin meglumine in 9-month-old Holstein calves undergoing surgical castration without local anesthesia. Flunixin reduced plasma cortisol concentrations during the first 12 hours post-castration, indicating a reduction in acute stress. However, no differences were observed in other pain markers compared to untreated controls, including infrared thermography, gait analysis, or substance P levels, suggesting limited broader analgesic effects.

**Meloxicam versus flunixin.** Cull et al. (2022) compared no medication, oral meloxicam, and intravenous flunixin meglumine in beef calves castrated with the Henderson tool technique. When looking at the effects on the visual analog scale pain scores as a measure of pain intensity, both meloxicam and flunixin reduced behavioural indicators of pain compared to the no pain control group (on days 1 to 3 and on day 1, respectively), with no significant differences between the two treatment groups.

Cumulatively, the studies summarized above indicate that meloxicam has demonstrated consistent effectiveness in reducing pain behaviours, acute inflammation, and chronic stress across various castration methods and calf ages over 1 week of age. Injectable and oral formulations perform similarly, and immediate administration yields the most significant benefits. Ketoprofen at a single time seems to provide minimal analgesic benefits, particularly for behavioural and performance outcomes, while flunixin effectively reduces acute cortisol levels but lacks prolonged efficacy. Compared to flunixin, meloxicam offers longer-lasting relief, likely making it a preferred option for managing castration pain.

### 2.6.3.3 *Combination of Pain Control Methods*

Combining local anesthetics with NSAIDs can address both immediate and prolonged discomfort. Local anesthetics target acute pain at the site of castration, while NSAIDs reduce inflammation and extend pain relief over time. This section reviews studies evaluating the combined use of these pain control methods.

**Local anesthetic and meloxicam.** Meléndez et al. (2018b) investigated the effects of meloxicam, lidocaine, and their combination in 7- to 8-month-old Angus calves undergoing knife castration. Lidocaine effectively reduced acute pain during castration, lowering salivary cortisol levels within the first hour and decreasing pain-related behaviours, such as escape attempts and leg and head movements. Meloxicam provided longer-lasting effects, reducing haptoglobin and cortisol concentrations at 24 and 48 hours post-castration. Additionally, calves treated with both lidocaine and meloxicam exhibited less scrotal swelling. Given that lidocaine and meloxicam impacted physiological and behavioural pain parameters at different time points, the authors concluded that their combined use was more effective at mitigating pain than either drug alone.

Martin et al. (2022a) also evaluated multimodal pain management, where bupivacaine, lidocaine, and lidocaine combined with meloxicam were evaluated in 16- to 20-week-old Holstein calves undergoing surgical castration. The administration of lidocaine alongside meloxicam resulted in the lowest concentrations of prostaglandin E2 metabolites and cortisol, as well as the fewest pain-related behaviours, such as hunched standing, compared to calves castrated without pain control. Additionally, gait improvements were also found in calves administered the

combination. Results were comparable to those seen with bupivacaine liposome suspension, a long-acting local anesthetic.

Laurence et al. (2016) found similar benefits in 6- to 8-month-old Brahman bulls undergoing surgical castration. The combination of lidocaine and post-operative meloxicam reduced cortisol levels on day 1, increased activity, and improved weight gain over 13 days compared to calves treated with either drug alone. Vindevoghel et al. (2019) further noted that calves receiving lidocaine and meloxicam were calmer and more alert post-castration compared to those castrated without pain control.

***Local anesthetic and flunixin.*** Nordi et al. (2019) evaluated flunixin meglumine combined with lidocaine in 6-month-old Angus calves undergoing knife or band castration. The combination significantly reduced salivary cortisol levels for up to 48 hours post-castration, improved feeding behaviour, and moderated increases in scrotal and eye temperatures compared to untreated control. Pain-related behaviours were also alleviated, suggesting effective pain control across both immediate and extended periods. Webster et al. (2013) also evaluated the effects of flunixin combined with a local anesthetic block in 2- to 30-month-old Holstein-Friesian calves. Local anesthetics alone temporarily reduced cortisol concentrations but was also associated with increased head turning and reduced feeding. Flunixin alone improved feeding behaviour and reduced crouching. However, the combination provided the most effective relief, minimizing behavioural pain indicators and reducing cortisol to baseline levels, comparable to sham-castrated calves.

These studies find that combining local anesthetics with NSAIDs provides superior pain relief compared to using either method alone. Local anesthetics, such as lidocaine, effectively mitigate immediate procedural pain, while NSAIDs, like meloxicam and flunixin, address systemic inflammation and extend analgesic effects. Studies consistently highlight the benefits of these combinations, including reductions in pain markers, fewer pain-related behaviours, and enhanced performance.

#### **2.6.4 Future Research**

Future research should aim to improve pain control methods for castration, focusing on options that balance efficacy with practicality for producers. In particular, on-farm evaluations of combination therapies to manage both immediate and prolonged pain are needed. Significant knowledge gaps exist regarding the effects of different castration methods, such as knife castration with a scalpel or Henderson tool, cutting versus pulling the spermatic cord, incision type, band tension, and placement on the testes, as well as their interactions with calf age and pain mitigation strategies. Additionally, alternatives to traditional castration, such as the use of GnRH vaccination, warrant further investigation as potential solutions to avoid testes removal and the associated pain. Finally, qualitative research, including interviews and focus groups, could provide valuable insights into producer perceptions, barriers, and motivators for adopting pain mitigation practices, helping to inform education and outreach efforts.

## 2.7 Branding

### Conclusions:

- 1. Branding causes significant short- and long-term pain, with sensitivity and behavioural indicators persisting for weeks or months post-procedure.**
- 2. Larger brand sizes and combining branding with other invasive procedures, such as castration, exacerbate pain-related behaviours and discomfort.**
- 3. Using NSAIDs like meloxicam and flunixin only provides limited pain relief, reducing some acute pain behaviours but failing to alleviate long-term pain or accelerate healing.**
- 4. Combining pain control methods, such as NSAIDs, with local anesthesia show mixed results, with minimal improvements in pain-related behaviours or healing rates.**
- 5. Future research should focus on multimodal pain management strategies, optimal branding techniques and timing, and evaluating and promoting alternative identification methods to improve welfare, minimize pain, and reduce the risks associated with improper application and substandard tools.**

Branding has long been a traditional method of livestock identification, serving essential purposes such as signifying ownership, deterring theft, distinguishing commingled cattle, and fulfilling requirements for interstate and international transportation. In a survey of 94 cow–calf producers in western Canada, it was estimated that 54% of calves represented were branded (Moggy et al., 2017). In this same study, only 4% of respondents reported using freeze branding, compared to 52% who reported using hot iron brands; or, looked at another way, 92% of producers who reported branding used hot iron brands. However, over 21% of these indicated they only branded a portion of their herd.

Branding causes significant pain and requires extended healing time. The previous Review of Scientific Research on Priority Issues (Schwartzkopf-Genswein et al., 2012) concluded that both freeze branding and hot iron branding cause pain and distress in cattle. More recent work has highlighted the persistent pain associated with branding. For example, Tucker et al. (2014a) found that hot iron branding in 4-month-old cattle led to sensitivity to pressure that peaked 7 days after the procedure and persisted for at least 71 days. Healing was also slow, with only 67% of brands fully healing by day 71 and the first complete healing observed 8 weeks post-branding, highlighting the potential for prolonged discomfort. Building on these findings, Keogh et al. (2024) found in 2-month-old beef calves that larger hot iron brand sizes increased pain-related behaviours, such as tail flicking and restlessness. Behavioural responses varied over time, with standing behaviour spiking 6 hours after branding and peaking at 24 hours. When branding was combined with castration, pain-related behaviours intensified, demonstrating the additive effects of multiple painful procedures performed at the same time. In Nellore calves, de Oliveira et al. (2024) found that hot iron branding increased skin temperatures at the branding site for up to 2 days. Additionally, electronic ear tags were found to be faster and more accurate for cattle identification than hot iron branding, though tag retention has been noted as an issue. Despite the

evidence of pain associated with branding, the use of pain mitigation remains uncommon. A Canadian survey revealed that while 85% of cow–calf operators agreed that branding was painful if pain management was not used, only 4% implemented pain relief practices (Moggy et al., 2017).

### ***2.7.1 Pain Mitigation for Branding***

The studies summarized below collectively highlight the ongoing challenges of effectively mitigating the pain caused by hot iron branding. While interventions like meloxicam show some efficacy, they offer only limited relief and fail to address the long-term pain and delayed healing associated with the procedure. Developing comprehensive, multimodal strategies or alternative procedures for animal identification remain essential for improving animal welfare.

#### *2.7.1.1 Non-Steroidal Anti-Inflammatory Drugs Alone*

Tucker et al. (2014a) investigated the use of flunixin meglumine in 4-month-old calves, finding that while the drug improved weight gain shortly after branding and influenced lying behaviour on specific days, it did not alleviate brand-specific pain sensitivity, surface temperature, or healing. Further, pain persisted for at least 71 days post-branding, and a single injection of flunixin provided no measurable relief. Similarly, Martin et al. (2022b) evaluated the effects of oral meloxicam in branded yearling cattle. Meloxicam reduced prostaglandin E2 metabolites at 6, 24, and 48 hours post-branding and minimized infrared thermography differences, an indicator of inflammation and burn severity, between branded and unbranded sites. Treated calves also exhibited fewer lying bouts in the first 12 hours, which may indicate reduced restlessness and immediate discomfort. However, meloxicam did not effectively reduce pain-associated biomarkers or behavioural responses. Finally, Keogh et al. (2024) investigated the effects of oral meloxicam in 2-month-old beef calves of both sexes undergoing hot iron branding. Meloxicam reduced the proportion of branded heifers displaying pain-related behaviours compared to untreated calves; however, its analgesic effect of meloxicam was less evident in calves that were both branded and castrated.

#### *2.7.1.2 Combination of Pain Control Methods*

Hernandez et al. (2022) examined interventions to manage pain in 92 Nellore heifer calves subjected to hot iron branding on the cheek, a practice banned in many regions worldwide. The study compared no pain relief, subcutaneous local anesthesia administered at the branding site, systemic meloxicam, and a combination of both local anesthesia and systemic analgesia. Although untreated calves exhibited more tension in masticatory muscles 5 days post-branding, no significant differences in behaviour, speed of exit from the squeeze chute, or weight gain were observed across treatments over 60 days. The limited detected effect of these pain management protocols may reflect confounding factors, such as stress and fear during handling or other factors related to study design, underscoring the complexity of addressing welfare concerns, particularly for the facial location of branding in this study.

### 2.7.1.3 *Alternative Methods of Pain Control*

Exploring non-pharmaceutical methods, Tucker et al. (2014b) explored the potential of a cooling gel with tea tree oil to mitigate branding pain and improve skin healing. Although the gel lowered surface temperatures immediately after application, it did not reduce pain sensitivity or accelerate healing. Brands remained painful throughout the 70-day study, with over half of wounds still unhealed by the end. In one of the groups, where gel was applied twice, delayed healing was found compared to single applications or controls, suggesting potential negative effects.

### 2.7.2 *Future Research*

Future research should focus on alternative methods to branding, such as electronic identification or biometrics, to evaluate their efficacy and welfare impacts. Current pain mitigation strategies, including NSAIDs and local anesthetics, provide only limited relief, underscoring the need for more effective multimodal approaches that address both acute and prolonged pain. Additionally, little is known about how specific branding methods interact with factors such as the animal's age, the location on the body where the procedure is performed, and the effectiveness of various pain mitigation strategies, underscoring the need for further research. Furthermore, research should consider the method and technique of branding, as improper application or the use of substandard tools may contribute significantly to increased pain, swelling, and the risk of secondary infections.

## 2.8 Painful Health Conditions

### Conclusions:

- 1. BRD elicits a clear sickness response, including fever, reduced activity, altered lying behaviour, and decreased feed intake. Evidence of hyperalgesia and increased pain scores suggests that pain is likely a component of the condition.**
- 2. Lameness leads to altered mobility, reduced activity, and production losses, highlighting the pain associated with this condition.**
- 3. The use of NSAIDs has shown potential in alleviating pain and clinical symptoms in both BRD and lameness, but further research is needed to better understand their efficacy and optimize treatment protocols.**

In addition to the painful procedures and conditions discussed earlier, certain health issues can also cause significant pain in beef cattle. Two primary examples are lameness and BRD.

### 2.8.1 *Bovine Respiratory Disease*

BRD is the most prevalent illness affecting beef cattle, yet the extent of pain associated with this condition remains unclear. Evidence from existing literature suggests that cattle alter their behaviour during episodes of respiratory disease. For instance, a systematic review in feedlot

cattle (Wolfger et al., 2015) found that cattle with BRD exhibit significant behavioural changes, including reduced activity, decreased feeding time and intake, increased lying time, and altered movement patterns, which often precede visible clinical signs of the disease. Further, in beef heifers, Toaff-Rosenstein and Tucker (2018) found that fever occurred 2 days prior to and on the day of BRD diagnosis, although feeding time was only reduced on the day of diagnosis. In this study, it was also found that BRD did not affect brush use, though behaviour was influenced by acclimation to a novel grooming device. In young beef bulls with BRD, Marchesini et al. (2018) reported reduced daily activity and rumination several days before clinical signs became evident. Pillen et al. (2016) also observed that feedlot beef calves experienced declines in activity levels up to 6 days prior to BRD detection, with the most significant reductions occurring the day before diagnosis. Toaff-Rosenstein et al. (2016) described a clear sickness response in BRD-induced steers, including fever, reduced dry matter intake, lower average daily gain, increased total lying time, longer lying bouts, reduced grooming, and hyperalgesia, as indicated by lower mechanical nociceptive thresholds. Further supporting the association between BRD and pain, Martin et al. (2022c) demonstrated that Holstein steers with experimentally induced BRD exhibited reduced activity, decreased force on the right front limb, and increased visual analog scale pain scores. These findings collectively highlight the complex sickness response associated with BRD and suggest that pain is a likely component, though further research is needed to fully understand its impact and implications for welfare and management practices.

#### *2.8.1.1 Non-Steroidal Anti-Inflammatory Drugs Use for Bovine Respiratory Disease*

Several studies have explored the use of NSAIDs as an ancillary treatment for BRD in combination with an antibiotic in both beef and dairy cattle.

**Beef cattle.** Several studies have evaluated the use of NSAIDs as ancillary treatments for BRD in beef cattle. Bednarek et al. (2003) demonstrated that calves treated with meloxicam in combination with oxytetracycline showed faster clinical improvement and more rapid normalization of body temperature compared to oxytetracycline alone. Lockwood et al. (2003) assessed flunixin, ketoprofen, and carprofen in combination with ceftiofur for treating BRD in 66 beef cattle. The NSAID-treated groups experienced faster reductions in fever, with flunixin and ketoprofen acting most rapidly, and flunixin significantly reducing lung consolidation compared to ceftiofur alone. In 280 cattle of various breeds with BRD, De Koster et al. (2022) compared tulathromycin alone to tulathromycin combined with ketoprofen. While both treatments had high success rates and low relapse rates, the tulathromycin-ketoprofen combination provided better temperature control within the first 24 hours and faster improvement in respiration and depression scores. In 264 fattening bulls with BRD, Masebo et al. (2024) compared individual antimicrobial treatment, metaphylactic tulathromycin, and tulathromycin combined with a second antimicrobial, with 128 bulls also receiving NSAIDs in addition to these treatments. Bulls treated with NSAIDs showed higher white blood cell counts, neutrophil counts, and neutrophil-to-lymphocyte ratios compared to those not administered NSAIDs, and fewer cattle with lung lesions at slaughter. It is important to note that not all studies have shown a positive effect. For example, in an experimental BRD model, Toaff-Rosenstein et al. (2016) found that meloxicam administered alongside an antibiotic had limited impact, with no significant effects observed apart from an interaction with lying time. The authors attributed the lack of differences with NSAID therapy to study design limitations, namely the small sample size likely causing the study to be too underpowered to detect a difference.

**Dairy cattle.** In young dairy calves, the efficacy of NSAIDs as supplemental treatments for BRD has been explored in multiple studies. Guzel et al. (2010) found that Holstein calves with BRD treated with either diclofenac sodium or flunixin meglumine, in addition to tulathromycin, showed improvement in clinical signs, such as pyrexia and respiratory rate, within 48 hours compared to antibiotic treatment alone, with diclofenac achieving the greatest reduction in pyrexia. In 6- to 7-month-old Holstein steers with experimentally induced BRD, Martin et al. (2022c) demonstrated that administration of transdermal flunixin led to increased force applied to the right front limb by affected calves and improved activity levels compared to untreated BRD calves. Achard et al. (2018) evaluated the efficacy of combining florfenicol with either meloxicam or flunixin in 40-day-old dairy calves with experimentally induced BRD. Both combinations significantly reduced rectal temperature and clinical scores compared to saline-treated calves, with cure rates of 100% for the florfenicol-meloxicam group and 96.6% for the florfenicol-flunixin group, whereas the saline group had a cure rate of only 29.6%. It was also noted that calves treated with florfenicol and meloxicam were cured more quickly and experienced fewer relapses than those treated with florfenicol and flunixin. Similar to above, not all the studies found a positive effect. Ferree et al. (2023) did not detect differences in growth, behavioural attitude, or clinical and lung ultrasound scores when a single dose of oral meloxicam was administered alongside tulathromycin compared to tulathromycin alone at the onset of respiratory disease in preweaned dairy calves, although again, this may be related to study design rather than a true lack of difference.

In summary, NSAIDs have shown potential as ancillary treatments for BRD in both beef and dairy cattle, offering benefits such as faster clinical recovery and reduced fever when combined with antibiotics. However, further research is needed to better understand their likely efficacy and to optimize treatment protocols for different contexts, including addressing pain associated with BRD.

### **2.8.2 Lameness**

Lameness is a common condition in the beef industry (Erikson et al., 2024). Erickson (2023) conducted a retrospective analysis of 1,772,565 cattle in 28 western Canadian feedlots (2014–2018) and found that lameness represented 28.5% of all treatments, with foot rot, digital dermatitis, and toe-tip necrosis syndrome comprising 71.8% of lameness cases. Marti et al. (2021), who evaluated records from 9,719 calves from 2 Alberta feedlots, also found a similar proportion of treatments being attributed to lameness (36.3% of all treatments), with the most common diagnoses being foot rot, digital dermatitis, upper-limb lameness, joint infections, injuries, and toe-tip necrosis syndrome. Davis-Unger et al. (2019) highlighted similar trends, noting that lameness was influenced by cattle type and sex, with foot rot being most prevalent (74.5% of lameness cases) and joint infections accounting for nearly half of lameness-associated deaths. Their findings also revealed a significant association between BRD and subsequent lameness diagnoses, underscoring the importance of early intervention and targeted resource allocation for at-risk groups.

As reviewed by Coetzee et al. (2017), lameness is a painful condition in which cattle alter their mobility and posture, exhibiting behaviours such as head bobbing, arching the spine, and changing stride length due to pain experienced during walking and standing. In beef cattle, several studies have explored the impact of digital dermatitis. Thomas et al. (2022a) found that

digital dermatitis in feedlot cattle is strongly associated with pain-related gait abnormalities, including reluctance to bear weight and asymmetric gait, particularly in cattle with active lesions, although a substantial proportion of cattle with digital dermatitis did not show visible pain-related behaviours. In beef heifers, Thomas et al. (2021) investigated the behavioural changes associated with digital dermatitis and found heifers with digital dermatitis spent less time ruminating and more time inactive compared to unaffected heifers, with those exhibiting active lesions showing the most pronounced changes in behaviour. Further, Thomas et al. (2022b) provided objective evidence that digital dermatitis causes significant pain, as cattle with affected feet, especially those with active lesions, showed reduced mechanical nociceptive thresholds, indicating heightened pain sensitivity. Pain was most severe in lame cattle, who also exhibited higher foot temperatures linked to inflammation. Beyond the behavioural changes, there are also production consequences, with Kulow et al. (2017) finding that indoor-housed feedlot cattle with digital dermatitis had a lower average daily gain, final body weight, and hot carcass weight. Although most of the research has focused on lesions in the foot, pain occurs regardless of cause of lameness, whether septic arthritis, laminitis, musculoskeletal injuries, or diseases of the feet.

#### *2.8.2.1 Non-Steroidal Anti-Inflammatory Drugs Use for Lameness*

Several studies have investigated the use of NSAIDs for lameness in cattle, with most focusing on dairy cows (as reviewed by Roche et al., 2024). Field studies evaluating ketoprofen have demonstrated several benefits, including improved weight distribution across all four limbs and more symmetrical steps in cows with abnormal gait (Flower et al., 2008), higher recovery rates from lameness 35 days post-treatment when used alongside therapeutic trimming (Thomas et al., 2015), reduced risk of culling when administered at the onset of lameness (Wilson et al., 2022), and a lower likelihood of persistent lameness with increased milk yield during treatment for digital dermatitis (Kasiora et al., 2022). Beyond ketoprofen, Warner et al. (2021) found that oral meloxicam or intravenous flunixin administered at the onset of induced lameness in dairy cattle led to reduced lameness severity, as assessed by visual lameness scoring and lower cortisol levels compared to the placebo group. Mason et al. (2022) conducted a systematic review assessing NSAID use during the treatment of claw-horn lesions in dairy cows. Although NSAIDs showed a tendency to reduce lameness risk and increase nociceptive thresholds in some comparisons, significant differences were not consistently observed across outcomes, and substantial heterogeneity was reported. Similarly, Sadiq et al. (2024) conducted a systematic review of 10 studies evaluating claw-horn lesion treatment, finding that cows treated with a hoof block or a combination of a block and NSAID alongside claw trimming had higher rates of complete lameness resolution and faster recovery compared to claw trimming alone. However, this review also noted considerable heterogeneity across studies.

Very few studies have evaluated the use of pain control in lame beef cattle. In beef calves with experimentally induced lameness, Coetzee et al. (2014) found that calves treated with meloxicam had increased activity and improved weight distribution compared to placebo, while the combination of meloxicam and gabapentin showed additional benefits in pressure and force metrics. Nagel et al. (2016) evaluated the use of oral meloxicam in 53 beef cattle with musculoskeletal lameness and found that when lameness was reassessed 3 days after treatment, 92.8% of meloxicam-treated cattle showed reduced lameness scores compared to only 12% of control animals.

### **2.8.3 *Future Research***

Future research should focus on better understanding pain mechanisms in lameness and BRD to improve treatment strategies. While NSAIDs show promise, more studies are needed, especially in beef cattle, to evaluate their long-term effects on welfare and productivity. Early pain detection methods, such as behavioural and physiological indicators, and multimodal treatments combining NSAIDs with other approaches, warrant further exploration.

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### 3 Health Conditions at Different Stages of Production

#### 3.1 Health Management in the Cow–Calf Sector

##### Conclusions:

1. **Respiratory disease, diarrhea, and umbilical infections remain the leading causes of calf morbidity in Canadian cow–calf herds, although overall antimicrobial use remains relatively low.**
2. **Earlier calving seasons (December to March) and longer calving seasons are consistently associated with higher risks of treatment for calf disease, mortality, and outbreaks of diarrhea and respiratory disease.**
3. **Management practices such as providing timely colostrum, intervening after difficult calvings, and minimizing herd mixing are key strategies associated with improved calf health outcomes.**
4. **Vaccination of dams against diarrhea-related pathogens, particularly *Escherichia coli*, is associated with reduced disease risk, while evidence for respiratory disease vaccination strategies is more mixed.**
5. **Although several management strategies show promise, the certainty of available evidence is generally low, highlighting the need for further high-quality cohort studies and randomized controlled trials.**

Maintaining calf health is a critical component of cow–calf production systems, with early-life disease having lasting impacts on animal welfare, productivity, and antimicrobial use (AMU). Diarrhea and BRD are the most common and economically important conditions affecting preweaned beef calves. Effective health management focuses on early disease identification, implementation of preventive strategies, and targeted treatment where necessary. Crucially, antimicrobial stewardship is an essential consideration, emphasizing judicious use of antimicrobials to preserve their effectiveness while ensuring animal health and welfare are not compromised. This section summarizes recent research on the prevalence and management of these key health conditions in cow–calf herds, with a particular emphasis on evidence generated since 2012.

##### **3.1.1 Prevalence of Disease**

Recent research provides important insights into the prevalence of key health challenges in Canadian beef cow–calf herds. Wilhelm et al. (2023) conducted a scoping review of AMU and antimicrobial resistance (AMR) in beef cow–calf herds in Canada and the United States (US). Across 23 included studies, most reported low frequencies of AMU, with fewer than 10% of calves treated for major diseases such as BRD, diarrhea, and umbilical infections. Two Canadian studies provided detailed within-herd estimates of AMU. In a 2013–2014 survey, 71% of herds reported treating fewer than 5% of cows with antimicrobials and 46% of herds reported treating fewer than 5% of calves (Waldner et al., 2019). In a 2019–2020 survey, 91% of herds treated

fewer than 5% of cows and 88% treated fewer than 5% of calves (Fossen et al., 2023). Pinkeye and lameness were the most common reasons for AMU in cows, whereas BRD, diarrhea, and umbilical infections were most common reasons for AMU among calves. The review by Wilhelm et al. (2023) also identified herd size and livestock class as significant predictors of AMU, with larger herds and calves having higher odds of treatment. Operations that disinfected water troughs or quarantined introduced animals had lower odds of AMU, while herds retaining ownership of calves post-weaning had higher odds of using Category I antimicrobials as classified by Health Canada.

Waldner et al. (2022) provided specific estimates of disease treatment patterns in western Canadian cow–calf herds. Among 89 surveyed herds, BRD was the leading cause of treatment, affecting 5% of calves, followed by calf diarrhea (3%) and umbilical infections (2%). Treatments for BRD were reported in 51% of herds before calves reached 2 months of age, whereas diarrhea treatments peaked between 6 days and 1 month of age. Umbilical infections were most common in calves shortly after birth. Approximately 20% of herds reported routine prophylactic antimicrobial administration at birth, a practice that contrasts with veterinary opinion in western Canada, where such strategies were rated among the least useful for disease control (Sanguinetti et al., 2024).

Building on this, Waldner et al. (2024) analyzed herd-level calving and weaning data from 171 herds across Canada, collected between 2018 and 2022. Across 565 calving record questionnaires representing 110,658 calving female records, the mean percentage of calves treated with antimicrobials between 24 hours and 30 days of age was 3.9% for diarrhea, 3.1% for BRD, and 2.2% for umbilical or joint infections. During the same period, the mean proportion of calves dying between 24 hours and 30 days was 1%, with diarrhea accounting for 50% of calf deaths, BRD for 40%, and umbilical or joint infections for 10%.

Sanguinetti et al. (2025c) surveyed 125 Canadian cow–calf producers participating in the Canadian Cow-Calf Surveillance Network, the same population used by Waldner et al. (2024), to benchmark outbreaks of diarrhea, BRD, and calf mortality. Outbreaks were defined as a situation where at least 5% of a group of calves were treated for the same disease or a similar set of clinical signs during a single season, while mortality outbreaks specifically referred to at least 5% of calves dying during a single season. Between 2019 and 2021, more than 40% of herds experienced at least 1 outbreak of diarrhea, BRD, or mortality. Individually, 26% of herds reported a BRD outbreak, 24% reported a diarrhea outbreak, and 8% reported a mortality outbreak. Co-occurrence of disease was common, with 80% of herds reporting mortality outbreaks also experiencing diarrhea or BRD outbreaks and 40% of herds had outbreaks of both diarrhea and BRD over 3 calving seasons.

Finally, Fossen et al. (2025) evaluated calf treatment records from 56 herds and fecal samples from 31 herds to assess AMU and AMR patterns. Although most herds reported some AMU, the median cumulative incidence of any AMU was 10%, with notable variation between herds. A total of 30% of herds treated more than 25% of calves, and 13% treated more than 50%. Among the 2,045 calf treatments recorded, BRD accounted for 30% of treatments, diarrhea for 15%, and umbilical infections for 12%. Herds selling seedstock, maintaining larger herd sizes, and assisting a greater proportion of calvings had higher odds of AMU. Resistance levels were generally low, with no consistent association between AMU and resistance in *Escherichia coli* or

*Enterococcus* spp., although increased macrolide use was associated with higher macrolide resistance in *Enterococcus* spp. in fecal samples collected in the fall.

Together, these studies demonstrate that BRD, diarrhea, and umbilical infections remain leading causes of calf morbidity in Canadian cow–calf herds. While the overall frequency of AMU is relatively low, herd-level management practices and structural factors such as herd size and production goals continue to influence both disease occurrence and AMU patterns.

### **3.1.2 Managing Disease in Cow–Calf Herds**

Recent studies have highlighted key management practices associated with reducing disease and improving calf survival in cow–calf operations. Sanguinetti et al. (2024) conducted a modified Delphi study with 12 veterinarians familiar with western Canadian cow–calf management systems to identify the most useful disease prevention practices for reducing preweaning calf mortality. Experts scored each practice based on its effectiveness, ease of implementation, and economic feasibility across 2 questionnaire rounds, with feedback provided between rounds. Administering clostridial vaccines to calves and feeding colostrum or colostrum replacer using a nipple bottle or oesophageal tube when a calf had not nursed were the only practices considered useful “always for all herds.” Most other practices, including those related to breeding and calving management, nutrition and pasture management, biosecurity, and vaccination protocols, were rated as having intermediate usefulness. Practices considered least useful, described as “somewhat for some herds,” included the metaphylactic and prophylactic use of antimicrobials, vaccination of calves against neonatal calf diarrhea pathogens during the first week of life, and vaccination of dams against BRD pathogens at spring turnout.

Building on this work, Sanguinetti et al. (2025a) conducted a systematic review to evaluate the effectiveness of herd management practices in reducing preweaning calf mortality. Eleven studies were included, 10 of which were observational cross-sectional studies and 1 a randomized controlled trial. Eight studies originated from North America, with the remainder conducted in Estonia, Japan, and Brazil. Practices most consistently associated with reduced mortality included intervening with colostrum when calves had not nursed or required assistance at calving and managing the timing and length of the calving season. In 3 out of 4 assessments, the criteria used to guide colostrum intervention were significantly associated with calf mortality risk. Specifically, herds that intervened based on udder fullness or calving assistance had 0.7% to 0.8% lower mortality (Murray et al., 2016). In contrast, when producers reported intervening when colostrum had an abnormal appearance, this was associated with a 1.9% increase in mortality (Murray et al., 2016). Similarly, 3 out of 4 assessments, all conducted in western Canada or the northwestern US, reported that early-calving herds, calving in January or February, had a higher incidence of calf mortality compared to later-calving herds (Clement et al., 1993; Murray et al., 2016; Pearson et al., 2019a). Two assessments also found that longer calving seasons increased mortality risk (Dutil et al., 1999), with a 1.4% rise in risk for each additional week the calving season was extended (Murray et al., 2016). Nutritional interventions were less consistently studied, but 1 study in western Canada reported that calves not receiving vitamin E and selenium supplementation at birth had over 10 times greater odds of mortality compared to supplemented calves (Waldner & Rosengren, 2009). Overall, the certainty of the available evidence was rated as low, underscoring the need for further well-designed cohort studies and randomized controlled trials to better inform herd health recommendations.

These findings provide a foundation for understanding how broader herd-level strategies, particularly around calving and early calf management, can reduce disease burden and improve preweaning survival. The following sections will examine specific evidence and recommendations for managing diarrhea and BRD in cow–calf herds.

### 3.1.2.1 Neonatal Calf Diarrhea

Sanguinetti et al. (2025b) conducted a systematic review evaluating management practices for the prevention of neonatal calf diarrhea (NCD) and BRD in preweaned beef calves. Seventeen studies met the inclusion criteria, including 6 randomized or controlled trials and 11 observational studies, all reporting on naturally occurring disease. Studies were conducted in Canada (7), the US (5), France (2), Argentina (1), Belgium (1), and Italy (1). Most management practices demonstrated some evidence of effectiveness, although the overall certainty of the findings was low to very low.

For NCD prevention, 5 studies reported NCD-specific outcomes, while another 5 studies reported outcomes for both NCD and BRD combined or separately. Several key management strategies were associated with significant reductions in NCD risk. Two out of 3 assessments, again all from western Canada or the northwestern US, found that calves from early-calving herds had greater odds of treatment and higher disease risk compared to later-calving herds (Waldner et al., 2013; Clement et al., 1993). One out of 3 assessments found that a longer calving season was associated with a higher risk of NCD outbreaks in large herds, defined as those with more than 40 females (Dutil et al., 1999). Breeding and calving season management practices also showed mixed findings: for example, breeding heifers earlier than cows was associated with either a higher (Clement et al., 1993) or lower (Waldner et al., 2022) risk of NCD depending on the study, and frequent night-checking during calving was linked to an increased risk of diarrhea in 1 study (Waldner et al., 2022). In general, practices associated with more intensive calving management were often associated with increased risk of NCD, which may be associated with higher disease detection and treatment rather than differences in disease risk or may be related to more intensive management being implemented in herds experiencing greater disease challenges.

Findings for nutritional management of dams were similarly inconsistent. One study, conducted in Belgium, found that selenium supplementation with 0.5 ppm of organic selenium derived from *Saccharomyces cerevisiae* was associated with lower NCD incidence in calves compared to 0.5 ppm or 0.1 ppm of selenium provided as sodium selenite (Guyot et al., 2007). However, another study, this one conducted in Saskatchewan, Canada, found no significant difference in NCD incidence when selenium was provided through pre-calving injections (Cohen et al., 1991). Feeding corn pre- or post-calving to dams was also not associated with NCD outcomes (Clement et al., 1993). For calf-level nutritional interventions, 1 study reported that calves injected with vitamins D and A within 2 days of birth had a higher risk of NCD than untreated calves (Waldner et al., 2022).

Evidence for biosecurity practices was limited. Only 1 out of 5 assessments reported a significant association, with sorting cow–calf pairs from the calving area into nursery pastures reducing the risk of NCD within the first 5 days of life but increasing risk after 6 days (Waldner et al., 2022).

Other biosecurity measures, such as commingling cows and heifers or the timing of movement out of calving areas, were not associated with changes in NCD risk (Waldner et al., 2022).

Vaccination practices were among the most consistently effective strategies for reducing NCD risk. Eight of 10 assessments found that vaccinating dams against NCD-related pathogens lowered disease incidence. In particular, 7 of 8 assessments showed that vaccines containing *Escherichia coli* antigens reduced NCD morbidity or mortality (Cornaglia et al., 1992; Myers et al., 1980). Protection was strongest when both heifers and cows received 2 doses, and calves born to vaccinated cows had lower NCD risk than those born to vaccinated heifers, suggesting a potential influence of parity (Cornaglia et al., 1992). Vaccinating dams against clostridial pathogens in the spring prior to calving was also associated with reduced NCD risk in 1 assessment (Waldner et al., 2013). However, 1 observational study reported that herds vaccinating calves directly against NCD pathogens had higher odds of detecting disease and increased mortality (Waldner et al., 2022), likely reflecting reverse causation.

The review by Sanguinetti et al. (2025b) concluded that although several management practices show promise for NCD prevention, the low certainty of evidence, particularly due to suspected reverse causation in cross-sectional studies, underscores the need for more high-quality cohort studies and randomized controlled trials to better inform herd health recommendations.

Additional evidence of management-related risk factors for NCD was provided by Sanguinetti (2025c), who surveyed Canadian beef cow–calf producers to identify practices associated with NCD outbreaks ( $\geq 5\%$  treated for NCD). Herds that brought dams into barns to calve only during bad weather had higher odds of experiencing NCD outbreaks compared to herds using more consistent outdoor or barn-based calving systems. Calving heifers and cows together in the same pasture, keeping all heifers in the calving area until the end of the calving season, and assisting more than 20% of calvings with colostrum consumption were also associated with an increased risk of NCD outbreaks. Some biosecurity practices were linked to higher risk as well, with herds that vaccinated cattle before introducing them to the herd reporting more frequent NCD outbreaks. Waldner et al. (2024), using data from 172 cow–calf herds in Canada, also identified associations between NCD and management practices. Specifically, it was reported that herds beginning their calving season between December and March had higher odds of NCD compared to later-calving herds (April to September). Regional differences were also noted, with eastern Canadian herds experiencing higher levels of NCD than western herds.

Neonatal calf diarrhea remains a major health concern in cow–calf operations, particularly in herds with early or prolonged calving seasons and more intensive calving area management. Vaccination of dams, especially against *Escherichia coli*-related pathogens, was found to be consistently associated with reduced NCD risk, while the benefits of nutritional supplementation and biosecurity practices were less clear. Observational data from Canadian herds also highlighted that herds calving earlier in the year and those located in eastern Canada faced higher levels of disease. Although several management strategies show promise, the overall certainty of the evidence remains low, largely because studies are observational, have a high risk of bias, or are underpowered to detect statistically significant differences. This underscores the need for additional high-quality research to strengthen prevention recommendations.

### 3.1.2.2 *Bovine Respiratory Disease*

Sanguinetti et al. (2025b) conducted a systematic review evaluating the impact of herd management practices on BRD in preweaned beef calves. Seven studies reported BRD-specific outcomes, while 5 studies reported outcomes for both NCD and BRD either separately or combined. Studies were conducted in North America (12), Europe (4), or elsewhere (1).

Among colostrum management strategies, only 1 out of 6 assessments found a significant association. In this cross-sectional study, herds that provided colostrum using a tube or bottle had a higher reported risk of BRD (Woolums et al., 2013), likely reflecting reverse causation, as producers may have intervened more often in calves already at greater risk of disease. In contrast, interventions based on udder fullness (3 assessments), colostrum source (e.g., maternal, frozen, or supplement product; 1 assessment), or method of feeding colostrum (1 assessment) did not demonstrate any consistent associations with BRD risk.

Management of the calving season showed more consistency. Two out of 5 assessments found that early-calving herds (winter or early spring) experienced higher odds of BRD treatment or disease incidence compared to later-calving herds (Waldner et al., 2013; Woolums et al., 2013). These studies were conducted in Canada (Waldner et al., 2013) and throughout the US (Woolums et al., 2013). Three out of 5 assessments found that longer calving seasons were associated with higher BRD incidence (Dutil et al., 1999; Assié et al., 2009; Woolums et al., 2013). In these studies, longer seasons were typically defined as lasting  $\geq 3$  months or averaging 5.75 months in herds with BRD compared to 4.04 months in herds without BRD. These associations were consistent, despite the overall low certainty of evidence. Use of intensive calving areas was associated with increased BRD risk in 2 out of 4 assessments (Woolums et al., 2013; Waldner et al., 2022). Similarly, 1 study reported that herds using intensive grazing had 3 times higher odds of BRD treatment than those that did not (Woolums et al., 2018).

Nutritional management of calves produced mixed results. Two out of 5 assessments suggested that feeding concentrate, maize, or creep feed influenced BRD incidence (Assié et al., 2009; Woolums et al., 2013); however, no clear protective or harmful effect was established. Injecting vitamins near birth was also not found to have a statistically significant association with BRD outcomes in 2 observational studies conducted in western Canada (Murray C.F. et al., 2016; Waldner et al., 2022).

Biosecurity practices showed more consistent associations with BRD outcomes. Six out of 12 assessments found that external biosecurity practices, defined as practices aimed at limiting the introduction of pathogens from outside the herd, impacted BRD risk. Five assessments reporting that introducing new cattle increased the risk of disease (Hanzlicek et al., 2013; Woolums et al., 2013; Waldner et al., 2022). In addition, 1 study found that herds that had 1–2 or more than 30 visitors per month had higher BRD rates compared to herds with 3–30 visitors per month (Hanzlicek et al., 2013). Internal biosecurity practices, such as gathering cow–calf pairs before pasture turnout or using the same area for overwintering and calving (25), were associated with higher BRD risk in 6 out of 9 assessments. However, findings on the use of nursery pastures were inconsistent. One assessment reported a reduced risk of BRD when cow–calf pairs were sorted into nursery pastures (Waldner et al., 2022), while 2 others found increased odds of BRD detection or treatment in herds using this practice (Woolums et al. 2013, 2018).

Vaccination practices yielded mixed results. Two out of 4 assessments found associations between dam vaccination against BRD pathogens and BRD outcomes, but the direction of the associations was contradictory (i.e., one showed reduced risk [Waldner et al., 2022] and the other showed a higher risk [Woolums et al., 2013]), and the certainty of evidence was low. Calf vaccination was evaluated in 11 assessments, with only 1 study showing a beneficial effect in reducing BRD treatment and mortality after 2 doses of an inactivated vaccine targeting BRSV, PIV3, and *Mannheimia haemolytica* (Makoschey et al., 2008). In contrast, 4 assessments found that herds reporting calf vaccination had higher rates of BRD detection or treatment (Assié et al., 2009; Hanzlicek et al., 2013; Woolums et al., 2013; Waldner et al., 2022); however, all were based on cross-sectional studies, so reverse causation is likely.

A scoping review by Chen et al. (2022) summarized 265 studies published between 1990 and 2021 on BRD prevention in cow–calf operations. Herd and farm management factors, such as transport practices, environmental conditions, herd mixing, herd size, and source of animals, were found to be associated with the incidence of BRD in 91% of observational studies. Key protective strategies included minimizing herd mixing, controlling herd density, and sourcing animals carefully. Metaphylactic antimicrobial use was evaluated in 65 studies, with 78% of field trials and 94% of controlled studies reporting reductions in BRD incidence, particularly with tulathromycin, oxytetracycline, gamithromycin, and tilmicosin. Vaccination was evaluated in 64 studies, with 74% of field trials and 69% of controlled trials showing a protective effect, especially for vaccines targeting viral agents, such as BVDV, BRSV, and BHV-1. Vaccines targeting bacterial pathogens, such as *Mannheimia haemolytica* or *Pasteurella multocida*, were less consistently effective. Diet and nutritional interventions showed less consistent effects, with only 30% of studies reporting significant reductions in BRD risk. Animal-level factors, such as younger age, lower body weight, male sex, and Hereford breed, were associated with increased BRD risk, and several genetic traits were identified as linked to disease susceptibility.

Further evidence from observational data in Canadian cow–calf herds support the influence of management practices on BRD outcomes. Sanguinetti (2025c) surveyed Canadian producers and found that herds leasing bulls for at least 1 season had 3 times higher odds of BRD outbreaks compared to herds not using this practice. Similarly, Wennekamp et al. (2021) reported that BRD outbreaks were associated with purchasing more than 10 bulls, purchasing cows, failing to vaccinate newly introduced animals, and using community pastures. Waldner et al. (2024), using data from 172 cow–calf herds, also found that herds beginning their calving season between December and March had higher odds of BRD and BRD-related mortality compared to later-calving herds (April to September).

With respect to vaccination, a randomized controlled trial by Erickson et al. (2024) provides additional evidence supporting the potential value of calf vaccination under natural exposure conditions. In a herd with previously diagnosed bovine coronavirus BRD, calves that received an intranasal dose of a commercial bovine coronavirus vaccine at 2 months of age had significantly lower odds of BRD treatment post-weaning compared to unvaccinated controls. While results are specific to bovine coronavirus and in a single herd context, the study highlights how targeted vaccination strategies may be effective in operations with known pathogen risks and underscores the importance of high-quality trials to inform BRD prevention in cow–calf systems.

In summary, BRD remains a major cause of morbidity and mortality in cow–calf herds, with risk influenced by calving season timing, calving area management, and biosecurity practices. While Sanguinetti et al. (2025b) found mixed effectiveness of vaccination strategies in cow–calf herds and low certainty of evidence when focusing only on natural disease challenge, a broader review by Chen et al. (2022) that included challenge studies reported more consistent protective effects of vaccination, particularly against common viral pathogens. Management practices such as minimizing herd mixing, controlling herd density, and careful sourcing of cattle were consistently associated with reduced BRD incidence. Recent Canadian data further confirmed that earlier calving seasons and leasing bulls were associated with higher odds of BRD outbreaks. Although several management practices show potential for reducing BRD risk, additional high-quality research is needed to refine prevention strategies in cow–calf operations.

### **3.2 Health Management in the Feedlot Sector**

#### **Conclusions:**

##### **Bovine Respiratory Disease**

- 1. BRD remains the most common reason for antimicrobial use, morbidity, and mortality in North American feedlot cattle, especially within the first 45 days on feed.**
- 2. BRD risk is additive and influenced by lighter arrival weights, recent weaning, commingling, long-distance transport, adverse weather, and pen-level management factors.**
- 3. Metaphylactic antimicrobials, particularly macrolides, consistently reduce BRD morbidity and mortality, but concerns around antimicrobial stewardship are driving interest in alternatives.**
- 4. Evidence supporting vaccination at arrival is mixed; viral vaccines may offer benefit under natural exposure, but bacterial vaccine efficacy is poorly studied and remains inconclusive.**
- 5. Preconditioning reduces BRD risk and improves early behavioural adaptation to the feedlot, though its effects on growth are variable, and adoption remains limited.**
- 6. Novel technologies, such as behaviour tracking, offer promise for earlier and more accurate BRD detection than traditional pen-checking.**

##### **Lameness**

- 1. Lameness is the second most common reason for treatment in feedlot cattle, with foot rot, digital dermatitis, and joint infections as leading causes.**

- 2. Foot rot remains the most prevalent lameness diagnosis. Risk is highest in fall- and winter-placed cattle and appears linked to environmental factors and mechanical damage to the interdigital skin.**
- 3. Digital dermatitis is less common than foot rot but can impair growth and carcass value. Risk is elevated in cattle from confined systems, larger feedlots, and muddy pens, with prevention efforts focused on footbaths and possibly mineral supplementation.**
- 4. Toe tip necrosis syndrome is sporadic but severe, typically emerging early in the feeding period and linked to claw abrasion, compromised hoof integrity, and possibly magnesium deficiency.**
- 5. Joint infections account for a disproportionate number of lameness-related deaths. Risk is elevated in younger, fall-placed calves and heifers compared to yearlings and steers. *Mycoplasmosis* species appear to be the predominant pathogen.**
- 6. The most informative signs for detecting lameness in feedlot cattle include asymmetric gait, reluctance to bear weight, and associated elevated locomotion scores, particularly in cattle with digital dermatitis. Automated behavioural monitoring and wearable sensors show promise for improving early identification and management of lameness in feedlot settings.**

#### **Nutritional Diseases (Ruminal Acidosis and Liver Abscesses)**

- 1. Transitioning to high concentrate finishing diets increases the risk of ruminal acidosis, which facilitates the mucosal injury and bacterial translocation (e.g., *Fusobacterium necrophorum*) that are essential for liver abscess formation.**
- 2. Greater forage inclusion in finishing diets, slower diet adaptation, and longer fiber particle size improve rumen health and reduce acidosis risk but with variable consequences on growth performance and carcass quality.**
- 3. Liver abscesses are common and economically important. Tylosin remains effective at reducing liver abscess prevalence, and evidence suggests that shorter durations of use may be similarly effective, though further research is needed to guide optimal timing and stewardship.**
- 4. Increasing dietary fiber and managing starch content in the diet can reduce liver abscess severity. These strategies may reduce feed efficiency and growth in some contexts, reflecting the trade-off between managing health and welfare challenges and maximizing performance.**

The feedlot phase of beef production presents distinct health challenges compared to the cow-calf sector, largely due to animal sourcing, commingling, nutritional management, and production intensity. BRD remains the leading cause of morbidity and mortality in feedlot cattle, but lameness and nutritional diseases, such as ruminal acidosis and liver abscesses, are also

important animal welfare and economic concerns. Effective feedlot health management emphasizes early disease detection, preventive strategies at arrival and throughout feeding, and minimizing the impact of high-concentrate diets. This section summarizes current evidence on the prevalence, risk factors, prevention, and management of these key conditions in feedlot cattle, focusing on research published since 2012.

### **3.2.1 *Antimicrobial Use***

Antimicrobial use (AMU) practices in North American feedlots have been described in several studies. Brault et al. (2019) evaluated AMU patterns on 36 feedlots in western Canada representing 2.6 million cattle between 2008 and 2012. In-feed AMU was substantially higher (28,690,598 animal daily doses) compared to individually dosed AMU (5,823,060 doses). However, it should be noted that this data is more than 20 years old and may not still be relevant in this quickly moving field (Hannon et al., 2020).

Apley et al. (2023) characterized antimicrobial use patterns in 20 feedyards in the US during 2018 and 2019, encompassing over 1.1 million cattle. Antimicrobial use was reported as milligrams per kilogram of liveweight sold and regimens per animal year. In a subset of 10 feedyards with detailed records, most AMU was associated with liver abscess control (98.4 regimens per 100 head), followed by BRD (37.1 regimens per 100 head) and lameness (0.8 regimens per 100 head). Within BRD-related use, metaphylaxis accounted for the largest proportion of regimens, followed by individual animal treatments and in-feed administration.

### **3.2.2 *Managing Bovine Respiratory Disease in Feedlot Cattle***

#### **3.2.2.1 *Vaccination***

Theurer et al. (2015) conducted a systematic review and meta-analysis evaluating the effectiveness of commercially available viral vaccines targeting bovine herpesvirus-1 (BHV-1), bovine viral diarrhea virus (BVDV), bovine respiratory syncytial virus (BRSV), and parainfluenza type 3 virus (PI3) for mitigating bovine BRD in cattle. Thirty-one studies comprising 88 trials were included, categorized as natural exposure or experimental challenge models, and further divided by viral antigen and vaccine type (modified-live virus or inactivated). In natural exposure trials, vaccination significantly reduced BRD morbidity risk compared to nonvaccinated controls. In experimental challenge trials, vaccination with BHV-1 and modified-live BVDV vaccines reduced morbidity, but no significant benefit was found for modified-live BRSV or PI3 vaccines. Theurer et al. (2015) cautioned that clinical efficacy estimates from experimental models must be interpreted carefully, as they may not fully reflect natural disease exposure.

O'Connor et al. (2019a) also conducted a systematic review and network meta-analysis evaluating the comparative efficacy of vaccines administered at or near arrival in feedlot cattle. Fifty-three studies reporting BRD morbidity within 45 days of arrival were identified through database and conference proceedings searches. Fourteen studies, comprising 17 vaccine protocols, formed the largest connected network and were included in the meta-analysis. The authors concluded that there is little compelling evidence that vaccines administered at or near feedlot arrival reduce the incidence of BRD.

Although both Theurer et al. (2015) and O'Connor et al. (2019a) reviewed BRD vaccine efficacy, differences in eligibility criteria, outcome selection, pooling strategies, and included studies likely explain their differing conclusions. Theurer et al. (2015) included younger calves and dairy cattle, extracted raw rather than adjusted data, combined studies involving concurrent bacterial vaccinations, and included studies with highly variable vaccine effects, all of which may have contributed to more favourable efficacy estimates compared to O'Connor et al. (2019a).

Bacterial BRD vaccines have also been evaluated, although fewer high-quality studies are available. Capik et al. (2021) conducted a systematic review to assess the efficacy of vaccines targeting *Mannheimia haemolytica*, *Pasteurella multocida*, and *Histophilus somni* for reducing BRD-related morbidity, mortality, or lung lesions in cattle raised in the US and Canada. Studies were eligible if they were peer-reviewed, conducted in the US or Canada, published after 1979, included a control group, demonstrated evidence of randomization or blinding, used appropriate statistical methods, and were available in English. Only 5 studies met these criteria. These included investigations of *Histophilus somni* and *Mannheimia haemolytica* vaccines in feeder calves, *Mannheimia haemolytica* vaccines in feeder and Holstein calves, and vaccines targeting *Pasteurella multocida* or *Mannheimia haemolytica* in nursing beef calves. Due to the limited number of comparable studies, no further analysis of bacterial vaccine efficacy was possible.

Overall, the evidence on vaccination for BRD prevention in feedlot cattle remains mixed and highlights important limitations. While one review suggested that viral vaccines, particularly those targeting BHV-1 and BVDV, may reduce BRD morbidity under natural exposure conditions, another concluded that there is insufficient evidence to support that vaccination at feedlot arrival significantly reduces BRD incidence. Evidence supporting the efficacy of bacterial vaccines against *Mannheimia haemolytica*, *Pasteurella multocida*, or *Histophilus somni* also remains sparse, with few high-quality studies available. Together, these findings emphasize the need for more robust, well-designed trials to better inform vaccination strategies for BRD control in feedlot cattle.

### 3.2.2.2 Prophylaxis or Metaphylaxis at Arrival to Feedlots

Prophylaxis and metaphylaxis are common strategies used in feedlots to control BRD. Prophylaxis refers to the administration of antimicrobials to healthy animals before any signs of disease are observed, while metaphylaxis involves treating a group of animals when disease has been identified in some individuals, aiming to prevent further spread within the group (Gomez & Weese, 2024). Both approaches are typically implemented at feedlot arrival in high-risk cattle.

Baptiste and Kyvsgaard (2017) conducted a systematic review and meta-analysis evaluating the effectiveness of antimicrobial mass medication for the prevention of BRD morbidity and mortality in cattle. A total of 58 publications, summarizing 169 randomized controlled trials (RCTs) conducted between 1966 and 2016, were included. Most studies were performed under feedlot conditions (149 RCTs), with fewer from veal, dairy, or cow-calf operations. After adjusting for publication bias, the combined relative risk estimate for reducing BRD morbidity with mass medication was 0.52, indicating a moderate risk reduction. For mortality, mass medication led to a relative risk of 0.62, but absolute reductions were generally small, particularly in trials where baseline mortality was low. Most trials (41.5% of prophylaxis RCTs

and 82% of metaphylaxis RCTs) reported 0 mortality in control groups, and mortality benefits were primarily observed when control group mortality exceeded 1.5%. Further, parenteral administration (subcutaneous or intramuscular) was more effective than oral antimicrobials. In prophylaxis trials, macrolides were the most effective antimicrobial class, followed by fluoroquinolones, tetracyclines, and cephalosporins, whereas no differences between antimicrobial classes were observed in metaphylaxis trials. Definitions of metaphylaxis impacted outcomes, with group treatment triggered by  $\geq 10\%$  morbidity performing better than strategies based on fever alone or cattle contact with clinical cases. Despite demonstrating reductions in BRD morbidity and mortality, the authors cautioned that the absolute gains were often small, and that the widespread use of mass medications likely reflects underlying systemic challenges in feedlot infrastructure rather than deficiencies in disease prevention alone.

Another systematic review and meta-analysis was conducted by O'Connor et al. (2019b), who aimed to evaluate the comparative efficacy of injectable antimicrobials for the control of BRD in weaned beef cattle entering feedlots. Eligible studies administered antimicrobials at feedlot arrival and reported BRD morbidity within 45 days after feedlot arrival. A total of 46 studies encompassing 167 study arms were included in the final meta-analysis. Most studies compared active antimicrobials to non-active controls, while others compared different active treatments. Results indicated that macrolides were the most effective antimicrobial class for reducing BRD incidence. Injectable oxytetracycline was also effective compared to no treatment but was less effective than macrolides. Rankings of treatment efficacy showed macrolides consistently associated with lower BRD rates, while oxytetracycline ranked lower but remained superior to no AMU. The review highlighted concerns about study quality: randomization was inconsistently reported, blinding was often absent, and many comparisons had wide confidence intervals reflecting imprecision. Nevertheless, the network meta-analysis supported the superior efficacy of macrolides for BRD prevention at arrival, while also acknowledging potential stewardship advantages of using oxytetracycline due to its lower critical importance rating for human medicine.

Finally, Abell et al. (2017) conducted a mixed treatment comparison meta-analysis to evaluate the effectiveness of parenteral metaphylactic antimicrobials for reducing BRD morbidity, mortality, and retreatment rates in feedlot and stocker calves. The analysis included 29 studies and 37 trials assessing 8 antimicrobials, with treatments administered within 48 hours of feedlot arrival. BRD morbidity was evaluated over 2 periods: day 1 to  $\leq 60$  and day 1 to closeout, with additional analyses for BRD-related mortality and retreatment. Tulathromycin, gamithromycin, and tilmicosin consistently ranked in the upper tier for reducing BRD morbidity within the first 60 days, while ceftiofur and oxytetracycline occupied a middle tier. For morbidity to closeout, tulathromycin remained the most effective, followed by gamithromycin, tildipirosin, ceftiofur, tilmicosin, and oxytetracycline. Trimethoprim sulfa and florfenicol were generally less effective. Although classification of treatments by efficacy for mortality and retreatment was limited due to overlapping credibility intervals, tulathromycin showed significantly lower BRD mortality odds compared to tilmicosin and oxytetracycline. These findings suggest substantial differences in performance between metaphylactic antimicrobials, particularly for tulathromycin, and underscore the need to consider drug-specific effectiveness when selecting metaphylactic protocols in feedlot cattle.

Collectively, these reviews support the use of metaphylactic antimicrobials to reduce BRD incidence in feedlot cattle, with macrolides consistently showing superior efficacy. Baptiste and Kyvsgaard (2017) reported moderate reductions in morbidity and mortality, though absolute benefits were often small. O'Connor et al. (2019b) confirmed the effectiveness of macrolides, while highlighting study quality concerns and the potential value of using oxytetracycline from an antimicrobial stewardship perspective. Abell et al. (2017) showed tulathromycin offered the greatest reductions in morbidity and mortality, outperforming tilmicosin and oxytetracycline. These findings underscore the importance of selecting antimicrobials based not only on disease risk but also on antimicrobial stewardship principles, with recognition that effectiveness may decline over time. Supporting this, DeDonder and Apley (2015) summarized North American studies showing increasing resistance of *Mannheimia haemolytica*, *Pasteurella multocida*, and *Histophilus somni* to antimicrobials commonly used for BRD treatment and control, reinforcing the need for judicious AMU.

### 3.2.2.3 Risk Factors for Bovine Respiratory Disease

The previous Review of Scientific Research on Priority Issues (Schwartzkopf-Genswein et al., 2012) identified multiple additive risk factors for BRD in feedlot cattle, including lighter weight, recent weaning, immune status, sex, commingling, transportation stress, and weather changes. Rather than a single dominant factor, the evidence pointed to the cumulative impact of these stressors in increasing BRD morbidity risk. More recent research has also identified this.

**Individual animal factors.** Multiple studies have highlighted the complex interplay of individual and environmental characteristics influencing BRD risk in feedlot cattle. In a retrospective analysis of 288,388 cattle across 1,904 cohorts, Cernicchiaro et al. (2012a) found that cattle arriving in September, weighing less than 318 kg, or housed in smaller cohorts had higher odds of BRD within the first 45 days on feed. Weather conditions, particularly wind speed, wind chill, and temperature changes in the week prior, were also significantly associated with the incidence of BRD, emphasizing how environmental and demographic factors combine to influence disease risk. In a prospective study of 35,131 cattle in Australian feedlots, Hay et al. (2016a) identified breed and arrival weight as key predictors. Specifically, Hereford cattle had twice the odds of BRD compared to Angus, while tropically adapted breeds were at lower risk. Further, heavier cattle ( $\geq 480$  kg) were less likely to develop BRD than lighter cattle ( $< 400$  kg). Season of arrival also played a role, with summer- and autumn-placed cattle having increased risk compared to those arriving in spring. Babcock et al. (2013) found similar results when analyzing data from over 8.9 million feedlot cattle. Using a multivariable negative binomial model, they found that lower arrival weight, male sex, and arrival during spring or summer were associated with increased losses, with significant interactions between weight, sex, and month. These studies demonstrate that BRD risk is not determined by a single factor but emerges from the cumulative impact of multiple interacting stressors present at feedlot arrival.

Transport-related stress has also been implicated as a risk factor for BRD. Cernicchiaro et al. (2012b), using data from 14,601 cohorts across 21 U.S. feedlots, reported that longer transport distances were associated with increased BRD morbidity, all-cause mortality, and reduced performance (hot carcass weight and average daily gain). These effects were modified by arrival weight, season, origin, and sex, indicating that the response to transport stress varies among demographic groups.

**Management-related risk factors.** A growing body of research highlights the substantial role that management practices play in BRD risk following feedlot arrival. Hay et al. (2017) estimated that 82% of BRD cases in Australian feedlots during the first 50 days on feed could be attributed to modifiable management-related factors. The most influential were shared pen water access, prior mixing with animals from other herds, timing of the move to the feedlot, group size prior to induction, presence of BVDV-1 in the cohort, breed, and arrival weight. Similarly, Hay et al. (2014) reported that mixing cattle from multiple sources and transport shortly before arrival to the feedlot increased BRD risk, whereas mixing earlier ( $\geq 4$  weeks prior), forming larger pre-feedlot groups ( $\geq 100$  head), and moving cattle to the feedlot vicinity at least 27 days before feedlot arrival were protective. Hay et al. (2016b) further identified that placing water troughs between pens and adding animals to pens over multiple days both elevated BRD risk. In U.S. feedlots, Rojas et al. (2022a) found that limited pen space ( $\leq 23.2$  m<sup>2</sup> per animal) increased BRD risk, particularly in cattle weighing 409–453 kg or in larger cohorts ( $> 175$  animals). Interestingly, within the 409–453 kg weight group, less bunk space ( $\leq 0.3$  m) was associated with lower BRD incidence compared to more bunk space, though reasons for this association remain unclear. In a separate study, Rojas et al. (2022b) found that 2 water sources per pen reduced BRD morbidity in medium-sized cohorts and lighter cattle, while shared fence lines and water access showed inconsistent associations. Finally, Wisnieski et al. (2021) linked higher BRD mortality within the first 60 days on feed to calves that were weaned at purchase, traveled over 1,082 km, came from multiple purchase groups, or weighed less than 255 kg. Environmental conditions at purchase, including rain, warmer temperatures, and arrival-week temperature fluctuations, further increased risk. Notably, low wind speeds on the purchase day were linked to higher BRD mortality in long-haul shipments, and heat stress effects were amplified in lighter calves.

Together, these studies confirm that BRD risk in feedlot cattle is driven not by a single dominant cause but by the additive and sometimes synergistic effects of multiple stressors acting at both the individual and management levels. Lighter weight, recent weaning, commingling, transport, and poor adaptation to environmental conditions continue to emerge as consistent contributors to BRD morbidity, especially when they occur in combination. The timing and manner in which cattle are prepared for and introduced into the feedlot, such as grouping strategies and housing conditions, can either mitigate or amplify this risk. These findings reinforce that effective BRD prevention must be multifactorial, proactive, and responsive to both animal-level traits and the broader production system context.

#### 3.2.2.4 Preconditioning

Research suggests that preconditioning, encompassing practices such as weaning, vaccination, and nutritional adaptation days before transport, can influence the risk of BRD and improve adaptation to the feedlot. In a longitudinal study of Australian cattle, Hay et al. (2016c) found that cattle that were yard-weaned, exposed to grain before feedlot entry, and vaccinated against BVDV or *Mannheimia haemolytica* were at reduced risk of BRD following arrival. Vanbergue et al. (2024) evaluated a preconditioning program in French beef herds by comparing calves that were weaned indoors 50 days before transport, given dietary supplements, dewormed, and vaccinated twice, with calves that remained with their dams until transport and received no interventions. Although the program aimed to improve health and performance, calves enrolled in the preconditioning group experienced higher morbidity during the preconditioning period

itself, likely due to suboptimal housing conditions. After arrival at the feedlot, morbidity was not different between groups. While early growth was improved in preconditioned calves, overall performance differences were inconclusive.

The effect of preconditioning on feedlot health and performance appears to depend on group composition. Mijar et al. (2023) reported that calves in pens composed entirely of preconditioned animals had significantly lower BRD morbidity (24%) than those in pens of only auction-derived, pre-sorted calves (50%). In commingled pens, BRD incidence was highest when preconditioned calves made up just 25% of the pen (63%) and lowest when they made up 50% (21%). Auction-derived calves had higher average daily gains than preconditioned calves, regardless of grouping, possibly because auction calves were pre-sorted before mixing. Within mixed pens, calves in the 25% preconditioned group had the greatest gains (1.08 kg/day), followed by the 50% and 75% preconditioned pens, while the 100% preconditioned group had the lowest gain. Commingling itself did not significantly affect BRD risk within either group, suggesting that exposure history and individual calf characteristics may be more influential than mixing.

Behavioural adaptations to the feedlot environment further support the benefits of preconditioning. Hodder et al. (2023) found that preconditioned calves spent more time eating and less time inactive than auction-derived calves, while ranch-sourced animals showed intermediate behaviour. As the proportion of auction-derived calves in the pen increased, time spent eating decreased, especially when preconditioned calves were in the minority. Similarly, Mijar et al. (2024) used activity monitors and hair cortisol to assess stress and adaptation to the feedlot. Although cortisol concentrations, levels of BRD, and growth did not differ between groups, preconditioned calves consistently spent more time eating, ruminating, and being active, and less time being inactive, compared to pre-sorted, auction-derived calves. This suggests that preconditioning supports more favourable patterns of adaptation to the feedlot environment.

Economic modeling also supports the value of preconditioning. Chiu et al. (2022) conducted an economic analysis comparing preconditioned cattle to non-preconditioned cattle given metaphylaxis on feedlot arrival. They found that preconditioned calves generated an average net return of \$48.15 USD more per head compared to non-preconditioned calves, indicating that feedlots could justify paying up to \$7.79 USD/cwt more for them.

Overall, the evidence supports that preconditioning can reduce BRD risk and improve early feedlot adaptation. While results on growth performance have been mixed, preconditioned calves show lower morbidity and more favourable feeding behaviours after arrival, such as increased time spent eating and reduced inactivity. These findings suggest that preconditioning helps calves better cope with the stressors of feedlot transition, even in commingled pens, by promoting stronger behavioural adaptation and health outcomes in the early feeding period. Despite the potential to reduce AMU and improve economic outcomes, widespread adoption of preconditioning is limited by current reliance on metaphylaxis and the absence of consistent market incentives to reward producers for preconditioned calves. The health benefits have been cited as a motivator for and the financial constraints as a barrier to the adoption of preconditioning practices; however, the lack of understanding of the perspectives of interest holders across the supply chain (Mijar et al., 2025) suggests that there remains a gap in knowledge that should be addressed using qualitative rather than quantitative methods.

### 3.2.2.5 *Diagnosis of Bovine Respiratory Disease*

BRD is typically diagnosed in feedlot cattle based on clinical signs or changes in behaviour. These signs, such as fever, anorexia, depression, coughing, nasal discharge, or abnormal breathing, reflect the animal's inflammatory response to infection. However, traditional diagnostic methods relying on clinical observation are limited in their accuracy and consistency. Timsit et al. (2016) conducted a Bayesian meta-analysis to evaluate the diagnostic accuracy of clinical illness detection by pen checkers, using lung lesions at slaughter as a proxy reference. They found that clinical observation had low sensitivity (27%) but high specificity (92%), meaning many true BRD cases are likely missed. Diagnostic performance also varied widely across studies, underscoring the need for standardized and more reliable diagnostic methods in feedlots.

Alternative approaches for confirming or facilitating earlier detection of BRD have also been explored. In a systematic review, Wolfger et al. (2015) found that serum haptoglobin is the most consistently useful biomarker for confirming BRD. In contrast, traditional tests like white blood cell counts, neutrophil–lymphocyte ratios, and cortisol showed low accuracy and are of limited value to confirm BRD in feedlot cattle. Further, clear differentiation between cases of BRD and healthy controls on the basis of BRD pathogen detection was found to be difficult. The review also highlighted the potential of automated behaviour and temperature monitoring for earlier detection of BRD. Feed intake monitoring and accelerometers could identify BRD-affected cattle several days before clinical signs of BRD presented. Reticulorumen temperature boluses and infrared thermography also detected early hyperthermia several days before visual signs. With regard to prognostic indicators, detection of specific pathogens, inclusion of automated stethoscope for lung scores, and ultrasonography could be helpful to predict BRD outcomes; however, rectal temperature did not seem to predict treatment outcomes.

Building on the findings of Wolfger et al. (2015), several studies have further evaluated behavioural and physiological monitoring technologies for earlier and more accurate detection of BRD in feedlot cattle. White et al. (2023) reported that calves later diagnosed with BRD were less active, spent more time within 1 metre of feed and water areas during the first 6 days on feed and overnight hours, and shifted from being more social to increasingly isolated after the first 7 days on feed. In an earlier study, White et al. (2016) compared visual observation to remote monitoring systems that track feeding and activity changes to diagnose BRD using Bayesian latent class analysis. Remote monitoring systems had higher sensitivity (81.3%) and specificity (92.9%) than visual observation (64.5% and 69.1%, respectively). Pillen et al. (2016), using accelerometers, found that reductions in standing time, step counts, and lying bouts were detected up to 6 days before clinical illness was identified. Further, on the day before diagnosis, BRD-affected calves stood 54 minutes less, took 629 fewer steps, and had fewer lying bouts compared to controls. Toaff-Rosenstein and Tucker (2018) also identified physiological and behavioural responses related to BRD in newly arrived heifers. Specifically, heifers that developed BRD showed elevated rectal temperatures 2 days before diagnosis and spent less time feeding on the day of diagnosis compared to healthy controls. Grooming behaviour, measured via brush use, did not differ between groups. Flattot et al. (2021) also found that monitoring temperature can be useful. Specifically, they found that steers with subclinical BRD experienced longer and more frequent episodes of elevated reticulorumen temperature ( $> 40^{\circ}\text{C}$ ) than healthy cattle. These temperature measures correlated with lung pathology at slaughter and were

associated with poorer performance. Schaefer et al. (2012) also found utility in using non-invasive, RFID-driven infrared thermography at water stations to detect BRD. They found that animals diagnosed with BRD showed significantly higher peak infrared thermal values (35.7°C) compared to healthy animals (34.9°C).

This growing body of evidence highlights both the challenges of diagnosing BRD accurately in feedlot settings and the promise of behavioural, thermal, and automated tools to support earlier and more consistent detection. Combining these approaches with better training and validation could enhance animal health outcomes and help guide more prudent antimicrobial use.

### ***3.2.3 Lameness in Feedlot Cattle***

Lameness is a common and significant health and welfare issue in feedlot cattle, consistently ranking among the top reasons for treatment. In a retrospective analysis of over 660,000 cattle from 28 North American feedlots, Davis-Unger et al. (2019) found that lameness accounted for 32% of all diagnosed disease cases. Similarly, Hendrick and Abeysekera (2014) reported that lameness represented 40% of all treatment events in 1.1 million cattle from 8 Canadian feedlots, second only to BRD (42%). Other studies have reported comparable findings: Marti et al. (2021) noted that lameness was the reason for treatment in 36.3% of pulled cattle in 2 Alberta feedlots, and Erickson (2023) found that 28.5% of all treatment events were for lameness in a dataset encompassing over 1.7 million cattle from 28 Canadian feedlots.

Across these studies, the most frequently diagnosed cause of lameness was foot rot. Davis-Unger et al. (2019) found that foot rot accounted for 74.5% of lameness diagnoses, followed by joint infections (16.1%), lameness without visible swelling (6.1%), and injuries (3.1%). Marti et al. (2021) similarly reported that foot rot was the leading cause (41.8%), followed by digital dermatitis (25.5%), upper limb lameness (5.9%), joint infections (5.5%), injuries (4.9%), toe-tip necrosis (3.9%), and laminitis (1.5%). Terrell et al. (2017) noted that the most common diagnoses were proximal limb injuries, followed by undefined lameness, septic joints or deep digital sepsis, and foot rot. Finally, Erickson (2023) identified that foot rot, digital dermatitis, and toe-tip necrosis accounted for 90%, 8%, and 2% of hoof-related lameness cases. These findings indicate that, while foot rot remains the most prevalent cause, other forms such as digital dermatitis and joint infections also represent a significant portion of lameness cases.

Lameness has also been associated with meaningful economic losses. Cortes et al. (2021a) reported that cattle with digital dermatitis had significantly lower average daily gain than healthy animals, with reductions ranging from 0.11 to 0.17 kg/day across several groups. Cattle with foot rot also showed lower average daily gains (0.05 to 0.06 kg/day) in some yearling heifers. Further, Cortes et al. (2021a) estimated that digital dermatitis had the greatest economic impact, based on treatment cost, processing labour, and additional feed, among lameness conditions, with losses of up to \$98 CAD per animal, while foot rot was associated with more modest losses of up to \$30 CAD per animal. Davis-Unger et al. (2017) also evaluated the economic impact of different forms of lameness using a modified decision-tree model based on 10 years of feedlot data. They found that feedlot cattle diagnosed with foot rot or foot rot diagnosed in heavier cattle (i.e., those with higher days on feed) had the highest average daily gains before treatment (1.14 and 1.57 kg/day, respectively), while those with joint infections or lameness without visible swelling had much lower gains (0.53 and 0.64 kg/day, respectively). After final treatment, cattle

with foot rot had an estimated net return of \$568 CAD per animal, while those with joint infections or were lame with no visible swelling had negative returns of -\$286 and -\$701 CAD per animal, respectively.

Marti et al. (2021) and Erickson (2023) both identified multiple animal- and management-level risk factors for lameness in Canadian feedlots. Marti et al. (2021) found that heavier cattle were more likely to develop lameness than lighter animals, which helps explain the greater risk observed in yearlings compared to fall- or winter-placed calves. Ranch-sourced cattle were more likely to become lame than auction-derived cattle, and reductions in dietary forage and pen density further increased the likelihood of lameness. Seasonally, the risk peaked in spring and was elevated by precipitation and temperature fluctuations, pointing to the role of pen condition. Erickson (2023) focused specifically on hoof-related lameness and found that risk was higher in cattle placed in small-capacity feedlots. Cattle from confined backgrounding operations or grass-based systems were also at higher risk, potentially due to increased commingling or poor hoof integrity before arrival at the feedlot. The effect of age varied by both source and feedlot size. For example, calves sourced from auction markets and placed in large-capacity feedlots were more likely to become lame than yearlings, while the opposite was true in small-capacity feedlots. These studies together highlight the complex interplay of weight, source, season, and feedlot conditions in shaping lameness risk.

### 3.2.3.1 Foot Rot

Foot rot, also known as interdigital necrobacillosis, is a polybacterial infection of the interdigital skin and underlying tissues, most commonly initiated by *Fusobacterium necrophorum* following mechanical damage to the skin between the claws. Additional organisms such as *Porphyromonas levii* and *Prevotella intermedia* are believed to contribute to lesion persistence or severity. Recent microbiome analyses also support the role of microbial dysbiosis in disease progression, with significant shifts in bacterial community structure observed in affected feet (Erickson et al., 2024a).

A single study specifically evaluated the risk factors associated with foot rot in feedlot cattle. Davis-Unger et al. (2019) analyzed health records from over 660,000 animals and reported that calves placed in the fall and winter had higher odds of foot rot compared to yearlings. The risk also varied by sex. Fall-placed steers were more likely than yearling steers to develop foot rot, while winter-placed steers had lower odds. Among heifers, those placed in winter had lower odds of foot rot compared to yearling heifers. These findings suggest that age at placement, season, and potentially associated environmental conditions may influence the risk of foot rot.

### 3.2.3.2 Digital Dermatitis

Digital dermatitis is a major cause of infectious lameness in cattle, marked by painful ulcerative lesions typically found near the heel bulbs. These lesions are most often associated with *Treponema* species; however, a recent meta-analysis by Caddey and De Buck (2021) also identified *Mycoplasma*, *Porphyromonas*, and *Fusobacterium* as consistently present, suggesting that broader microbial dysbiosis may contribute to disease progression. Building on this understanding of etiology, Thomas et al. (2022a) demonstrated that digital dermatitis lesions can be experimentally induced in beef calves using a model originally developed for dairy cattle. In

their study, both hind feet were abraded and wrapped to create an anaerobic environment before being inoculated with macerated digital dermatitis lesion material. Lesions developed in 3 of 5 inoculated calves within 14–18 days, while none of the mock-inoculated calves were affected. *Treponema* species were confirmed by PCR in lesion biopsies, reinforcing their central role in the pathogenesis of digital dermatitis.

Digital dermatitis in feedlot cattle has been associated with both individual- and system-level risk factors. Erickson et al. (2024b) analyzed health records from over 1.2 million cattle across 28 western Canadian feedlots and reported that cattle sourced from confined backgrounding operations had a higher incidence rate of digital dermatitis compared to those from auction markets. In contrast, ranch-direct cattle had a substantially lower rate than those sourced from auction. Female cattle were more likely to be diagnosed than males, although the magnitude of this difference varied by year. Larger feedlots were also more likely to report cases than smaller ones, highlighting the influence of operation scale. In a separate study, Cortes et al. (2021b) followed 2,854 feedlot cattle housed in 11 pens at 2 commercial feedlots. Digital dermatitis was diagnosed in 2.5% of cattle, although only 22% of affected animals showed clinical signs of lameness. Foot and leg conformation did not differ between affected and unaffected cattle, but poor pen hygiene was strongly associated with digital dermatitis risk. Compared to dry pens, cattle housed in pens with more mud than bedding or excessive mud had significantly higher odds of digital dermatitis. The evidence points to management practices, particularly cattle sourcing and pen hygiene, as key factors in the occurrence of digital dermatitis in feedlot systems.

Preventing digital dermatitis in cattle has primarily focused on the use of footbaths. Jacobs et al. (2019) conducted a systematic review and network meta-analysis to evaluate the effectiveness of walk-through footbath protocols for both treatment and prevention in dairy cattle. Among 14 studies reviewed, only the use of 5% copper sulfate at least 4 times per week showed consistent benefit, outperforming no footbath and water placebo in treatment efficacy. No other protocols demonstrated significant preventive or therapeutic effects, likely due to small sample sizes and high methodological variability. While footbaths are commonly used with dairy cattle, published studies evaluating their effectiveness for beef cattle are lacking. Their uptake in the beef industry in Canada is unknown.

Alternative preventive strategies have been explored in beef cattle. Anklam et al. (2025) used an experimental infection model to test the effects of a feed supplement containing *Saccharomyces cerevisiae* fermentation product on digital dermatitis development in Holstein steers. Although all animals developed early or active lesions, those in the control group were 1.5 times more likely to develop ulcerated lesions. While lesion size did not differ between groups, these findings suggest the supplement may reduce lesion progression and offer a nutritional approach to risk reduction.

Mineral supplementation has also been explored as a preventive strategy. In a longitudinal feedlot study, Kulow et al. (2017) compared a control diet containing only inorganic trace minerals with a diet that included a combination of organic and inorganic trace minerals fed throughout the feeding period. During the initial 60-day adaptation phase, a higher proportion of steers in the supplemented group developed digital dermatitis lesions. However, in the post-adaptation period, which continued until slaughter, the relative risk of digital dermatitis was

higher in the control group, suggesting a potential long-term benefit of including organic minerals. Building on this work, Anklam et al. (2022) conducted an 11-month randomized controlled trial with 1,120 beef heifers to assess the impact of organic trace minerals on digital dermatitis and carcass performance. Although no significant differences in lesion prevalence were observed at the pen level during the post-adaptation phase, animal-level analysis showed that cattle receiving organic trace minerals had a slower rate of lesion increase. These cattle also had significantly heavier hot carcass weights at slaughter, averaging 9.7 kg more than the control group.

### 3.2.3.3 *Toe Tip Necrosis Syndrome*

Toe tip necrosis syndrome is a painful condition in feedlot cattle, characterized by progressive necrosis of the third phalanx and surrounding hoof tissues (Erickson et al., 2024a). The most widely supported explanation is the abrasion hypothesis, which suggests that repeated mechanical trauma leads to excessive wear and apical white line separation, creating an entry point for bacterial invasion into the hoof capsule and bone. In a case-control study of 222 cattle, Paetsch et al. (2017) found that affected animals had significantly thinner soles and were more likely to yield heavy growth of *Escherichia coli* and *Trueperella pyogenes*, supporting bacterial colonization as a central feature of pathogenesis. Affected animals were also more likely to be acutely or transiently infected with bovine viral diarrhea virus, which may contribute to lesion development through virus-induced vasculitis.

Gyan et al. (2015) evaluated hind feet from feedlot cattle and found that apical white line separation was highly predictive of toe tip necrosis. Gross and histologic findings demonstrated a consistent pattern of ascending infection beginning at the distal toe, reinforcing the hypothesis that infection initiates at the apical white line. Johnston et al. (2019) extended this understanding by examining cadaveric limbs under mechanical loading. Claws from animals with toe tip necrosis exhibited significantly greater white line separation than controls, with separation worsening as compressive load increased. These results highlight how organic material may become lodged within the hoof capsule of claws, contributing to the development of toe tip necrosis (Erickson et al., 2024a). More recently, Hedayati et al. (2025) used an abrasion simulator to replicate claw wear on concrete flooring. Compared to controls, abraded claws had significantly lower stiffness in the apical white line, and imaging data suggested that abrasion may create pathways for foreign material to enter the claw. These findings offer further support for abrasion as an initiating factor in the development of toe tip necrosis.

Several risk factors have been associated with toe tip necrosis syndrome. Jelinski et al. (2016) analyzed health records from 1,904 cattle lots across 48 western Canadian feedlots and found that toe tip necrosis syndrome occurred sporadically but clustered within specific lots and feedlots. Only 4% of lots had at least one case, and 26% of these occurred in a single feedlot, suggesting that facility-level factors may influence disease occurrence. The condition was observed throughout the year and affected calves, yearlings, steers, and heifers. No consistent relationship was found between animal source and the timing of euthanasia or death due to toe tip necrosis syndrome. Among 702 affected cattle, the median time to diagnosis was 19 days on feed, and the median time to death or euthanasia was 27 days. Erickson (2023) also reported that most cases occurred early in the feeding period, with a mean of just 9 days on feed until

diagnosis. Given this early onset, Erickson et al. (2024a) proposed that the disease may be linked to stressors, such as transport and feedlot processing.

To explore potential nutritional risk factors, Jelinski et al. (2018) investigated whether mineral concentrations differed between cattle with toe tip necrosis and healthy controls. Hoof samples were collected from 183 cattle across 16 feedlots and analyzed for 8 minerals in the hoof wall and solar horn. Magnesium concentrations were significantly lower in claws from affected animals. For every 10 ppm decrease in magnesium, the odds of toe tip necrosis syndrome increased by 1.13 times in the hoof wall and 1.21 times in the solar horn, suggesting that magnesium deficiency may impair horn quality and predispose cattle to disease.

#### 3.2.3.4 Joint Infections

Despite how commonly they occur, joint infections in feedlot cattle remain poorly understood, particularly with respect to underlying risk factors. A specific and severe form of joint infection is septic arthritis. Warr (2024) analyzed the microbial composition of 66 synovial fluid samples, selected from an initial 137 cases of septic arthritis collected across 11 commercial feedlots. *Mycoplasmosis* accounted for 94.8% of genus-level abundance in septic joints, with significantly higher abundance and lower microbial diversity observed in joints affected by septic arthritis and in postmortem samples. Contrary to prior assumptions, *Histophilus* was not among the top 15 genera detected, and members of the Pasteurellaceae family accounted for only 1% of amplicon sequence variants. Species-level identification revealed *Mycoplasma alkalescens* and *Mycoplasma wenyonii* in a small subset of samples. These findings suggest that *Mycoplasma*, rather than *Histophilus*, are the predominant organism in septic joints of feedlot cattle.

In an analysis of risk factors, Davis-Unger et al. (2019) reported that fall-placed calves had significantly higher odds of joint infections compared to yearlings, suggesting increased susceptibility in younger animals. Sex differences were also noted, with steers less likely to be diagnosed with joint infections than heifers. Importantly, joint infections accounted for nearly half of all lameness-associated deaths in the study, highlighting their clinical severity and need for targeted intervention.

#### 3.2.3.5 Diagnosis of Lameness

Lameness is a painful condition in cattle that alters mobility and posture. Affected animals often exhibit signs such as head bobbing, arched backs, and shortened or uneven stride length due to discomfort while walking or standing (Coetzee et al., 2017). Evaluation of these visual indicators can aid in the detection of lameness and provide insights into underlying hoof pathologies.

Thomas et al. (2022b) explored the relationship between digital dermatitis, locomotion scores, and specific gait traits in 480 feedlot cattle. Animals were assessed while walking for signs of arched back, asymmetric gait, head bobbing, reluctance to bear weight, and tracking up (e.g., hind hooves failing to land in or near the position of the fore hooves). Hind feet were then examined for digital dermatitis and classified by lesion stage. Cattle with digital dermatitis had significantly higher locomotion scores, with the highest odds of lameness seen in those with active lesions (i.e., those that were ulcerative). Among the gait traits, asymmetric gait and

reluctance to bear weight were most strongly associated with digital dermatitis. Although sensitivity was low for individual traits, locomotion score and asymmetric gait were the most predictive, supporting their use in diagnosing digital dermatitis in feedlot cattle, although additional refinements to improve sensitivity are warranted.

Other hoof-related conditions produce distinct clinical signs. Chamorro et al. (2019) focused on clinical signs associated with septic arthritis of the distal interphalangeal joint in beef cattle. In a study of 39 animals presenting with single-limb lameness, diagnosis of septic arthritis was confirmed using radiographic changes and synovial fluid analysis. Two clinical signs were particularly diagnostic, with asymmetric swelling at the coronary band and a lameness score of 4 out of 5 or higher being associated with septic arthritis. Specifically, these indicators increased the odds of diagnosing septic arthritis by 63- and 120-fold, respectively, highlighting their value during on-farm evaluation.

Despite the utility of gait assessment, observer agreement can be inconsistent. Fitzsimmonds et al. (2024) evaluated the reliability of a four-point mobility scoring system using 40 video clips scored by 39 beef farmers and 42 veterinarians. Agreement across all respondents was fair (Fleiss kappa = 0.34), with veterinarians showing higher inter-observer reliability than farmers (0.38 vs. 0.29). Intra-observer agreement varied widely, ranging from slight to almost perfect. These findings indicate that variability in scoring may reduce the reliability of visual lameness detection in beef cattle, underscoring the need for consistent training and standardized assessment practices.

To overcome the limitations of gait scoring, technology-based approaches may offer more accurate and consistent methods for diagnosing lameness. Thomas et al. (2021) evaluated whether behavioural monitoring could aid in early diagnosis of digital dermatitis. Using ear-mounted accelerometers, they tracked rumination, feeding, activity, and inactivity in 120 heifers throughout the feeding period. Of the 114 animals with complete data, 45% were diagnosed with digital dermatitis. In the 5 to 2 days prior to diagnosis, affected heifers ruminated less and were more inactive than unaffected cattle. These results suggest that digital dermatitis influences behaviour prior to clinical detection and that automated behaviour monitoring could aid in early identification. It is important to note that while visual gait scoring and behavioural monitoring are useful for identifying lameness, accurately determining the underlying cause typically requires lifting the feet to examine for specific lesions or signs of joint involvement. Additional studies exploring the use of advanced technologies to improve the diagnosis of lameness and its various causes are needed.

### ***3.2.4 Nutritional Diseases Associated with High Concentrate Feeding***

#### ***3.2.4.1 Ruminal Acidosis***

Ruminal acidosis is a common metabolic disturbance in feedlot cattle, particularly during and after transitions to high-concentrate diets. Castillo-Lopez et al. (2014) monitored 250 steers, including 28 fitted with indwelling rumen pH sensors, to evaluate the incidence and severity of acidosis across backgrounding, transition, and finishing phases. As cattle advanced to a finishing diet containing more than 80% barley grain, mean ruminal pH declined, with the lowest values observed during the latter half of the finishing period. Time spent below a pH of 5.5, which was

used to define ruminal acidosis, exceeded 3 hours per day in many steers. By the end of the feeding period, 38% of cattle were affected with ruminal acidosis. Higher dry matter intake and days on feed were strongly associated with both the likelihood and severity of acidosis. In a commercial setting, Wiese et al. (2017) found similar trends during a 40-day transition to a high-concentrate diet. Reticuloruminal pH decreased with each step up in dietary concentrate, and by the end of the transition, 83% of cattle had experienced at least one episode of low pH lasting more than 180 minutes. These findings highlight the increased risk of ruminal acidosis as cattle move toward finishing rations, particularly when forage content declines and grain inclusion rises.

The strong association between high-grain diets and subacute ruminal acidosis has prompted investigations into how forage inclusion and physical form influence rumen pH and acidosis risk. Chibisa et al. (2016) compared a high-starch, low-forage diet (30% forage, 45.3% starch) to a high-forage diet (70% forage, 30.9% starch) and found that cattle fed the low-forage diet spent an average of 2.5 hours per day with ruminal pH below 5.5, compared to only 0.09 hours in the high-forage group. The low-forage diet also reduced eating and resting salivation, contributing to reduced buffering capacity. In a follow-up study, Chibisa et al. (2020) fed finishing diets containing 0%, 4%, 8%, or 12% barley silage (dry matter basis) with barley grain as the primary concentrate. Increasing silage inclusion increased ruminal pH and reduced the duration and severity of acidotic episodes, though acidosis was not completely prevented even at 12% inclusion. Koenig et al. (2020) similarly evaluated barley silage inclusion at 0%, 4%, 8%, and 12% of dietary dry matter in barley-based finishing diets. While dry matter intake increased with greater silage inclusion and average daily gain was unaffected, feed efficiency declined linearly, indicating poorer conversion of feed to gain as silage levels rose. Rumen pH was not directly measured, but cattle fed higher silage levels had lower eating rates, which typically prevents sudden pH drops in the rumen. However, liver abscess prevalence did not differ, and carcass traits were largely unchanged. Pickinpaugh et al. (2022) examined roughage levels of 10–16% in wheat-based diets containing 30% modified distillers grains and found that increasing roughage elevated ruminal pH and shifted fermentation patterns toward greater acetate and butyrate production. Feedlot performance was unaffected; however, marbling tended to decline with more roughage.

Other studies have examined the role of dietary adaptation. Tomczak et al. (2019) evaluated steers fed a high-energy finishing diet from arrival, either alone, with intermittent hay supplementation, or following a lower-energy starter diet (beginning at low concentrate levels and gradually increasing). Despite no differences in growth performance, cattle that received the gradual starter diet ruminated more and maintained higher ruminal pH early in the study, highlighting the stabilizing effects of higher forage content and slower adaptation. Crawford et al. (2022) similarly compared high-risk feedlot cattle fed either a high-energy finishing diet from arrival or a lower-energy receiving diet followed by transition to the finishing diet. Cattle on the finishing diet had lower dry matter intake during the first 74 days but showed greater average daily gain, better feed efficiency, and higher ruminal pH early in the study, despite ruminating less. No statistical differences were detected in health outcomes or liver abscess rates. Final carcass weight was higher in the finishing group, while other carcass traits were similar. Collectively, these studies show that higher forage inclusion and gradual dietary adaptation

consistently support rumen pH stability, although the effects on growth performance and carcass quality remain variable.

Beyond forage inclusion level, the physical form of fiber can also influence rumen environment. Addah et al. (2015) evaluated how chop length and bacterial inoculation of barley silage affected rumen pH and feeding behaviour in finishing steers. Barley silage was chopped to either 1 cm (short chop) or 2 cm (long chop) and included in finishing diets. While average daily gain and feed efficiency did not differ among treatments, steers fed the 2 cm long-chop silage consumed more dry matter and spent more time eating at a slower rate, behaviours that enhance rumen buffering. Inoculating the silage with an esterase-producing bacterial strain reduced the duration and severity of low ruminal pH in steers fed long-chop silage, but it worsened ruminal pH outcomes in those fed short-chop silage. Similarly, Arbaoui et al. (2025) compared long-form straw with ground and pelleted straw and found no benefit of pelleting for growth, intake, digestibility, or emissions. However, steers fed pelleted straw had lower rumen pH and tended to have reduced protozoal counts, suggesting increased acidosis risk. These findings highlight that coarser forage particles may help support rumen health, even when diet composition remains constant.

While dietary fiber and forage management are important for maintaining rumen function, grain type and processing characteristics are also critical determinants of acidosis risk. Ream and Chibisa (2021) evaluated the impact of replacing corn with 20% or 40% wheat grain. Inclusion of wheat grain reduced mean and minimum ruminal pH and increased the time pH remained below 5.8, indicating a greater risk of subacute acidosis. Similarly, He et al. (2015) substituted wheat for barley in finishing diets processed to a consistent index and found that, although nutrient digestibility and volatile fatty acid profiles were unaffected, increasing wheat levels led to longer durations with rumen pH below 5.8. Supporting these findings, Yang et al. (2014) reported that substituting barley with either soft or hard wheat resulted in lower mean ruminal pH and longer periods below pH 5.8 and 5.5, despite similar digestibility. Moya et al. (2015) also found differences in behaviours of cattle fed wheat or barley. Specifically, wheat-fed cattle showed shorter meals, fewer feeding visits, and tended to have lower intake and feeding time than those fed barley. Further, stress indicators such as flight speed and hair cortisol were also lower in barley-fed cattle. These findings suggest that wheat may increase acidosis risk and result in behavioural change, even when processed similarly.

The rolling method used for grain processing also influences rumen pH and may contribute to acidosis risk. Pereira et al. (2022) compared dry-rolling and temper-rolling of hybrid rye and found that cattle fed dry-rolled rye spent more time with ruminal pH below 5.5, despite greater digestibility of dry matter and crude protein. In contrast, temper-rolled rye maintained higher ruminal pH and supported similar starch digestibility. Similarly, Meadows et al. (2023) assessed ruminal pH responses in cattle fed dry-rolled versus temper-rolled high and low protein wheat. Ruminal pH was lower in steers fed high-protein, dry-rolled wheat compared to those fed high-protein, temper-rolled wheat. These findings indicate that tempering may help mitigate the pH depressions associated with fine particle size and high fermentability, potentially lowering the risk of subacute acidosis during dietary transitions.

Grain processing index also plays a role in modulating rumen environment and performance. Moya et al. (2015) compared barley- and wheat-based diets processed to either a high (75%) or

low (85%) processing index. A lower processing index increased dry matter intake but reduced feed efficiency and carcass yield. Similarly, Ribeiro et al. (2016) found that low processing index (processing index of 75% vs. 85%) lead to higher dry matter intake but reduced starch digestibility, feed efficiency, and net energy gain, without negatively affecting rumen pH. Ran et al. (2021) examined the interaction between barley processing index and dietary undigested neutral detergent fiber (NDF) levels. While reducing the processing index did not affect rumen pH or fermentation, increasing dietary undigested NDF improved ruminal pH and chewing activity, with cattle spending more time eating and less time below the acidosis threshold. Together, these findings suggest that although processing index affects nutrient utilization and performance, dietary fiber content may have a more direct and consistent role in stabilizing rumen pH and mitigating acidosis in high concentrate finishing diets.

#### 3.2.4.2 *Liver Abscess*

Liver abscesses are a common and economically significant issue in feedlot cattle. Grimes et al. (2024) analyzed more than 1.5 million carcasses and reported abscesses across a range of severities: approximately 7% had 1 to 2 small abscesses or scars, 3–5% had 1 or 2 large abscesses or multiple small ones, 2–5% had multiple large abscesses, 4–6% had abscesses with adhesions, 1–2% had open abscesses, and about 1% had both open and adhered abscesses. Herrick et al. (2022) conducted audits at 11 beef processing facilities on 130,845 fed-beef and 30,646 cull-beef cattle. They found liver abscess prevalence averaged 20% in fed-beef cattle and 18% in cull cattle, with fed Holsteins showing the highest prevalence (25%) compared to fed-beef steers (18%) and heifers (19%).

The economic impact of liver abscesses is substantial. Grimes et al. (2024) found that severe abscesses were associated with reductions in hot carcass weight (up to 13 kg), decreased longissimus muscle area, and lower subcutaneous fat compared to carcasses with normal livers. Severe lesions also increased the chance of carcasses being removed from the production line and significantly reduced overall carcass value. Similarly, Herrick et al. (2024) reported that Holstein carcasses with both adhered and open abscesses weighed 25 kg less (a 7% reduction) and required more carcass trim (up to 4 kg) compared to those without abscesses. These carcasses also generated \$94 to \$121 USD less in gross revenue, with offal value losses ranging from 20% to 84% depending on severity.

Several risk factors have been associated with liver abscess development. Champagne et al. (2025) evaluated 900 feedlot mortalities across 6 U.S. feedyards and identified greater odds of liver abscesses in steers, dairy-influenced breeds, and cattle with more than 100 days on feed. Peritoneal adhesions were also more common among affected animals. Histologically, cattle with abscesses showed wider rumen papillae with thinner keratin layers and signs of small intestinal damage. These gastrointestinal tract alterations, particularly damage to the ruminal epithelium and intestinal mucosa, may facilitate bacterial translocation and contribute to liver abscess formation, with both ruminal acidosis and pathogen exposure playing key roles in pathogenesis.

Liver abscess development in feedlot cattle is multifactorial, with ruminal acidosis and bacterial translocation playing key roles. Theurer et al. (2021) demonstrated that steers with more severe liver abscesses spent significantly more time with ruminal pH below 5.6 and 5.2, thresholds for

subacute and acute acidosis, especially during the first transition to a higher-energy diet. These findings suggest that periods of low ruminal pH may facilitate mucosal damage and bacterial passage from the rumen. Herrick et al. (2022) provided supporting microbiological evidence, reporting that *Fusobacterium necrophorum* was isolated from 80% of liver abscesses and *Salmonella enterica* from up to 28% of samples in fed-beef cattle, implicating both pathogens in abscess formation.

Experimental studies have further clarified these relationships. McDaniel et al. (2024a) showed that an acidotic diet alone induced ruminal acidosis but did not result in liver abscesses unless cattle were also inoculated with *F. necrophorum* or *F. necrophorum* and *S. enterica*. Liver abscess prevalence reached 40–50% in the inoculated groups, validating the importance of bacterial presence. Similarly, Childress et al. (2025) found that bacterial inoculation with *F. necrophorum* and *S. enterica* could induce liver abscesses even in cattle fed a high-forage diet, indicating that acidosis is not a prerequisite for abscess formation. In that study, steers with liver abscesses had more severe rumenitis, reinforcing that both mucosal injury and pathogen exposure contribute to pathogenesis. Together, these findings underscore that while acidosis may increase risk, bacterial colonization, particularly with *F. necrophorum*, plays a central role in liver abscess development.

To reduce the risk of liver abscesses, tylosin, a macrolide antimicrobial, is commonly included in feedlot diets during the finishing period. As previously reviewed in the Review of Scientific Research on Priority Issues (Schwartzkopf-Genswein et al., 2012), Wileman et al. (2009) conducted a meta-analysis of 6 studies and reported that, while tylosin did not consistently improve average daily gain or feed efficiency, it significantly reduced liver abscess prevalence from 30% in control cattle to 8% in treated cattle. However, concerns have been raised about the long-term use of tylosin and its impact on antimicrobial resistance. Cazer et al. (2020) conducted a systematic review and meta-analysis and found that extended tylosin use, particularly beyond 100 days of supplementation, consistently increased the prevalence of macrolide-resistant *Enterococcus* species in the gastrointestinal tract. The effects on *Escherichia coli*, *Salmonella*, and *Campylobacter* were mixed or unclear, in part due to inconsistent reporting of tylosin administration.

Several studies have evaluated whether tylosin can be administered more strategically to reduce antimicrobial use while still limiting liver abscesses in feedlot cattle. Linneen et al. (2023) assessed tylosin phosphate fed during different portions of the feeding period in large groups of steers and heifers. In steers, liver abscess prevalence was lowest when tylosin was fed for the first 75% of the feeding period or continuously, and highest when it was provided only during the last 50% or not at all. In heifers, the lowest abscess rates occurred when tylosin was fed during the last 83% or continuously, while earlier withdrawal or no tylosin increased both prevalence and severity. Davedow et al. (2020) compared continuous tylosin administration with use only during the first 125 days or the last 121 days in over 7,500 yearlings. Although overall liver abscess prevalence, growth, and carcass traits were not statistically different, cattle that received tylosin for the first 125 days had more severe abscesses, and a similar trend was observed in cattle receiving tylosin during the final 121 days. Further, antimicrobial resistance in *Enterococci* was found to increase over time, but resistance levels were not significantly different among treatment groups. Feitoza et al. (2025) evaluated tylosin given during the first 30 or 60 days of the finishing period, compared to a control group that received no tylosin. Tylosin-

fed steers had greater body weight at day 30 or 60, but final performance and carcass traits were not different by treatment. These findings suggest that targeted tylosin use, especially during high-risk transition periods or later in the feeding phase, may help reduce abscess severity while limiting overall antimicrobial exposure.

Several studies have explored whether increasing dietary fiber can help reduce liver abscess prevalence in feedlot cattle, particularly as an alternative or complement to in-feed antimicrobials like tylosin. Paterson et al. (2024) investigated how different forage inclusion strategies affected growth performance and liver abscess outcomes. In this study, beef steers were assigned to 1 of 4 treatments: a conventional finishing diet with tylosin, the same diet without tylosin, or diets without tylosin that either decreased or increased in forage concentration over time. While growth performance was greatest in the tylosin group, steers on the decreasing-forage diet had a similar prevalence of minor liver abscesses as those receiving tylosin (52% in both groups), and both were lower than in the control and increasing-forage groups (62% and 64%, respectively). Word et al. (2024) also examined the role of roughage in liver abscess prevention, focusing on corn stalk inclusion levels. Steers were fed diets with either 7% corn stalks with or without tylosin, or higher roughage levels of 13% or 19% without tylosin. As roughage increased, dry matter intake rose, but average daily gain, gain-to-feed ratio, and hot carcass weight declined. Tylosin reduced liver abscess prevalence by 32% and lowered the number of adhered livers. While increasing roughage inclusion also reduced abscess prevalence, it did not affect severity. McDaniel et al. (2024b) further refined the relationship between fiber and liver health by evaluating the effects of increasing NDF from alfalfa hay and the bulk density of steam-flaked corn. In a  $2 \times 3$  factorial study, cattle were fed diets containing 3%, 4.5%, or 6% roughage NDF, along with either low- or high-density steam-flaked corn. Liver abscess prevalence, including severe abscesses, declined as roughage NDF increased. Additionally, cattle fed higher-density steam-flaked corn (412 grams per liter) had nearly 14 percentage points fewer abscesses than those fed lower-density corn, without any negative effects on growth. Together, these studies suggest that strategic use of dietary fiber, particularly when provided early in the feeding period or through increased NDF levels, can help reduce liver abscess prevalence, although trade-offs in growth performance may occur depending on the roughage source and inclusion rate.

In addition to fiber content, dietary starch concentration has also been implicated in liver abscess risk. Schneid et al. (2024) evaluated how starch level and feeding consistency influenced liver abscess prevalence and performance outcomes in finishing steers. In this  $2 \times 2$  factorial study, cattle fed a high-starch diet (64.4%) had a markedly greater prevalence of liver abscesses (55.1%) compared to those fed a lower-starch diet (49.1%, 33.4%). High-starch diets also resulted in reduced final body weight, average daily gain, dry matter intake, hot carcass weight, and marbling score. Interestingly, variation in feeding schedule, whether consistent or erratic, did not affect liver abscess prevalence or growth performance. These findings highlight dietary starch concentration, rather than timing or quantity variability, as a key driver of liver abscess risk in feedlot cattle.

Overall, the literature demonstrates that liver abscesses remain a prevalent and economically significant condition in feedlot cattle, driven by a combination of dietary, microbial, and host factors. While ruminal acidosis can facilitate bacterial translocation through mucosal injury, bacterial exposure, particularly to *Fusobacterium necrophorum*, is essential for abscess

formation. Tylosin continues to be an effective preventive tool, especially when used strategically during high-risk periods, but its contribution to antimicrobial resistance and its status as a World Health Organization (WHO) critically important antimicrobial has prompted efforts to identify alternative or complementary strategies. Research suggests that dietary interventions, such as increasing fiber inclusion early in the feeding period or adjusting starch concentration, can reduce abscess prevalence. These strategies likely work by stabilizing the rumen environment, thereby reducing the frequency and severity of acidotic episodes that promote mucosal damage and enable bacterial entry. Although liver abscesses can still occur in the presence of *Fusobacterium necrophorum* even without acidosis, limiting epithelial injury through diet appears to reduce risk by limiting pathogen invasion. However, nutritional approaches may carry trade-offs in terms of growth performance and carcass quality, depending on the source and amount of fiber or starch used.

#### 3.2.4.3 *Behavioural Adaptations to Nutritional Diseases*

Beyond the well-documented physiological markers described above (e.g., rumen pH, liver abscess biopsies), recent research has begun to explore how these conditions also drive motivational and behavioural changes, which can be used to infer affective state and overall well-being. Cattle that experienced low rumen pH showed behavioural adaptations that would help attenuate the effects of acidosis, by either sorting their ration to consume a greater proportion of long, fibrous particles (DeVries et al., 2014a, 2014b) or changing the feeding pattern to have more frequent and smaller meals throughout the day (Moya et al., 2011, 2014). Van Os et al. (2018) showed that cattle fed a high-energy, low-roughage diet were more motivated to obtain forage compared to those fed a high-roughage diet. Similarly, Coon and Tucker (2024) determined that the motivation of feedlot cattle to access forage increased as rumen pH depression became more severe. Nevertheless, the same study, and Coon and Tucker (2023), showed that despite a prolonged reticulorumen pH depression, feedlot cattle were still more motivated to access a high-grain total mixed ration (TMR) than to access additional forage. The results of these studies suggest that the caloric density, palatability, and previous experiences with the TMR may be driving a strong motivation to ingest high-concentrate rations despite the potential negative digestive consequences. This poor association between acidotic diets and its post-ingestive consequences can lead to the chronicity of digestive upsets, with a demonstrated impact on cattle health and welfare. Moya et al. (2015) showed how a wheat-based diet resulted in a greater concentration of cortisol in hair and cattle with more excitable temperaments upon being handled, likely a reflection of the stress and discomfort caused by liver pathology. These behavioural indicators provide valuable insights into the negative consequences of acidosis and liver abscesses of feedlot cattle and highlight the importance of dietary management to promote animal welfare. Further research is needed to determine how these behavioural adaptations are connected with cattle affective states, as a key component of animal well-being.

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## 4 End-of-Life Management

### Conclusions:

- 1. Euthanasia decisions regarding livestock are complex and influenced by factors such as the likelihood of recovery, animal pain and distress, transport feasibility, and economic considerations. Clear decision-making guidelines, including timelines, are essential to ensure humane treatment and prevent unnecessary suffering.**
- 2. Training and education are critical to improve euthanasia practices, including accurate shot placement, proper equipment maintenance, and decision-making skills. Consideration should also be given to supporting caretakers with resources and training to alleviate emotional stress related to euthanasia practices.**
- 3. Captive bolt paired with a secondary step (i.e., a second captive bolt shot, pithing, exsanguination, or intravenous injection of salt solutions) and gunshot (given appropriate firearm choices are made and close range can safely be achieved) are effective methods for euthanasia.**
- 4. Non-penetrating captive bolts and smaller caliber bullets (0.22 long rifle (LR)) are only suitable for euthanizing calves (2–3 months and 4 months, respectively).**
- 5. Confirmation of death is critical to ensure humane outcomes and requires checking for cessation of breathing, heartbeat, and reflexes.**
- 6. Further research is needed to develop improved tools, training programs, and decision-making guidelines tailored to beef cattle, with a strong emphasis on enhancing human and animal safety while enhancing overall welfare during euthanasia practices.**

### 4.1 Decision-Making Surrounding Euthanasia

Ending the life of an animal in order to reduce or eliminate distress and/or suffering is referred to as euthanasia (Shearer, 2018). The decision to euthanize livestock is complex and influenced by both practical and emotional factors. Moggy et al. (2017) surveyed cow–calf producers in western Canada and found that the primary considerations for on-farm euthanasia were the likelihood of recovery (73%) and the animal’s pain and distress (64%). Qualitative interviews revealed that producers often viewed euthanasia as a difficult and emotional decision, frequently consulting veterinarians for advice but ultimately feeling personally responsible for the decision. Other influencing factors included the animal’s ability to access feed and water, transport feasibility, and meat salvage quality, with minimizing suffering consistently prioritized. It is important to note that 13% of respondents also reported that cattle were not euthanized on farm, which suggests they were either transported off site or died without assistance, either of which might lead to prolonged suffering. Indeed, the criteria for deciding when to euthanize is critical

to minimize suffering, particularly with respect to when an animal is not responding to treatment and/or has a poor prognosis and is unlikely to recover.

Difficulty in making euthanasia decisions may also explain findings by Goldhawk et al. (2015), who reported that half of the cull beef cow shipments in Canada contained at least one compromised cow, suggesting producers may struggle with timely euthanasia or assessing fitness for transport. Windeyer et al. (in preparation) evaluated 9,643 cattle from 8 auction markets, 11 provincial abattoirs, and 1 federally inspected abattoir across Alberta and found that, 95% of cattle were considered fit for transport upon arrival. However, that study elucidated additional details that suggest there is room for improvement regarding on-farm decision-making about end-of-life care. Specifically, 0.4% (16 of 4,461) of cattle arriving at auction markets, 2% (26 of 1,069) at provincial abattoirs, and 0.1% (5 of 4,013) at federal abattoirs were considered unfit for transport. However, it is important to note that the arrival condition may not accurately represent the animal's status on the farm and may instead reflect issues arising during transport or delays in decision-making to address compromised conditions. Furthermore, 4% (197/4,561) of cattle arriving at auction markets and 2% (73/4,013) arriving at federal abattoirs were considered compromised, which is likely not appropriate given that such animals may only be locally transported with special provisions to receive care be euthanized or humanely slaughtered (Government of Canada, 2019). These findings underscore the importance of support and training to improve euthanasia decision-making on farms.

Decision-making surrounding euthanasia in the dairy industry has also been found to be complex and emotionally challenging. Wagner et al. (2020) emphasized the lack of clear guidelines for determining euthanasia timelines for cattle with injuries or illnesses who are unlikely to recover. A survey of 307 dairy producers revealed significant variability in euthanasia practices, with 6% and 12% of respondents indicating they would never euthanize a non-ambulatory cow or calf, respectively. Focus groups highlighted three key themes influencing decision-making: animal welfare, human psychology, and farm operations, with participants emphasizing the need to minimize animal suffering while grappling with the emotional burden of euthanasia decisions. Merenda et al. (2023a) further explored dairy workers' attitudes toward euthanasia, identifying three clusters: confident but uncomfortable, confident and comfortable, and unconfident with limited knowledge. Workers on medium-sized farms and those with less experience were more likely to lack confidence and knowledge, underscoring the need for targeted training. Similarly, Denis-Robichaud et al. (2023) reported that 17% of Canadian dairy farmers felt discomfort with the responsibility of performing euthanasia and 19% observed unease among others on the farm. Half of the participants noted that those performing euthanasia experienced at least one painful emotion or source of anxiety, highlighting the emotional complexities inherent in euthanasia decision-making. Collectively, these findings underscore the importance of clear guidelines, targeted training, and emotional support to enhance euthanasia decision-making and improve both human and animal welfare.

## 4.2 Current Methods and Practices

Humane euthanasia may entail a single step that causes immediate death or may be achieved using two steps: an initial stunning step that causes loss of consciousness followed quickly by a secondary step that causes death while the animal is insensible (Terlouw et al., 2016).

Euthanasia practices in cattle production vary depending on operation type and region. Lee et al. (2015) surveyed 23 consulting feedlot veterinarians in the US and Canada and found that 91% identified gunshot as the most commonly used method for humane euthanasia on the feedlots they served, consistent with 87% in 2009. In comparison, captive bolt was reported by only 9% of participants, compared to 13% in 2009. A survey of 109 cow-calf producers in western Canada documented on-farm euthanasia practices (Moggy et al., 2017). The most common method for euthanasia was gunshot, with 94%, 88%, 82%, and 96% of respondents reporting it as the main method of euthanasia for preweaned calves, weaned calves, adult cows, and adult bulls, respectively. These findings highlight the prevalence of gunshot as the primary method of euthanasia across different cattle production systems.

### 4.2.1 Appropriate Methods of Euthanasia

#### 4.2.1.1 Firearm

**Rifles and handguns.** Baker and Scrimgeour (1995) isolated cadaver heads from adult steers and heifers and tested various firearms and ammunition. Firearms included the Ruger Mini-14 with .223 FMJ and Core-Shot pre-fragmented rounds, the Ruger 10/22 with .22 LR standard and high-velocity rounds, and a .30-06 rifle with soft-nose rounds, among others. The Ruger Mini-14 with Core-Shot pre-fragmented rounds demonstrated superior performance, causing extensive brain damage without overpenetration, whereas the Ruger 10/22 with .22 LR standard and high-velocity rounds proved inadequate for penetration. Thomson et al. (2013) assessed euthanasia methods for feedlot cattle by using computed-tomography imaging to analyze cranial penetration and brain tissue disruption in cadaveric steer heads. Rifle-fired .22-caliber solid-point rounds, pistol-fired .45-caliber ACP rounds, and carbine-fired .223-caliber rounds were highly effective, while rifle-fired .22-caliber hollow-point rounds and pistol-fired 9-mm rounds were less reliable due to insufficient brainstem damage. Shearer (2018) attributed these limitations to bullet fragmentation, which reduced penetration, and the shorter barrel length of pistols, which decreases muzzle velocity, as rounds like 9 mm and .45 caliber require barrels longer than 16 inches for optimal performance.

Based on these studies and expert opinion, the American Veterinary Medical Association (AVMA, 2020), Canadian Veterinary Medical Association (CVMA, 2021), and American Association of Bovine Practitioners (AABP, 2023) have established guidelines for euthanasia in cattle. A .22 LR is commonly used to euthanize cattle in North America and consistently delivers bullets at a velocity of 1,200 feet/s with a muzzle energy (ME) in the range of 120 to 130 foot-pounds (AVMA, 2020). ME is the kinetic energy of a bullet and is a measure of its destructive potential. Heavier bullets with greater velocity have higher ME and capacity for destruction. The AVMA (2020) indicates the ME requirements needed to penetrate and traverse the skulls of cattle for the purpose of euthanasia has been poorly understood, and prior recommendations of a minimum ME of 300 foot-pounds for animals up to 400 lb and as much as 1,000 foot pounds for

animals over 400 lb have been deemed excessive (AVMA, 2020). A study by Blackmore (1985) found 94 foot-pounds was adequate to penetrate the frontal bone of a 3-year-old Angus cow and sufficient for humane slaughter or euthanasia of mature cattle.

The AVMA emphasizes that .22 caliber long rifle ammunition should only be used with a rifle (though this specification regarding rifles may not be relevant in Canada due to differing gun laws), equipped with a solid point bullet, fired from close range (30–90 cm [1–3 feet]), and aimed at the correct anatomic placement on the skull. Further, the AABP's current recommendations (AABP, 2023) suggest that a .22 caliber handgun or rifle loaded with a long rifle solid point bullet is sufficient only for calves less than four months of age. In cattle over four months of age, it is necessary to use .22 Magnum or higher calibers for consistently effective euthanasia.

**Shotgun.** Baker and Scrimgeour (1995) evaluated three shotguns for euthanasia using isolated cadaver heads from adult steers and heifers. The .410-gauge shotgun with #4 and #6 birdshot caused sufficient brain damage but required close range to prevent shot dispersion and needed reloading after every shot, offering little advantage over a captive bolt gun. The 12-gauge Remington 870 with a rifled slug was powerful but lacked accuracy at 25 metres, with excessive recoil making it unsuitable for repeated use, though the impact likely induced unconsciousness. When loaded with #7 1/2 game shot, the same shotgun achieved total brain destruction but was excessively powerful and offered limited benefits compared to a captive bolt gun at close range. Thomson et al. (2013) similarly found that shotguns loaded with birdshot or slugs were effective for euthanasia of feedlot cattle based on a simulation study using feedlot steer cadaver heads shot from a distance of 3 metres.

The AABP (2023) emphasizes that shotguns are highly effective for euthanasia at close range (less than 90 cm or 3 feet), recommending 12-, 16-, and 20-gauge shotguns for adult cattle and 28- or .410-gauge shotguns for calves. Using shot shells at close distances ensures the projectiles strike the skull as a compact mass, enhancing consistency and effectiveness. Similarly, the AVMA (2020) recommends shotguns loaded with birdshot (#6 or larger) or slugs for cattle euthanasia at short ranges (91–183 cm [1–2 yards]). At these distances, birdshot impacts the skull as a compact mass, effectively penetrating and causing extensive brain tissue destruction, leading to immediate unconsciousness and rapid death. It is important to note that the use of shotguns is only appropriate at close range, which means that appropriate restraint and immobilization of the animal is necessary for both animal and human safety.

**Human safety.** Although not extensively detailed in the literature, human safety is paramount when using firearms for euthanasia. Bottleneck centrefire rifle cartridges pose a significant risk of ricochet and over-penetration, as their high energy can cause the projectile to pass through the animal and travel considerable distances, potentially endangering people or property. For safer alternatives, shotgun slugs or rifles chambered for pistol ammunition, such as .357 Magnum or .44 Magnum, are recommended, as they offer sufficient stopping power while minimizing the risk of ricochet and over-penetration. As mentioned previously, proper restraint and immobilization as well as consideration of the surrounding environment (e.g., the risk of ricochet within the confines of a trailer) are also critical considerations for maintaining both animal and human safety. Sedation, such as the use of xylazine prior to euthanasia, has been shown to improve animal immobilization, enhance handler safety, and facilitate a more practical and

efficient process, particularly in large-scale depopulation scenarios (Hanthorn & Sanderson, 2019).

#### 4.2.1.2 *Captive Bolt*

***Non-penetrating versus penetrating captive bolt.*** Finnie (1995) assessed non-penetrating percussive captive bolt stunning in 12 cattle, finding it caused immediate unconsciousness with a 3 cm depressed frontal bone fracture and extensive subarachnoid hemorrhage over the brainstem, temporal, and frontal lobes. Microscopic examination revealed petechial hemorrhages in the thalamus and basal ganglia, linked to concussive forces and brain acceleration within the skull. However, larger studies highlight the limitations of non-penetrating captive bolts for adult cattle. Gibson et al. (2019) evaluated 31 approximately 30-month-old Zebu × Hereford crossbred bulls, finding all bulls stunned with a penetrating captive bolt exhibited electroencephalogram patterns (e.g., measures of electrical activity in the brain) consistent with unconsciousness, while only 82% of those stunned with a non-penetrating bolt showed unconsciousness and two non-penetrating stuns resulted in incomplete unconsciousness. Similarly, Oliveira et al. (2018) examined 455 Zebu and Zebu-cross cattle and found penetrating captive bolts outperformed non-penetrating bolts in velocity, momentum, and energy, with fewer repeat shots required (12% vs. 29%). Penetrating bolts achieved higher rates of immediate collapse (99% vs. 91%) and fewer signs of distress, such as rhythmic respiration and reflexive movements, indicating superior welfare outcomes. Supratikno et al. (2024) further reported a success rate of only 74% for non-penetrating pre-slaughter stunning in Brahman-cross cattle, highlighting its limitations for adult cattle. Cumulatively, these studies suggest that non-penetrative captive bolts are not effective on adult cattle. However, it should be noted that non-penetrative captive bolts, when used properly, may be used for humane slaughter if followed immediately with a secondary method such as exsanguination (Musk & Johnson, 2024). It is important that the “stun-to-stick” interval is short, ideally less than 60 s and no more than 90 s (Jerlström et al., 2025).

In contrast, Collins et al. (2020) found non-penetrating captive bolts effective for younger animals, demonstrating immediate and sustained unconsciousness in sedated 4- to 5-month-old Holstein steers, with only minor differences in cessation of respiration and convulsions between penetrating and non-penetrating captive bolts.

Reflecting these findings, the AVMA (2020) and CVMA (2021) recommend that solely penetrating captive bolts should be used for humane euthanasia of older cattle, with non-penetrating captive bolts used only in calves. Similarly, the AABP (2023) guidelines for humane euthanasia of cattle suggest non-penetrating captive bolt can be used for the euthanasia of neonates and calves less than 2 to 3 months of age

***Type of penetrating captive bolt.*** Baker and Scrimgeour (1995) evaluated euthanasia methods for cattle during foreign animal disease outbreaks and found that two .25-caliber penetrating captive bolt stunners from Accles and Shelvoke, including the Magnum stunner, effectively induced immediate unconsciousness in adult cattle at abattoirs. Kaluza et al. (2022) compared pneumatically powered and cartridge-fired captive-bolt stunners in cattle, reporting superior outcomes with pneumatic stunning. This method required fewer repeat shots (6% vs. 18%) and had fewer deviations in shot placement (25% vs. 34%) and direction (10% vs. 47%), particularly in bulls, indicating greater efficacy and reliability with pneumatic systems. Finally, Frazer et al.

(2023) compared three penetrating captive bolt devices, the Blitz-Kerner, Jarvis BABOOM, and Matador SS3000, using ballistic gelatin and cadaver heads from male and female cattle of varying ages. The Matador SS3000 demonstrated the greatest penetration depth, followed by the Jarvis BABOOM and the Blitz-Kerner, with significant differences between the devices. Additionally, the Blitz-Kerner exhibited the lowest kinetic energy.

The length of the penetrating captive bolt is also an important consideration. Kline et al. (2019) evaluated the impact of three captive bolt lengths (15.2 cm, 16.5 cm, and 17.8 cm) on tissue damage and hind limb kicking in properly stunned fed-beef cattle and Holstein steers and heifers using a pneumatic stunner. All 45 cattle were rendered unconscious with a single shot. Visual examination indicated that the shortest bolt caused the least brain damage, with intact brainstems observed across all treatments. The findings confirm that cattle can be stunned without visible brainstem disruption, regardless of bolt length, which is desirable when attempting to diagnose neurologic diseases, including BSE surveillance. In a similar study, Anderson et al. (2025) reported that a penetrating depth of approximately 35–52 mm would be needed to reach the brain of most mature Holstein cows when using most recommended frontal positions, and 96.3 mm penetration depth would be needed to reach the hypothalamus when using an ideal frontal position. They also stated that most commercial penetrating captive bolts are not of adequate length to be used for the poll position in mature cattle. Importantly, they also mention the dimensions measured for the cadaver heads used in their study were not substantially different than what is reported in the literature for mature cattle of beef breeds. As such, their findings are likely also relevant for mature beef cattle.

***Secondary steps for euthanasia with captive bolts.*** Death is not always assured when captive bolts are used alone, emphasizing the importance of adjunctive steps. Grandin (2002) evaluated penetrating captive bolt stunning in 21 U.S. beef slaughter plants, observing over 2,500 cattle, including steers, heifers, cows, and bulls. While 81% of plants rendered all cattle insensible before hoisting onto the bleed rail, 0.2% of fed steers and heifers and 1.2% of bulls and cows showed signs of returning to sensibility. Gilliam et al. (2018) further demonstrated the need for secondary steps, as the CASH Euthanizer captive bolt system failed to euthanize 9.7% of adults, 10.5% of young animals, and up to 20% of neonates with penetrating shots. Failures were associated with the return of respiration or prolonged time until cardiac arrest. Similarly, Dewell et al. (2015b) evaluated penetrating captive bolt use in 22 feedlot calves, finding that cardiac death (i.e., ventricular standstill) occurred an average of 8 minutes and 34 seconds after stunning. Clinical cardiac death, defined as the absence of an audible heartbeat, occurred earlier, with only 70% of calves presumed deceased based on clinical parameters prior to ventricular standstill.

These findings support AVMA (2020), AABP (2023), and CVMA (2021) guidelines, which emphasize that captive bolts should be paired with an adjunctive step to ensure complete euthanasia.

***Second shot.*** Robbins et al. (2021) evaluated the efficacy of frontal sinus and poll locations as secondary shot sites for cattle euthanized with a penetrating captive bolt. Clinical assessments showed no signs of sensibility after the initial frontal sinus shot in this study, regardless of the secondary shot location. While poll shots resulted in fewer animals with a heartbeat 5 minutes post-shot, pathology revealed limited brainstem damage, indicating that such damage may not be required for irreversible insensibility and death. Both locations were found to be similarly

effective as secondary shot sites. A follow-up study by Robbins et al. (2023) confirmed these findings in mature Jersey × Holstein dairy crosses, showing minimal signs of consciousness after an initial frontal sinus shot. The time to the last heartbeat and gross brain trauma scores did not differ significantly between frontal sinus and poll shots, suggesting that either location is an effective secondary method.

***Intravenous administration of salts.*** Intravenous administration of potassium chloride or magnesium sulfate following the use of a captive bolt disrupts the heart muscle's electrical conductivity to ensure death. The AVMA (2020) notes that potassium chloride typically induces death more rapidly than magnesium sulfate, but the CVMA (2021) highlights that magnesium sulfate may result in fewer violent neuromuscular reactions. Stanger et al. (2019) supports this, finding both methods humane based on measures of pain perception in sheep; however, potassium chloride caused severe reflex movements during infusion, while magnesium sulfate did not.

***Exsanguination.*** Exsanguination is typically performed by making an incision on the ventral side of the throat or neck, cutting through the skin, muscle, trachea, esophagus, carotid arteries, jugular veins, and numerous sensory and motor nerves, along with other vessels. The AVMA (2020) and AABP (2023) state this procedure must not be used as a standalone method of euthanasia but is acceptable for use as an adjunctive method.

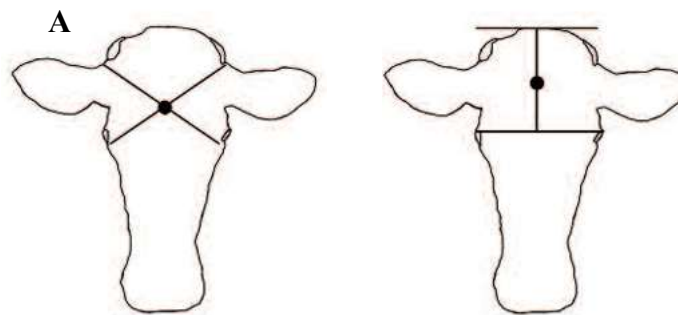
***Pithing.*** Pithing involves inserting a rod through the skull's entry site created by a penetrating captive bolt to destroy the brainstem and spinal cord. Appelt and Sperry (2007) compared stunning alone to stunning followed by pithing, primarily in cull dairy cows. They found that none of the pithed animals regained consciousness, whereas 5 of 12 animals that were not pithed exhibited signs of returning to consciousness, underscoring the effectiveness of pithing. However, Leach and Wilkins (1985) noted that pithing after captive bolt stunning in Hereford × Holstein crosses at slaughter induced violent muscular activity, which could pose challenges during implementation.

***Single step with captive bolt.*** Derscheid et al. (2016) assessed a penetrating captive bolt device with an integrated air-channel pithing mechanism as a one-step euthanasia method for feedlot cattle. Among 66 steers and heifers, 94% were euthanized with a single shot, while 6% required additional shots due to placement errors. All shots penetrating the cranial vault rendered cattle unconscious with no return to sensibility.

In a study using a penetrating captive bolt with an extended bolt, Dewell et al. (2024) euthanized 17 cattle of various ages and breeds by positioning the device flush against the parietal bone behind the poll and aiming toward the base of the tongue. Properly placed shots resulted in immediate loss of consciousness without return to sensibility, followed by clinical death, with only one animal requiring a second shot due to an improper angle. Postmortem assessments confirmed sufficient brain trauma, supporting the poll shot as an effective euthanasia method when executed correctly.

While these studies demonstrated varying success with different bolt devices and shot positions, a secondary step is still recommended, as neither study achieved 100% success in all animals with a single shot.

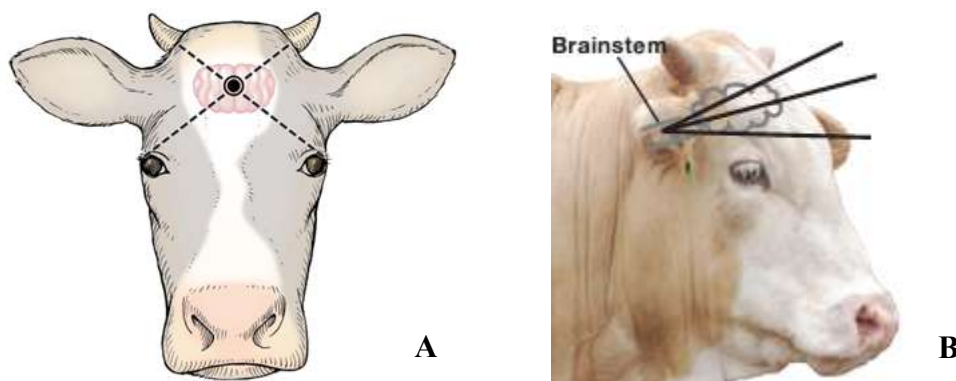
**Placement of captive bolt or firearm shot.** The positioning of the captive bolt or the firearm shot on the head of the cattle is critical, with Schiffer et al. (2017) finding accurate shot placement was more critical than the choice of firearm caliber. This was further emphasized by Gilliam et al. (2016), who randomly assigned intact cadaver h **B** ; of beef and dairy cattle to a high or low single shot of a penetrating captive bolt. The low group used the standard landmark (intersection of lines from the medial canthus of the eye to the top of the opposite ear; Figure 1A), while the high group used a modified landmark (midline halfway between the top of the poll and an imaginary line connecting each lateral canthus of the eye; Figure 1B). Results showed greater brainstem disruption in the high group for adult cattle (16/18 high vs. 7/14 low) and young cattle (13/16 high vs. 11/19 low), with both landmarks performing equally well in neonates (11/11 high and 14/14 low). These findings suggest that the higher shot placement improves the likelihood of brainstem disruption in adult cattle, potentially reducing the risk of regaining sensibility.



**Figure 1.** Figure from Gilliam et al. (2016)

**A** demonstrates the position of the shot used in the low group (intersection of lines from the medial canthus to the top of the opposite ear), while **B** demonstrates the position of the shot used for the high group (midline halfway between the top of the poll and an imaginary line connecting each lateral canthus).

Based on this, the AVMA (2020), AABP (2023), and CVMA (2021) recommend the shot should be placed at the intersection of two lines drawn from the lateral canthus (outer corner) of each eye to the centre of the base of the opposite horn (or the area where the horn would be) as shown in Figure 2A. The angle of the shot must be perpendicular to the front of the skull (Figure 2B).



**Figure 2.** *Appropriate landmarks for shot placement for euthanasia of cattle.*

**A)** Figure from AVMA (2020): demonstrates the position of the shot placed at the intersection of two lines drawn from the lateral canthus (outer corner) of each eye to the centre of the base of the opposite horn (or the area where the horn would be). **B)** Figure from AABP (2023): the trajectory of the shot is along the midline between the base of the ears at the level of the external ear canal, directing it perpendicular or slightly downward (no more than 45 degrees). The angle can be adjusted, as illustrated in Figure 2B, to accommodate the position of the animal and caretaker, particularly when using a firearm. Penetrating captive bolts should be discharged with the device held flush and perpendicular to the frontal bone.

More recently, the commonly recommended positions for captive bolt placement were assessed by Anderson et al. (2025). They not only assessed the potential from brain contact, but also contact with the thalamus, the major area of the brain responsible for consciousness. Based on this, the ideal placement was in fact 1cm above the intersection described above (Figure 2A), which achieved thalamus contact in 100% of the mature Holstein cow cadaver heads. However, both the placement in Figure 2A and the placement in Figure 1B also made 100% contact with the brain but only 94% and 0% contact with the thalamus, respectively.

**Barbiturates and barbituric acid derivatives.** Barbiturates lead to rapid transition from consciousness to unconsciousness and death when administered at the appropriate dosage intravenously (AVMA, 2020). However, there are drawbacks stated by the AVMA (2020) and AABP (2023), including the cost, need for adequate animal restraint, administration by registered personnel (i.e., veterinarians), and limited options for carcass disposal. Further, AABP (2023) highlights that there are risks of ingestion by wildlife and rendered material consumed by domestic pets and as such recommend it as a last resort for euthanasia, unless appropriate carcass disposal can be carried out. However, this method of euthanasia is perhaps preferable for neurological conditions or suspected cases of bovine spongiform encephalopathy, where it is essential to preserve the brain, particularly the brainstem, intact.

**Confirmation of death.** Confirming the success of a euthanasia method is essential to ensure humane treatment and prevent unnecessary suffering. Moggy et al. (2017) found that among western Canadian cow–calf respondents who euthanized cattle, the most common method of confirming death was checking for breathing (68%), followed by absence of the corneal reflex (62%), heartbeat (47%), limb movement (38%), and bellowing or vocalization (15%). However, of concern, 8% of respondents who performed on-farm euthanasia did not confirm death at all. Since surveys often capture responses from more engaged producers, the proportion is likely higher in the general population.

The CVMA (2021) guidelines state the last step of euthanasia is to confirm death by ensuring all of the following indicators: immediate and permanent cessation of rhythmic breathing, absence of vocalization, absence of eye reflexes, a glazed or glassy appearance of the eyes, eyes remaining open and facing straight forward, and absence of a detectable heartbeat. The AABP (2023) guidelines also state that confirmation of death following a euthanasia procedure is absolutely essential, with lack of heartbeat and respiration for 3 to 5 minutes used to confirm death.

### 4.3 Training to Improve Euthanasia Practices

Training is essential for ensuring the success of any euthanasia method. Setijanto et al. (2024) highlighted that improper shot placement and shooting distances significantly reduced the success rates of penetrating captive bolt use. Similarly, Grandin (2002) identified factors contributing to the return of sensibility after captive bolt stunning, including damp cartridge storage, poor stunner maintenance, and operator inexperience. Schiffer et al. (2017) found shot location was more critical than the choice of firearm caliber when testing five firearm and bullet combinations, further emphasized the importance of accurate shot placement.

Effective training programs are critical for improving the skills, including placement, equipment, and confirmation, and confidence of individuals responsible for euthanasia of livestock. Dewell et al. (2015a) evaluated an interactive workshop for beef cattle handlers and found that participants reported moderate improvements in their ability to identify the optimal point of entry for firearms and captive bolts, demonstrating the value of training. In dairy cattle, Merenda et al. (2023b) assessed an interactive, case-based euthanasia training program aimed at improving decision-making and awareness of timely euthanasia. Participants reported increased confidence in identifying compromised animals, determining when euthanasia is necessary, and recognizing its importance, with younger and less-experienced workers benefiting the most. These findings highlight the effectiveness of such programs in enhancing euthanasia decision-making. Reflecting this need, the AABP (2023) recommends that owners, facility employees, or non-veterinarian third parties performing euthanasia receive annual training and certification.

### 4.4 Future Research

Studies are needed to evaluate the effectiveness and reliability of different euthanasia tools and techniques under real-world conditions across diverse cattle production systems. Additionally, euthanasia recommendations for captive bolts and firearms may need to account for breed-specific differences, as variations in skull morphometric characteristics have been observed between dairy and beef breeds (Çakar et al., 2024). Research should also focus on developing improved decision-making frameworks that integrate practical, emotional, and welfare considerations, enabling producers to make timely and humane euthanasia decisions. Furthermore, designing and implementing training programs tailored to different experience levels and farm sizes could significantly enhance confidence and precision in euthanasia practices. For firearms, requiring appropriate licensing and training is critical to ensure both safety and the humane application of euthanasia practices. An additional research priority is monitoring the prevalence of appropriately versus inappropriately euthanized animals arriving at diagnostic laboratories, within feedlots, and/or by veterinarians performing field necropsies, particularly as an outcome measure to assess the effectiveness of training programs.

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## 5 Weaning Practices and Pre- and Post-Weaning Management

### 5.1 Introduction, Scope, and Main Principles

Weaning is considered a necessary management practice in most modern beef cattle systems, where the dam and calf are separated to facilitate cows regaining body condition, support the next pregnancy, and allow the specialized feeding of the calves. While necessary, the process of weaning is widely recognized as a source of stress for both the cow and the calf. This stress can have short-term and long-term implications for welfare, health, and performance.

The 2012 Review of Scientific Research on Priority Issues (Schwartzkopf-Genswein et al., 2012) summarized the evidence available at that time, highlighting the behavioural and physiological responses to weaning and describing several weaning methods. Since then, additional research has expanded our understanding of how weaning practices influence the welfare of both beef cows and calves and has introduced refinements to pre- and post-weaning management aimed at mitigating negative outcomes.

This updated review highlights the scientific literature on weaning in beef cattle from 2012 onwards. It focuses on four key areas: (1) the welfare impacts of weaning on both the cow and the calf, (2) common and emerging weaning procedures and practices, (3) management strategies that may influence weaning outcomes, and (4) future research priorities. This review focuses exclusively on studies conducted in beef cattle or those applicable to Canadian beef production systems.

### 5.2 The Welfare Impacts of Weaning on Both the Cow and the Calf

#### Conclusions:

- 1. Weaning is a significant welfare challenge for both cows and calves, consistently associated with behavioural and physiological indicators of distress, which last for several days, reinforcing conclusions from earlier scientific reviews.**
- 2. Individual and management-level factors influence the welfare impacts of weaning. While some characteristics, like cow parity, are not easily modified, evidence clearly supports that weaning younger calves or using abrupt methods results in greater distress, and that combining weaning with other stressors (e.g., transport) can further compromise welfare.**

The 2012 Review of Scientific Research on Priority Issues (Schwartzkopf-Genswein et al., 2012) concluded that weaning causes distress to both the cow and the calf, as evidenced by behavioural changes and increased morbidity (Since then, research has continued to document the behavioural, physiological, and health-related consequences of weaning, reinforcing the conclusion that imposing weaning is a significant welfare challenge.

A key strength of a study by Ungerfeld et al. (2014) was the inclusion of a non-weaned control group, allowing for a direct comparison of behavioural and physiological outcomes in cows

subjected to weaning with those allowed to maintain the cow–calf bond. Cows that had calves weaned using either abrupt or nose-flap methods exhibited increased behavioural signs of distress, such as vocalization and pacing, compared to cows of non-weaned calves. Although the nose-flap method reduced behavioural signs of distress compared to abrupt separation, cows in the control group showed minimal signs of stress and maintained higher milk production throughout.

There is also individual variation that occurs in the response to weaning. Stěhulová et al. (2017) evaluated how cow and calf characteristics influence behavioural outcomes following abrupt separation at 151 to 274 days of age. Cows vocalized more if their calves were younger at weaning or had higher growth rates or if the cows were not pregnant, while younger cows moved more. Among calves, vocalization and movement were greater in females and in those with higher weight gain. Behavioural responses also differed in cows and calves over time, with cow vocalizations peaking 6 to 8 hours post-separation before declining, while calf vocalization frequency continued to rise for 24 hours after separation. De Paula et al. (2023) also examined the effect of cow parity on their stress response following abrupt weaning with remote separation in Nellore cattle. While both primiparous and multiparous cows displayed behavioural and physiological responses, multiparous cows showed greater increases in cortisol, red blood cell counts, hematocrit, and hemoglobin. These data suggest that older, multiparous cows may experience a more intense physiological stress response, perhaps due to a more strongly established maternal bond.

The negative welfare implications of weaning extend beyond behavioural changes. Hodgson et al. (2012) investigated how maternal separation at the time of a viral infection impacts susceptibility to secondary bacterial pneumonia. Calves abruptly weaned with remote separation and transported at the time of a primary bovine herpesvirus type-1 infection were twice as likely to die following challenge with *Mannheimia haemolytica* compared to calves pre-adapted to weaning (i.e., separated from their dams, housed separately on the ranch, and fed hay and grain for 2 weeks prior to transport and challenge). Although viral shedding did not differ, abruptly weaned calves mounted an exaggerated immune response, elevated interferon- $\gamma$ , acute-phase proteins, CD14, and TNF- $\alpha$ . This work underscores that the stress of weaning may exacerbate disease severity in the face of respiratory co-infections and highlights the critical importance of management strategies that reduce cumulative stressors during the weaning period.

### 5.3 Common and Emerging Weaning Practices

#### Conclusions:

- 1. Weaning method significantly influences calf and cow welfare, with gradual strategies, such as fence-line separation and nose-flap use (i.e., two-stage weaning), reducing behavioural signs of stress in calves compared to abrupt weaning with remote separation.**

- 2. Two-stage weaning using nose flaps reduces distress in both cows and calves, with variable impacts on immune status but has inconsistent impacts on performance, immune status, and physiological indicators of stress.**
- 3. A proportion (~30%) of nose-flap devices can be lost, and a high percentage (86–100%) of calves fitted with the device had nasal lesions, which raise welfare concerns that must be weighed against their other benefits.**
- 4. Fence-line weaning improves early post-weaning growth and reduces calf distress but may prolong stress-related behaviours in cows compared to abrupt weaning. Long-term performance benefits are inconsistent throughout different production stages.**

The method used for weaning plays a central role in determining both immediate and longer-term outcomes for calf welfare, growth, and health. A growing body of research demonstrates that weaning strategies not only influence behavioural and physiological stress responses in calves, but also that they can affect post-weaning performance, and, in some cases, the degree of stress experienced by the cow. Gradual weaning approaches, such as fence-line separation and two-stage weaning using nose flaps, reduce distress and promote a smoother transition. Despite the availability of lower-stress alternatives, abrupt weaning remains a common practice among Canadian cow–calf producers. A 2015 survey of 109 producers in western Canada found that 70% used abrupt weaning, often citing cost, logistics, and pasture availability as key constraints to implementing more gradual weaning approaches (Moggy et al., 2017). More recent data from the 2023 Canadian Cow–Calf Survey, which included 600 respondents, indicate that the use of abrupt weaning has declined to 51%. Among those using this method, the main reasons cited for continuing to use abrupt weaning were selling calves immediately after weaning (59%), limited time, labour, or infrastructure (21%), and no perceived financial benefit to alternative approaches (12%) (BCRC, 2024).

### ***5.3.1 Nose-Flap versus Abrupt Weaning***

Two-stage weaning using a nose flap device is often proposed as a lower-stress alternative to abrupt weaning. This method allows calves to remain in contact with their dams while preventing nursing for a short period of time prior to physical separation. Use of two-stage weaning among Canadian cow–calf producers appears to be increasing, with 4% of respondents reporting its use in a 2015 western Canadian survey (Moggy et al., 2017) compared to 12% in a national survey conducted in 2023 (BCRC, 2024).

Behavioural studies consistently report that nose-flap weaning reduces signs of distress in both cows and calves. For example, Lambertz et al. (2014) found that cows vocalized significantly more when calves were abruptly weaned with remote separation (19.2 times/hour) compared to when calves were fitted with nose flaps 7 days prior to separation (3.7 times/hour). Calves in both groups increased walking behaviour post-weaning, but the increase was lower in those fitted with nose flaps. Similarly, Alvez et al. (2015) reported that calves abruptly weaned with remote separation vocalized, walked, and paced more frequently, and showed reduced standing and grazing after weaning compared to those weaned using a two-stage method with nose flaps. These behavioural indicators of stress were substantially lower in calves fitted with nose flaps for

either 7 or 21 days prior to separation, with minimal differences between the two durations. Further, Freeman et al. (2021) found that nose-flap-weaned calves vocalized less and were less active than abruptly weaned calves during the first few days post-separation, indicating a muted behavioural stress response. Wiese et al. (2016) evaluated how weaning method and timing influence calf behaviour and intake during weaning, transport, and a two-week simulated receiving period. Calves were assigned to 1 of 3 treatments: abrupt weaning with remote separation 5 days before transport, two-stage weaning using nose flaps applied 5 days before transport, or abrupt weaning on the day of transport. In the days leading up to transport, calves fitted with nose flaps were less active than those abruptly weaned early but were more active than calves that had not yet been weaned. Calves abruptly weaned early also spent more time lying in the first 2 days post-weaning. After transport, calves weaned on the day of shipping showed the highest levels of behavioural stress, with increased movement and reduced lying time.

Studies have also examined the effects of nose-flap weaning on cow behaviour. Ungerfeld et al. (2014) compared the behavioural and production responses of beef cows whose calves, averaging 184 days of age, were weaned either abruptly with remote separation or through a two-step method involving nose flap placement 14 days before separation. Cows in the abrupt group vocalized and paced more after separation from their calves than cows in the nose flap group, indicating a stronger behavioural stress response. Milk yield declined in both groups after weaning, as expected; however, cows in the nose flap group lost less body weight than those in the abrupt group, suggesting they experienced less physiological stress or maintained better energy balance during the transition. In a follow-up study, Ungerfeld et al. (2016) evaluated two-stage weaning in early-weaned calves, around 2 months of age, using nose flaps placed 6 days prior to separation. Cows in the nose flap group exhibited fewer stress-related behaviours, such as pacing, vocalizing, and reduced grazing, compared to cows whose calves were abruptly weaned with remote separation. This suggests that the two-stage method can lessen maternal distress even when the cow-calf bond is expected to be particularly strong, such as when calves are still quite young. Mijar (2025) also reported that cows whose calves were fitted with nose flaps showed fewer behavioural signs of distress after weaning, including reduced pacing and vocalizing, and had lower salivary cortisol concentrations compared to cows whose calves were weaned abruptly or by fence line. Cows of abruptly weaned calves exhibited the most vocalization, pacing, and activity on the first day after weaning, but also spent more time eating and ruminating that same day.

The performance outcomes of two-stage weaning are mixed. Lambertz et al. (2014) did not detect statistically significant differences in weight gain between nose-flap and abruptly weaned calves, whereas Freeman et al. (2021) found that calves fitted with nose flaps for 7 days prior to separation had lower average daily gain over a 42-day period post-weaning than abruptly weaned calves. Similarly, Taylor et al. (2020) studied 288 beef calves aged 7 to 8 months and reported that calves fitted with nose flaps 6 days prior to weaning had reduced weight gain in the 13 days before weaning and from 13 days before to 7 days after weaning compared to calves abruptly weaned with remote separation. However, calves in the nose flap group showed higher growth from 13 days before to 28 days after weaning compared to those abruptly weaned and immediately shipped, suggesting that the nose flap group had some compensatory gains after weaning. Lippolis et al. (2016a) also observed lower average daily gain in nose-flap calves

during the 21-day period prior to separation, compared to calves that remained with their dams and were abruptly weaned without nose flaps. It is important to note that reduced growth found prior to separation in nose-flap calves likely reflects their limited diet, as they are prevented from nursing and must rely solely on forage intake, whereas calves that continue to suckle receive both milk and forage, and abruptly weaned calves are typically offered hay or a forage-based total mixed ration.

Lippolis et al. (2016a) further explored the impact of weaning method on immune response. Compared to calves that were abruptly weaned, calves fitted with nose flaps showed reduced humoral immune responses after weaning, including lower antibody titers to bovine viral diarrhea virus type-1 and bovine herpesvirus type-1, a lower percentage seroconverting for bovine viral diarrhea virus type-1, and reduced ovalbumin-specific IgM levels. These differences occurred despite similar post-weaning feed intake, feed efficiency, and morbidity between groups. In contrast, Browning (2023) found that, although body weights and cortisol levels did not differ between groups, calves in their nose flap group mounted a stronger immune response to vaccination compared to those weaned abruptly or by fence-line separation. Griebel et al. (2014) examined how the combination of weaning method and transport timing influenced immune responses in calves following a bovine herpesvirus type-1 challenge. Abrupt weaning combined with transport heightened systemic inflammation, increasing haptoglobin and TNF- $\alpha$ . In contrast, calves fitted with nose flaps 4 days prior to transport showed reduced inflammatory responses, suggesting that both the nature and timing of weaning-related stressors shape immune function and disease vulnerability.

Despite the utility of nose flap devices, concern has been raised about their physical effects. Lambertz et al. (2014) reported that over 95% of calves exhibited nasal abrasions at device removal after 7 days, with 30% showing heavy bleeding and 10% sustaining more severe injuries. Further, 1 week following removal, 45% of calves still showed signs of nasal irritation. Valente et al. (2022) similarly found that despite 27% of calves losing their nose flaps before removal, all calves, regardless of device retention, developed ulcerative nasal lesions that were not present at device placement. Kirk and Tucker (2023) reported that 32% of calves lost their flaps prematurely, while 86% of those that retained the flap for 7 days showed visible bleeding immediately after removal. Six days later, all calves still had tissue damage, although healing had begun. Freeman et al. (2021) also noted similar issues with device retention and nasal injuries.

In summary, nose-flap weaning reduced several behavioural indicators of stress in calves and cows and some physiological indicators of stress in cows, indicative of improved health and welfare compared to abrupt separation. Some studies have observed reduced average daily gain in nose-flap-weaned calves compared to abruptly weaned calves, particularly during the pre-separation period when nursing access is restricted, that often preceded compensatory gains, while other studies did not detect significant differences. Findings regarding immune function are variable, with some studies indicating reduced humoral immune responses, while others report no negative effects or even improved vaccine responses or reduced inflammatory responses to a viral challenge. However, the risk of nasal injury associated with the device, the need for two handling events, and the added labour or stress these may impose remain important considerations.

### 5.3.2 *Fence-Line versus Abrupt Weaning*

Fence-line weaning, which allows visual and auditory contact between cows and calves while preventing nursing, is considered a less stressful alternative to abrupt separation. Among western Canadian cow–calf producers surveyed in 2015, 19% reported using fence-line weaning (Moggy et al., 2017), while a 2023 national survey of 600 producers found that 32% used this approach (BCRC, 2024). Several studies have compared abrupt and fence-line weaning, identifying differences in calf behaviour, performance, and physiological responses.

Behaviourally, fence-line weaning appears to reduce signs of distress in calves compared to abrupt weaning. In a 14-day study by Mac et al. (2024), calves weaned with fence-line contact exhibited more rest and rumination and reduced activity than abruptly weaned calves. Cows in the fence-line group also rested more and were less active in the first few days post-separation than abruptly weaned cows, who showed earlier and higher activity. However, fence-line cows demonstrated reduced eating and rumination for several days after complete separation, which contributed to their lower average daily gain compared to abruptly weaned cows. Similarly, Mijar (2025) reported that cows in the fence-line weaning group exhibited more persistent stress-related behaviours, such as vocalizing, walking, and pacing, from the time of weaning through to 7 days post-separation, compared to abruptly weaned cows. In contrast, abruptly weaned cows showed the highest levels of these behaviours only on day 1 post-weaning and also spent more time eating and ruminating that same day.

With respect to production parameters, most studies report that fence-line weaning, compared to abrupt weaning, has a positive effect on early post-weaning weight gain. In a field trial involving 288 calves, Taylor et al. (2020) found that calves weaned by fence-line contact for 7 days had higher weight gains compared to those weaned abruptly, using nose flaps, or by intermittent separation (i.e., removal from dams for 24-hour intervals on days 13 and 6 prior to weaning, followed by fence-line contact for 7 days post-weaning). Similarly, Gubbels et al. (2023) reported that calves provided fence-line contact for 7 days prior to weaning had the highest average daily gain from weaning to 7 days post-weaning compared to abruptly weaned calves, while the latter gained more between 7 and 26 days post-weaning. Final body weights and carcass traits did not differ among treatments, suggesting that early growth advantages of fence-line weaning may not persist through the finishing period. Silva et al. (2023) found that calves weaned with fence-line contact for 7 days had higher average daily gain and greater body weights up to 82 days post-weaning compared to abruptly weaned calves, with no differences observed in physiological stress markers, such as cortisol. Browning (2023) reported similar results, where fence-line calves gained more post-weaning than abruptly weaned calves, despite no treatment differences in cortisol. Bailey et al. (2016) found that abruptly weaned calves with remote separation in a drylot had greater average daily gain during the 28-day period after weaning and first 60 days following arrival to a feedlot compared to pasture-weaned calves managed with fence-line contact. However, drylot calves tended to have higher morbidity. Drylot-weaned calves also adapted more quickly to feed, approaching the bunk sooner and exhibiting higher feed intake and feed efficiency than pasture-weaned calves without supplemental feed. Interestingly, pasture-weaned calves without supplements demonstrated superior feed efficiency during the finishing phase, suggesting that the performance benefits of different weaning strategies may vary across production stages.

In summary, fence-line weaning reduces calf stress-related behaviours and supports greater early post-weaning growth compared to abrupt, remote separation. However, these benefits may not persist throughout the feeding period, and cows may exhibit more prolonged behavioural stress with fence-line methods. Further research is needed to clarify the long-term effects of fence-line weaning, particularly on dam welfare.

### ***5.3.3 Nose-Flaps with either Fence-Line or Abrupt Weaning***

Campistol et al. (2013) investigated the combined effects of two-stage weaning using a nose flap device for 7 days, followed by either fence-line contact or remote separation, on the growth and physiological responses of beef steers. Among calves fitted with nose flaps, remotely separated calves gained more weight and had lower cortisol concentrations than those that had fence-line contact. Nose-flap use was also associated with increased hematocrit prior to weaning, a higher neutrophil-to-lymphocyte ratio, and reduced lymphocyte percentages from day 0 to 7 post-weaning, indicating a greater physiological stress response regardless of separation method. Overall, while nose flaps may elicit a measurable physiological response due to stress or tissue damage, their impact on growth appears to depend on how calves are separated from their dams.

## **5.4 Management Strategies that may Influence Weaning Outcomes**

### **Conclusions:**

- 1. Weaning age strongly influences calf welfare and performance, with early weaning (under 3 months) leading to heightened behavioural and physiological stress, while delayed weaning (beyond 180 days of age) results in less distress and supports improved growth, assuming cow condition and forage availability are adequate.**
- 2. Nutritional strategies, such as creep feeding, preweaning supplementation, or targeted post-weaning concentrate diets, buffer stress responses and support growth, particularly when early weaning is implemented.**
- 3. Temporary cow–calf separation before weaning, delaying transport after weaning, carefully timing vaccinations relative to weaning, or a combination of these and other management strategies under a preconditioning program may improve resilience, calf behaviour, and health outcomes in the feedlot.**
- 4. Effects of preconditioning are highly dependent on the individual management practices it consists of. Preconditioning did not consistently enhance growth performance in the early feedlot period; however, behavioural adaptation was improved and, in some cases, disease risk and use of antimicrobials reduced.**
- 5. Novel tools, such as bovine appeasing substances, show some promise but need to be examined more thoroughly to assess their practical impact on stress during the weaning transition.**

A range of management strategies has been studied in an attempt to mitigate the welfare and productivity impacts of weaning in beef calves. These potential strategies span decisions around the timing of weaning, the nutritional and social environment pre- and post-weaning, and the use of supportive tools or interventions, such as temporary separation, pheromone therapy, or preconditioning programs.

#### **5.4.1 Weaning Age**

The age at which calves are weaned plays a critical role in shaping both their immediate stress response and longer-term productivity. Studies consistently show that early weaning is associated with greater behavioural and physiological distress. For example, de Souza Teixeira et al. (2021a) compared 36 beef calves, weaned at 30, 75, or 180 days of age (12 calves per group), and found that calves weaned at 30 days exhibited more stress behaviours, including increased vocalization, walking, and cross-sucking, as well as elevated cortisol levels and respiratory rates. These stress responses were consistent in a follow-up study by de Souza Teixeira et al. (2021b), which demonstrated that calves weaned at 30 and 75 days had higher and more prolonged inflammatory and stress markers, including higher cortisol, plasma fibrinogen, and neutrophil-to-lymphocyte ratios, than those weaned at 180 days of age. Together, these findings suggest that early weaning, particularly under 3 months of age, may compromise calf welfare and resilience.

In addition, delaying weaning beyond traditional timelines may offer advantages. Freeman et al. (2021) assessed calves that remained with their dams for an additional 49 days beyond the typical 7-month weaning age. Although both groups of calves were abruptly weaned, those with delayed weaning showed higher average daily gain in the 42 days post-separation compared to their earlier-weaned counterparts. Despite this performance advantage, delayed-weaned calves were just as vocal and active immediately after weaning, suggesting similar levels of behavioural distress. Ultimately, both groups performed comparably through finishing, indicating that delayed weaning can enhance early growth, provided cow condition and forage availability are adequate. Lambertz et al. (2014), who compared calves weaned at 6 versus 8 months of age, found that calves abruptly weaned and remotely separated at 6 months vocalized more, stood or walked longer, and laid down less in the days following separation than those weaned at 8 months, indicating a stronger behavioural stress response. Although post-weaning average daily gain did not differ, calves weaned at 8 months had greater growth between 6 and 8 months, further supporting the potential production benefits of weaning at a later age.

Lambertz et al. (2015) evaluated how the age at weaning and timing of Burdizzo castration relative to abrupt weaning affected the behaviour, physiology, and performance of beef calves aged 6 to 7 months. In a  $2 \times 2$  factorial design, calves were either castrated and weaned concurrently at week 0, castrated at week 0 and weaned 4 weeks later, or left intact and weaned at either week 0 or week 4. On day 1 after weaning, vocalizations were significantly higher in calves weaned at week 0 compared to those weaned at week 4. Further, calves weaned at week 0 also spent less time lying down and more time standing and walking, indicating heightened behavioural stress. Average daily gain was greater during the first 3 weeks post-weaning in early-weaned calves but declined in weeks 4 to 7, becoming lower than in calves weaned later. Haptoglobin concentrations declined over time in all groups, with no effect of castration or weaning timing. The study found no additional behavioural or physiological impacts when castration and weaning were performed concurrently. These findings suggest that weaning had a

stronger influence on calf behaviour and performance than Burdizzo castration, and that performing both procedures at the same time did not exacerbate stress responses.

Together, these studies provide evidence that earlier weaning may increase behavioural and physiological indicators of distress, while delayed weaning may support growth and ease the transition to solid feed.

#### ***5.4.2 Feed Supplementation Prior to Weaning***

Nutritional strategies before weaning can influence productivity and physiological responses to the stress of maternal separation. Campistol et al. (2016) evaluated whether providing a high-fiber supplement for 7 days prior to weaning would affect the physiological stress response and growth of steers managed with either fence-line or total separation. Although all steers gained weight and showed reduced interferon- $\gamma$  levels by the day of weaning, those receiving the supplement exhibited higher neutrophil-to-lymphocyte ratios and tended to have elevated cortisol and ceruloplasmin concentrations, indicating a more pronounced acute-phase response. After weaning, abruptly weaned unsupplemented steers experienced weight loss and higher cortisol levels compared to their supplemented counterparts. Further, from days 14 to 35 post-weaning, unsupplemented steers weaned by fence-line contact gained less weight than all other groups. These results suggest that short-term supplementation prior to weaning may help buffer calves against the negative effects of maternal separation. Reis et al. (2015) explored whether providing creep feed to heifer calves during the nursing phase would influence long-term growth and reproductive development. Heifers that had ad libitum access to a corn-based supplement for 50 days while still suckling had greater average daily gain and higher plasma IGF-I and glucose concentrations at the end of the supplementation period. They also showed differences in liver and adipose gene expression associated with growth and metabolism. However, these early physiological advantages did not result in differences in final body weight, age at puberty, or reproductive outcomes.

Where cow-calf pairs are kept and their nutritional management prior to weaning can also influence both short- and longer-term outcomes for cows and calves. Myerscough et al. (2022) housed cow-calf pairs in either drylots feeding a corn silage-based TMR or on rotationally grazed-pastures from 81 days postpartum through to fence-line weaning at 110 days to assess how housing environment influenced cow condition and calf performance. Cows managed and fed in drylots had greater body weight, body condition score, and milk production at the time of weaning compared to those managed on pasture. Their calves were also heavier and had higher average daily gain prior to weaning. Further, at weaning and during the period after arrival to the feedlot, pasture calves vocalized and walked more, indicating greater behavioural stress, while drylot calves were more active before weaning and vocalized more after transport. Although pasture calves exhibited greater average daily gain and tended to be more feed efficient in the 42-day period following weaning, they remained lighter than drylot calves. Reproductive performance of the cows did not differ between housing environments.

#### ***5.4.3 Nutritional Management After Weaning***

The nutrition provided post-weaning can significantly affect cow and calf performance depending on the timing of weaning. Jaeger et al. (2022) compared early (153 days of age) and

conventional (209 days) weaning strategies in cow–calf pairs managed either in confinement with a concentrate-based diet or on pasture without supplementation. Calves that remained with their dams and received concentrate in confinement had the highest average daily gain over the study period, followed by weaned calves fed concentrate in confinement. In contrast, weaned calves managed on pasture had the lowest gains, while calves that remained with their dams on pasture exhibited intermediate growth. Cow outcomes also varied, with cows in the early weaned group that were kept on pasture losing less body weight and preserving more rump fat, while cows of early-weaned calves housed in confinement lost the most body condition. Moriel et al. (2014) examined early weaning at 72 days of age in Brahman × British crossbred heifers under three post-weaning strategies: (1) fed concentrate until 180 days, (2) fed concentrate until 90 days then grazed, or (3) grazed until 180 days. These were compared to conventionally weaned heifers left with their dams until 180 days. Heifers fed concentrate to 180 days were the heaviest throughout the study, while those fed concentrate and transitioned to pasture at 90 days reached similar body weights to conventionally weaned heifers by day 180. Early-weaned heifers on concentrate diets also had greater average daily gain and higher expression of insulin-like growth factor-1 in the liver, and reached puberty earlier. This indicates that supplementing early-weaned calves with concentrates enhances growth and reproductive development compared to conventional pasture-managed calves, although information on the mid- to long-term effects of these nutrition strategies on health and welfare is limited.

#### ***5.4.4 Temporary Cow–Calf Separation and Handling Before Weaning***

The suckling stimulus and even the physical presence of the calf are influential factors prolonging postpartum anestrus in beef cows. Temporary weaning, involving short periods of separation or the use of nose flaps, has been evaluated both as a strategy to improve reproductive efficiency and as a means of reducing the stress of weaning. Pérez-Torres et al. (2016) assessed the behavioural and physiological responses of calves and cows to temporary separation of 24, 48, or 72 hours at 25 and 45 days postpartum. As the duration of separation increased, calves vocalized less, spent less time near the fence, and had lower cortisol concentrations and weight loss. Calves also appeared to have a lower stress response when separated at 45 days compared to 25 days. While cows exhibited fewer behavioural responses overall, cortisol concentrations were highest in cows whose calves were separated for 72 hours at 25 days postpartum compared to those separated for 24 or 48 hours at the same age, suggesting that prolonged separation at an early stage may heighten physiological stress in the dam. In terms of weaning stress, Hötzel et al. (2012) explored whether previous experience with temporary weaning improved calf responses to two-step weaning with nose flaps. Calves either temporarily wore a nose flap for 13 days at around 10 weeks of age or were allowed to continue suckling. Later, all calves were weaned using a two-step process involving nose flaps followed by permanent separation. Calves with prior nose-flap experience adapted more quickly during the nose-flap application period at weaning and showed fewer signs of distress following separation, including reduced vocalization and a faster return to grazing. Notably, prior nose-flap use did not appear to cause aversion when reapplied, despite concerns about nasal injury, indicating calves tolerated repeated exposure to the device. These results suggest that familiarity with temporary weaning methods might improve behavioural adaptation during final weaning. Similar findings were reported by Pérez et al. (2017), who evaluated the effects of separating *Bos indicus* cow–calf pairs for 24, 48, or 72 hours at both 25 and 45 days postpartum. Compared to continuously suckled calves, those

subjected to maternal deprivation displayed fewer signs of distress around the time of final weaning at 150 days of age. These calves vocalized less, spent more time grazing, and had lower cortisol concentrations in the days following weaning. By 270 days, calves previously separated for 48 or 72 hours were heavier than control calves, suggesting improved post-weaning growth. All these results suggest that the inclusion of temporary maternal separation strategies could reduce the signs of behavioural distress during the final weaning.

#### ***5.4.5 Time from Weaning Until Shipping***

The interval between weaning and transport can significantly influence calf health, behaviour, and performance. Taylor et al. (2020) showed that 7- to 8-month-old calves shipped at the time of weaning or within seven days afterward had the poorest average daily gain and the highest rates of morbidity, regardless of the weaning method, compared to delaying transport by 28 days post-weaning. Wiese et al. (2016) also investigated how the timing of weaning relative to transport impacts behavioural stress responses and feed intake. Calves weaned abruptly on the day of transport displayed the highest behavioural signs of stress after arrival at the feedlot, including increased locomotion and reduced lying time, compared to calves weaned 5 days prior, either abruptly or via a two-stage method. Despite these behavioural differences, dry matter intake during the period after feedlot arrival did not differ between groups. This evidence indicates that separating weaning from transport causes a significant improvement in calves' welfare.

#### ***5.4.6 Vaccination Timing***

The timing of vaccination relative to weaning can affect both immune responses and calf performance. Schumaker et al. (2019) compared 3 vaccination strategies in calves preconditioned for 30 days, each involving 2 doses of vaccine against BRD administered 30 days apart: at weaning and again at feedlot arrival, 15 days before both weaning and feedlot entry, or 15 days after each event. Calves vaccinated before weaning and before feedlot entry mounted stronger antibody responses to all measured respiratory pathogens and had a lower incidence of respiratory disease. Body weight and carcass traits did not differ among groups. In a similar study, Lippolis et al. (2016b) evaluated the same 3 vaccination strategies and found that calves vaccinated 15 days before both weaning and feedlot entry had higher antibody concentrations at feedlot arrival. Although these calves gained less weight before weaning, they had greater average daily gain after feedlot arrival compared to those vaccinated at weaning or 15 days after each event, likely reflecting compensatory growth. Overall body weight, feed intake, and health outcomes after arrival did not differ among groups. Silva et al. (2018) further explored how vaccination timing interacts with nutritional management. In their 2 × 2 factorial study, calves were vaccinated either before weaning (14 days before and at weaning) or after weaning (7 and 21 days post-weaning) and then provided a concentrate supplement either daily or 3 times weekly. Calves vaccinated before weaning and supplemented 3 times per week had the lowest average daily gain, while those vaccinated after weaning and fed daily had the highest. Pre-weaning vaccination increased plasma cortisol and haptoglobin concentrations and reduced serum antibody titers to parainfluenza-3 virus, indicating a stronger inflammatory and weaker humoral immune response. Infrequent supplementation was also associated with elevated cortisol and lower antibody titers to bovine viral diarrhoea virus type-1. Collectively, these studies suggest that vaccinating calves before weaning can enhance immune responses and may reduce

disease risk, but could impair growth unless paired with consistent, high-quality nutritional support.

#### **5.4.7 Preconditioning**

Preconditioning programs, typically involving a range of the management strategies mentioned so far, such as weaning calves several weeks before transport, combined with vaccination, deworming, and transition to feedlot-style diets, are designed to improve health and performance outcomes. However, their effectiveness can also be influenced by management practices, housing, and post-arrival conditions.

Vanbergue et al. (2024) evaluated a preconditioning protocol in 9 commercial herds where young bulls were weaned indoors 50 days before transport, vaccinated twice with a respiratory vaccine, dewormed, and transitioned to a concentrate-based diet. Control calves remained on pasture with their dams until transport and received no interventions. Preconditioned calves experienced higher morbidity and respiratory disease scores during the preconditioning period, likely due to indoor housing and increased pathogen exposure, and no health differences were observed after arrival at the feedlot. Further, preconditioned calves, having had earlier exposure and adaptation to a concentrate-based diet, showed higher average daily gain during the 50-day preconditioning phase. Long-term outcomes, such as final body weight, carcass weight, and days on feed, however, did not differ between groups, suggesting there might have been compensatory gain. In a study evaluating the first 40 days in a feedlot, Mijar et al. (2023) assessed health and performance in feedlot pens containing different proportions of preconditioned and auction-derived calves. Morbidity was lowest in pens with only preconditioned calves, and preconditioned animals were less likely to develop and be treated for BRD than pre-sorted, auction-derived calves. Auction-derived calves gained more weight over the 40-day trial period, regardless of pen composition, likely due to this group starting with a lower body weight and being more prone to compensatory gains. Interestingly, calves in pens with only 25% preconditioned animals showed both the highest morbidity and the highest average daily gain, with the authors suggesting interactions between use of antimicrobials and improved performance outcomes.

Preconditioning has been shown to support a more favourable behavioural time budget after arrival to the feedlot. Hodder et al. (2023) found that preconditioned calves spent more time eating and less time inactive in the first 7 days after feedlot arrival compared to both auction-derived and ranch-sourced calves. These patterns were partially maintained even when preconditioned calves were commingled with auction-derived calves, although feeding time declined slightly as the proportion of auction calves increased. Further, rumination behaviour did not differ among groups. Mijar et al. (2024) used behavioural sensors and hair cortisol analysis to evaluate stress and adaptation in the same groups of preconditioned and pre-sorted, auction-derived steers (Mijar et al., 2023) over 6 weeks in the feedlot. Preconditioned steers consistently spent more time eating, ruminating, and being active and less time inactive during the first 3 weeks, regardless of commingling status. These behavioural patterns indicate more rapid acclimation, although hair cortisol levels, disease incidence, and growth did not differ between groups.

Together, these studies suggest that a preconditioning program is only as good as the individual management practices included in it. While preconditioning may not consistently enhance growth performance in the early feedlot period, it improves behavioural adaptation and, in some cases, reduces disease risk and use of antimicrobials.

#### 5.4.8 Pheromone

Pheromone-based products, such as bovine appeasing substances, have been explored as a non-invasive approach to mitigate stress and support adaptation during the weaning and preconditioning period. These synthetic analogs mimic natural maternal pheromones and may influence behaviour, immune function, and growth. Schubach et al. (2020) evaluated the application of a bovine appeasing substance at weaning and monitored stress, behaviour, and performance in abruptly weaned beef calves over a 42-day preconditioning period. Treated calves had greater average daily gain during the first 28 days and higher feed intake during the first week after weaning. Further, treated calves showed more feeding, social, and play behaviours. They also had lower haptoglobin and hair cortisol concentrations, slower chute exit velocity, and stronger vaccine-induced antibody responses compared to untreated controls. Similarly, Vieira et al. (2023) studied the use of a bovine appeasing substance in abruptly weaned Nellore calves. Treated animals, compared those given saline, exhibited fewer behavioural and physiological signs of stress, including lower chute exit velocity, reduced vocalizations, and lower serum cortisol concentrations. They also spent more time grazing, eating, walking, ruminating, and playing, and had higher serum titer concentrations of parainfluenza-3 virus and bovine viral diarrhoea virus type 1. Finally, Kvamme et al. (2024) evaluated the effects of repeated bovine appeasing substance applications during a 42-day preconditioning program followed by transport to a feedlot. While average daily gain, final body weight, and feed efficiency did not differ between treatment groups, treated calves had lower plasma haptoglobin concentrations on days 3 and 7 relative to arrival at the feedlot, reduced non-esterified fatty acid levels on day 3, and lower exit velocity across multiple time points compared to calves administered a placebo.

More research has examined the use of bovine appeasing substances administered at the time of feedlot entry. Pickett et al. (2024) found that applying bovine appeasing substance to newly weaned, high-risk calves at feedlot arrival and at day 14 after arrival reduced hair cortisol levels, lowered *Mycoplasma* abundance in the nasal microbiota, and decreased respiratory disease-related mortality compared to the placebo. Although BRD incidence was similar across groups, pheromone-treated calves were more likely to recover with a single antibiotic treatment and had greater total pen-based weight gain. Cooke et al. (2025) reported that administering bovine appeasing substance during initial processing and at reimplant improved growth, final body weight, hot carcass weight, and feed intake compared to a placebo. Further, treated animals also had reduced morbidity and mortality due to respiratory disease in one of the experiments.

Collectively, these studies suggest that bovine appeasing substances could reduce behavioural and physiological indicators of stress, enhance immune responsiveness, and support positive adaptation during the weaning and preconditioning period. Further research is needed to validate these results with different commercially available or experimental products under Canadian conditions, and to assess the cost-benefit of such products.

#### **5.4.9 *Addition of Social Facilitator Cow***

Nickles et al. (2020) investigated whether placing a social facilitator cow with abruptly weaned calves on pasture could reduce walking behaviour and prevent weight loss. Heifer calves were randomly assigned within each replicate to either a group with a social facilitator cow or a control group without one, with multiple replicates conducted across two locations. Although calves with a social facilitator tended to spend less time walking and covered shorter distances on the day of weaning, no differences were observed in body weight or average daily gain between groups. These findings suggest that simply introducing an unrelated adult cow is not sufficient to meaningfully influence calf behaviour or performance, likely because the maternal bond is key to moderating the stress response.

### **5.5 Future Research**

While significant progress has been made in understanding the welfare and performance impacts of weaning, several knowledge gaps remain. Future research should explore how combinations of weaning methods and management strategies interact to influence long-term outcomes, including immune competence, feedlot performance, and carcass quality. It is also important to recognize that good performance, such as high average daily gain, does not always indicate better welfare or resilience. Studies should continue to assess behavioural and physiological indicators alongside production metrics. There is a need for field-based studies that evaluate the economic feasibility and practicality of low-stress weaning methods across diverse production systems. Finally, research should assess the potential benefits and limitations of novel strategies, such as pheromone use, in commercial settings and determine how these tools can be effectively incorporated into broader health and welfare programs.

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