CODE OF PRACTICE FOR THE CARE & HANDLING OF SHEEP: REVIEW OF SCIENTIFIC RESEARCH ON PRIORITY ISSUES

October 2012

Sheep Code of Practice Scientists' Committee

Michael S. Cockram B.Vet. Med., Ph.D. (Chair)
Chair in Animal Welfare, Sir James Dunn Animal Welfare Centre
Professor, Department of Health Management
University of Prince Edward Island

Paula Menzies D.V.M., M.P.V.M., Dip. E.C.S.R.H.M.
Professor, Ruminant Health Management
University of Guelph

David Barrett Ph.D.
Assistant Professor, Animal Physiology
Nova Scotia Agricultural College

John Hemsted
Sheep Code Development Committee Chair (ex-officio)
Canadian Sheep Federation

NATIONAL FARM ANIMAL CARE COUNCIL
CONSEIL NATIONAL POUR LE SOIN DES ANIMAUX D'ÉLEVAGE

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Excerpt from Scientists' Committee Terms of Reference

Background

It is widely accepted that animal welfare codes, guidelines, standards or legislation should take advantage of the best available knowledge. This knowledge is often generated from the scientific literature, hence the term "science-based".

In re-establishing a Code of Practice development process, NFACC recognized the need for a more formal means of integrating scientific input into the Code of Practice process. A Scientists' Committee review of priority animal welfare issues for the species being addressed will provide valuable information to the Code Development Committee in developing or revising a Code of Practice. As the Scientists' Committee report is publicly available, the transparency and credibility of the Code process and the recommendations within are enhanced.

For each Code of Practice being developed or revised, NFACC will identify a Scientists' Committee. This committee will consist of 4-6 scientists familiar with research on the care and management of the animals under consideration. NFACC will request one or two nominations from each of 1) Canadian Veterinary Medical Association, 2) Canadian Society of Animal Science, and 3) Canadian Chapter of the International Society for Applied Ethology.

Purpose & Goals

The Scientists' Committee will develop a report synthesizing the results of research relating to key animal welfare issues, as identified by the Scientists' Committee and the Code Development Committee. The report will be used by the Code Development Committee in drafting a Code of Practice for the species in question.

The full Terms of Reference for the Scientists' Committee can be found within the NFACC Development Process for Codes of Practice for the Care and Handling of Farm Animals, available at www.nfacc.ca/code-development-process#appendixc.

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1. STRESSFUL HANDLING AND MANAGEMENT PROCEDURES
(previously Low Stress Management and Handling)

Conclusions:

1. **Many handling and management procedures are stressful to sheep.**

2. **In many circumstances where sheep show either physiological signs of stress in response to a procedure or show behavioural responses indicative of aversion, it is likely that sheep experience an emotional state.**

3. **Application of emotional theory can increase understanding of the circumstances where sheep experience stress and help to identify measures to reduce stress responses to handling procedures. Sheep are sensitive to the suddenness, unfamiliarity and predictability of their environment and form expectations of events and consequences of these events.**

4. **Research findings have identified the components of some routine procedures that are stressful and these results can be used to recommend strategies for mitigating the stress response. Utilizing positive reinforcement during handling or when undertaking a procedure, familiarizing or habituating the sheep to the handling area, or providing some gentling with humans can help to reduce the stress of handling procedures. Other strategies such as avoiding isolation and inversion of individual sheep can also be used to mitigate stress.**

5. **Research on how to utilise the natural behaviour of sheep during handling procedures has provided practical information on best practices to adopt. Sheep are social animals to which flocking and following are important natural behaviours that can be utilised during handling procedures.**

Background: In all systems of management, sheep are handled and subjected to different management procedures. These procedures are undertaken for health reasons (e.g. vaccination, dipping, foot-bathing, foot-paring and drenching) and for production reasons (e.g. shearing and drafting [sorting]) (Hargreaves & Hutson, 1997). Most handling involves gathering the sheep, movement to another location, close human proximity and then performance of a procedure. Unfortunately, many of these handling procedures are stressful to sheep and if given the opportunity the sheep would avoid them. In a review of the behavioural principles of sheep handling, Hutson (2007) stated that “sheep movement is usually prompted using fear-evoking stimuli, and the treatment is usually stressful and aversive.” The circumstances in which sheep are stressed during handling (Table 1), the reasons why sheep are stressed during handling, the potential methods for mitigating stress during handling and the behavioural principles underlying optimal handling will be discussed.

Stress: The term stress is used in many contexts, but it has been defined as “the biological response elicited when an individual perceives a threat to its homeostasis," where the threat is the ‘stressor’ (Moberg, 2000). Certain conditions (stressors) can activate the hypothalamo-pituitary-adrenocortical axis and the sympatho-adrenal medullary axis (i.e. activation of physiological pathways between the brain, the nervous system and the adrenal gland that result in the secretion of stress hormones) (Minton, 1994). As a consequence of the early work by Selye and Canon (Cannon, 1939; Selye, 1936, 1946), the endocrine e.g. plasma cortisol and catecholamine concentrations, and associated physiological e.g. heart rate, and behavioural responses to stressors have been used to describe conditions that are stressful (Minton, 1994). However, they do not represent independent means for identifying stress. Stress is simply defined by this type of response (Rushen, 1986b). Similar physiological responses, e.g. raised plasma cortisol concentration, to those used to describe stress can also occur during times of arousal that may be associated with positive rather than negative experiences. Therefore a raised cortisol concentration cannot necessarily be interpreted as indicating a negative emotional state, e.g. distress (Moberg, 2000, Rushen, 1986b). In addition, the decline in a plasma cortisol concentration response to a stressor cannot necessarily be used to indicate that the sheep is less stressed than before. It is possible that a sheep could still be responding to a stressor e.g. at a higher level of the hypothalamo-pituitary-adrenocortical axis, but is no longer able to secrete cortisol from the adrenal cortex. For example, Coppinger et al. (1991) reported a decreased plasma cortisol response after 3 days of 6 hours/day of restraint and isolation, but this treatment still continued to cause an adrenocorticotrophic hormone (ACTH) response. Certain responses used to describe stress can also be influenced by other factors that are integral to either the response or the measurement of the response, for example an increase in activity often increases heart rate, regardless of whether the cause of the increased activity is a stressor. The types of physiological measurements used to assess stress and some of the methodological difficulties associated with their use have been reviewed by von Holst (1998), Cook et al. (2000) and Mellor et al. (2000). In many situations, the physiological responses that occur while animals experience distress cannot readily be distinguished from those that occur during fear, pain and other forms of suffering (Cockram, 2004). It is with these limitations that cortisol responses to management procedures (as shown in Table 1) have been interpreted as indicative of stress in sheep. As discussed by Ramos and Mormede (1998) and Veissier and Boissy (2007), the measurement of behavioural and neuroendocrine variables that typically change in stressful situations, in spite of all of the difficulties, is one of the few tools available and the approach most commonly adopted to assess the level of emotional activation of an animal.

In an attempt to clarify the different types of stress response, Sanford et al. (1986) differentiated distress from short-term, adaptive physiological stress by proposing that during distress detrimental effects to the animal can occur, and that the animal is likely to be aware that it is making an increased effort to respond to a stimulus. In this report, the term distress is used in a scientific context (see section below ‘Distress and fear as emotional states in sheep’) rather than in the legal manner used in some Canadian legislation. In some legislation, in addition to describing a situation where an animal is likely to be experiencing suffering, confusingly, the term is also used to include a situation where there is a lack of certain basic provisions, regardless of the actual emotional state of the animal.

Although inappropriate handling can result in: injury either directly or as a result of a behavioural response; delays and inefficiencies in performing a procedure; and in some circumstances, possibly long-term harm to the reproductive performance and health of sheep, it is the likely distress associated with normal, routine handling procedures that is addressed in this report. Other potential effects of stress, such as those on immunity (Dantzer & Kelly, 1989), productivity (Caroprese et al., 2010) and reproduction (Dobson & Smith, 2000; Rasmussen &

Malven, 1983; Tilbrook et al., 1999) are potentially important as they might indicate reduced fitness. However, most handling procedures only produce acute stress. Although acute stress can affect the emotional state of sheep, it does not normally cause lasting harm to body functions (Minton & Blecha, 1990).

Procedures that can cause stress:

Table 1: Examples of situations that in some circumstances can cause stress (i.e. a cortisol response) in sheep.

Stimulus	**Reference**
Social environment factors:	
Visual isolation	Apple et al. (1993); Bobek et al. (1986); da Costa et al. (2004)
Confinement that restricts movement	Holley et al. (1975)
Fear factors:	
Human movement/shouting	Harlow et al. (1987); Thurley & McNatty (1973)
Dog proximity/gathering/barking	Dawood et al. (2005); Harlow et al. (1987); Kilgour & de Langen (1970); Thurley & McNatty (1973); Hemsworth et al. (2011).
Handling factors:	
Restraint	
Legs tied together	Kilgour & de Langen (1970)
Legs tied together plus isolation	Coppinger et al. (1991); Minton &Blecha (1990)
Legs tied together and placed on side	Carcangiu et al. (2008)
Sitting position, placed on each side then in sitting position	Mears & Brown (1997)
On side	Stafford et al. (1996)
Exercise (vigorous)	Apple et al. (1994)
Drafting (sorting)	Hargreaves & Hutson (1990d)
Procedures:	
Shearing	Kilgour & de Langen (1970); Hargreaves & Hutson (1990a); Mears et al. (1999)
Crutching	Hargreaves & Hutson (1990d)
Drenching	Hargreaves & Hutson (1990d)
Dipping	Hargreaves & Hutson (1990d); Kilgour & de Langen (1970)
Shower dipping	Hargreaves & Hutson (1990d)
Milking (initial response)	Negrão & Marnet (2003)
Electroimmobilisation	Jephcott et al. (1986)
Electroejaculation	Damián & Ungerfeld (2011); Stafford et al. (1996)
Artificial insemination	Houdeau et al. (2002)

DISTRESS AND FEAR AS EMOTIONAL STATES IN SHEEP

Distress. The release of cortisol that characterises a stress response is not produced by the environmental change or stressor directly, but is thought only to occur when the animal perceives the situation as aversive (Désiré et al., 2002). This implies that an animal, such as a sheep, possesses some cognitive ability to process and interpret the changes in its environment. Therefore, stress responses to handling procedures suggest that if given the choice, the sheep would avoid the procedure, and that during the procedure, the sheep might experience an aversive emotional state. As animal welfare concerns are based on the recognition that animals are sentient and able to experience emotions, such as fear, distress and pain, minimising the stress response to a procedure is likely to be beneficial to the sheep.

The existence of emotions, such as distress, in animals is a controversial issue. Emotions and mental states cannot be measured directly. When a sheep is handled in a way that causes it some distress, it is not possible to directly perceive the suffering that it is experiencing (Rushen, 1996). Emotions in animals are postulated by interpreting the responses of animals in the light of human experience. There are clear analogies between the physiological and behavioural expressions of emotion in humans in response to a stressor and the behavioural or physiological responses reported in animals to similar events (Désiré et al., 2002). For at least some of the time when sheep could be experiencing distress, this is associated with the same types of physiological changes (e.g. cortisol excretion and changes in heart rate) that occur when humans report that they are experiencing distress (Lundberg & Frankenhaeuser, 1980; Morgan et al., 2002). The neurobiology that supports the experience and expression of emotions in humans also exists in animals. Therefore, it is a reasonable assumption that sheep are capable of experiencing the negative emotional state of distress (Désiré et al., 2002). Veissier et al., (2009) concluded that the neurophysiological responses of sheep to stressors, such as increased heart rate and plasma cortisol concentration, and the behavioural responses, such as startle and escape attempts, provide evidence of their emotional response. In human psychology, "emotions are viewed as the result of how an individual evaluates a triggering situation, beginning with an evaluation of the situation *per se* and followed by the possible responses to that situation." Veissier et al., (2009) describes the components of an emotional response as consisting of the internal-psychological component (i.e. feelings), the neurophysiological component (the stress response by the body), and the behavioural component (body demeanor and movements). In addition to measuring the neurophysiological and behavioural responses to a procedure, as an indirect way of attempting to assess the emotional response, it is also possible to perform psychological tests to determine the relative aversiveness of a procedure (Rushen, 1996). For example, the relative distress caused by two handling treatments can be tested by allowing sheep to choose between two alternatives. The relative distress is assessed by recording the number of times that the sheep choose each treatment (Rushen, 1990).

Fear: As part of an anti-predator mechanism, sheep have developed fear responses to many stimuli (Dwyer, 2004). A consequence of this is that sheep are particularly prone to show stress responses to many components of handling procedures that contain fearful stimuli (associated with potential predation), such as novelty, sudden events, isolation from other sheep and proximity to humans. Fear is an emotional state induced by the perception of an actual danger, and anxiety is the perception of a potential danger (Boissy, 1995). Fearfulness may be influenced by genetic and environmental factors (for a review see Boissy, 1995). In some systems of management, the opportunities for sheep to familiarise themselves with humans can be infrequent. Reducing the frequency of potentially aversive events or providing handling or training, that is perceived as a positive experience by the sheep could reduce fear or anxiety. As shown by Boissy et al. (2005) different breeds and genotypes within breeds show different behavioural responses to fearful situations, e.g. humans and isolation. Therefore, genetic selection aimed at reducing fearfulness is a potential approach to reducing stress associated with handling (Boissy et al. 2005).

Application of emotional theory to reduce stress responses of sheep to handling procedures: Human psychological theory has been applied to help understand the situations where sheep might experience stress and has provided the basis for studies that have tested whether sheep respond to some situations in a similar manner to that of humans. Although anthropomorphism carries the risk of misinterpreting animals' responses, animals and humans share common characteristics. Veissier et al. (2009) reviewed the evidence from a series of experiments on sheep (e.g. Désiré et al., 2006) that support the notion that in many ways the emotional responses of sheep to a situation are similar to those of humans. "Sheep are sensitive to the suddenness, unfamiliarity and predictability of their environment" and these components of a handling procedure are likely to affect their emotional responses. Sheep can also "form expectations about their environment". "They expect some events to occur, and they also expect these events to have specific consequences". If these events do not happen in the anticipated manner, the sheep is likely to show an emotional response to these events. Another important factor affecting the emotional response of a sheep is the extent to which it perceives that it is able to influence the event to which it is exposed and/or act on the consequences of this event. The emotional responses are also affected by dominance relationships with other sheep, with "more internal reactions when the sheep is dominated" and "more overt reactions when it dominates" other sheep. An understanding of the factors that are likely to influence whether a particular procedure is likely to be stressful and the options available to mitigate a stress response can be achieved from an appreciation of the above principles.

Hargreaves and Hutson (1997) proposed three approaches that could be undertaken to reduce the aversiveness of handling treatments: "reducing the severity of the treatment, changing the sheep's perception of the treatment as aversive, or breaking the association between handling and the aversive treatment". The following examples were suggested by Hutson (2007): separation of painful treatments from other handling procedures, training sheep to use food rewards, habituation to the procedure, gentling, conditioning to humans and handling, simplifying the learning procedure, e.g. cues associated with the treatment, location and handler, and avoid using humans as a fear inducing stimulus to move sheep.

Experience: Lambs can show stress responses to handling and restraint at 1 day of age (Moberg et al., 1980). However, experience affects subsequent responses to handling procedures through learning (any lasting change in behaviour resulting from experience) and memory (the ability to store and recall the effects of experience) (Hargreaves & Hutson, 1997). For example, Rushen (1996) describes a situation where before sheep were first exposed to a shearing treatment they would readily run through a race, but after four experiences of simulated shearing at the end of the race, they showed some resistance to re-entering the race and had to be pushed to move along the race. The sheep had learnt to expect the treatment and were reluctant to be exposed to a treatment that they found aversive. Some sheep will remember some procedures undertaken at the end of a race for up to a year (Hutson, 1985). Mears et al. (1999) found a significantly greater cortisol response to shearing in ewes that had been shorn 1-4 times previously than in naive ewes that had not been shorn (however, in this study, the day of measurement was confounded by treatment). In contrast, Carcangiu et al. (2008) found no significant difference between the cortisol response of adult ewes and that in lambs shorn for the first time.

Positive and negative experiences: Unfortunately, many handling procedures are aversive e.g. inversion/up-ending, and they act as negative reinforcement to free movement within a handling system (Hutson, 2007). The effect of a handling experience can depend on whether it is perceived as pleasant or unpleasant (Hargreaves & Hutson, 1997). “Sheep quickly learn to avoid negative reinforcers and to seek out positive stimuli linked with handling" (Hargreaves & Hutson, 1997). Once sheep have experienced a treatment in a handling system that they perceived as aversive they may be hesitant to move freely through the system on subsequent occasions. The treatment can act as a negative reinforcement of the preceding behaviour, i.e. the sheep receive a punishment for moving through the handling system. One possible solution to this problem is to utilise an alternative motivation for prompting movement. Rather than using fear-evoking stimuli followed by a negative reinforcement, movement can be encouraged by positive reinforcements. The simplest positive reinforcement to use with sheep is food. “Sheep rapidly develop a preference for handling associated with food rewards” (Hargreaves & Hutson, 1997) and appear to be able to discriminate between humans that feed them and those that do not (Davis et al., 1998). Hutson (1985) found that a small barley reward, immediately after handling, reduced the time needed to push the sheep back into the same race on a subsequent occasion. After 10 days of training over 1 month, when sheep were running through a race and then either not handled, clamped (i.e. held tightly against the walls of a handling crate), or clamped and inverted in the handling crate, less time was spent pushing up sheep that had been given barley after the treatments than for unrewarded sheep. When the treatment was repeated after 1 year, similar results were obtained for control and clamped groups (in both groups, less time was spent pushing up sheep that had been rewarded with barley). However, there was no significant effect of providing a barley reward on the time required to push up the sheep in the clamped and inverted group (Hutson, 1985).

Hargreaves and Hutson (1997) considered that another way of avoiding the development of a generalised aversion to handling would be to intersperse stressful procedures with more innocuous handling procedures.

Habituation: If sheep are repeatedly exposed to the same facilities, stress and fear reactions can decrease (Boissy, 1995). There are benefits in familiarizing sheep with yard and race configurations (Hutson, 1980). There are also advantages in taking sheep along the same route every time they are handled (Hargreaves & Hutson, 1997). Hutson (1980) showed that after a 6-week period, sheep that had experienced a particular route and direction of flow through that route fifteen times previously, ran faster than inexperienced sheep, who in turn ran faster than sheep who were familiar with the yard, but had learned to enter from a different direction or through a different configuration. Habituation to a procedure can lead to improvements in sheep handling by reducing the stress response (Hargreaves & Hutson, 1997) and the aversiveness to the treatment (Hargreaves & Hutson, 1990a). Habituation is a form of learning, consisting of a gradual decrease in a response after exposure to a repeated stimulus, such as handling, without reinforcement (i.e. the use of positive rewards or punishment). The physiological stress response to handling can decrease after several exposures (Hargreaves & Hutson, 1997). Repetition of the handling may also be sufficient to reduce aversion. In sheep subjected to sham shearing (i.e. all components of the shearing procedure, except for actual wool removal), once a week for 4 weeks, neither the flight distance of the sheep in response to human proximity nor the maximal cortisol response was significantly affected, but the cortisol concentration returned to a baseline value quicker than it did at the start of the treatments (Hargreaves & Hutson 1990b). The rate of habituation depends on the number of times that sheep are exposed to the handling treatment and the frequency of exposure. Under some systems of extensive management, the handling may be too infrequent for habitation to occur (Hargreaves & Hutson, 1997).

Gentling: Hargreaves and Hutson (1990c) investigated whether repeated tactile, visual and auditory contact with a human (gentling) could reduce stress and make sheep easier to handle during subsequent procedures. For 35 consecutive days, they placed three sheep in a solid-sided race, then lowered a gate to isolate a sheep and then 'gentled' the isolated sheep for 20 seconds by a human standing next to the sheep and talking and patting it. They then compared the responses once a week for 5 weeks of gentled and non-gentled sheep to either no treatment or sham shearing at the end of the race. The heart rate and the flight distance of the sheep were reduced by gentling. However, the time that the sheep took to move along race to receive sham shearing was not affected by gentling. Although gentled sheep took longer to enter the race than non-gentled sheep, Hargreaves and Hutson (1990c) interpreted this as a reduced fear response to the human moving behind the sheep to encourage it to enter the race rather than an increased fear response to the sham shearing at the end of the race. Markowitz et al. (1998) showed that young lambs that had received gentling and artificial feeding subsequently approached a stationary human more readily and spent more time near the person than lambs that had been reared with their mother. In response to a human walking towards them, the distance from the human was closer in handled lambs than in non-handled controls. Although Mateo et al. (1991) found that gentling for 5 minutes/day for 3 weeks reduced the latency of sheep to approach a handler, it did not affect the time taken for sheep either to move along a race or the time spent pulling on a rope after head restraint with a halter.

Stressful and/or aversive components of a procedure: Most handling procedures, such as shearing, have a number of components, and it is possible to evaluate which of these components are stressful and/or aversive and in some situations also rank how stressful or aversive each component is to the sheep. Hargreaves and Hutson (1990a) compared the following components of shearing: isolation/no isolation; restraint with inversion or up-ending/straddled and strapped to a saw horse and head restrained, but not up-ended; and shorn/not shorn. All eight treatment combinations performed for 4 minutes caused a cortisol response. However, shearing was responsible for the greatest cortisol response followed by isolation with up-ending restraint. In contrast, Mears et al. (1999), also found that both shearing and sham shearing caused a significant cortisol response, but they did not find a significant difference in the magnitude of the responses. In sheep allowed to choose between pairs of handling treatments by giving sheep repeated pairs of choices to enter a Y-shaped maze that contained a 2-minute treatment at the end of one arm, Rushen (1986a) was able to rank the aversiveness of the treatments to the sheep by the preferences shown by the sheep to each pair of treatments. The order of the treatments from least aversive to most aversive was as follows: human presence, confinement surrounded by other sheep, visual isolation, restraint and isolation, and restraint involving inversion and isolation. As a result of these studies, Hargreaves and Hutson (1990c) and Rushen (1996) suggested that shearing sheep in an upright position while in visual contact with other sheep, would be less aversive than the normal practice of isolating one sheep and then shearing it in an up-ended position. Isolation can be a component of many procedures. Where it cannot be avoided by maintaining visual contact with other sheep, the use of either a mirror (Parrott et al., 1988) or an image of the face of a sheep from the same breed (da Costa et al., 2004) can reduce the magnitude of the cortisol response to isolation.

Dogs are often used to move sheep. However, they can cause fear and stress because dogs are likely to be perceived as a predator by sheep (Hemsworth et al., 2011). Beausoleil et al. (2005), using distance from the social group as an assessment of fear, found that a dog was more aversive to a sheep than a human. As the “traditional motivation used to move sheep is the repeated application of fear-inducing stimuli" e.g. dogs, auditory or visual stimuli, Hutson (1985) suggested the use of leader sheep and food rewards as alternatives.

Utilizing natural behaviour during handling procedures: Another important consideration is the use of a handling procedure that “accommodates and exploits the animals’ behaviour” (Hargreaves & Hutson, 1997). Hutson (2007) reviewed the behavioural principles of sheep handling under the following headings: handling system design, handling technique and reason for handling. “Four factors are considered to affect the adequacy of a sheep handling system: the sheep; the stockperson; the physical environment; and the reason for sheep being handled - the treatment” (Hargreaves & Hutson, 1997). Hutson (2007) considered that the principles of ‘good’ handling are “minimal use of fearful stimuli, avoidance of loud noises, use of positive reinforcements rather than punishment and awareness of flight distance." Hutson (2007) recommended “that the most crucial design criterion was to give sheep a clear, unobstructed view towards the exit, or towards where they are meant to move.”

Social behaviour: Sheep are very social and group together as a flock. Flocking behaviour is influenced by a number of factors and there are some differences between breeds in the distances between individuals within a flock (Jørgensen et al., 2011). The behaviour within a flock tends to be synchronised, and they will walk together following one another (Hutson, 2007). “Following behaviour is exploited during handling when sheep are driven as a group and moved through chutes and races.” (Hargreaves & Hutson, 1997). Because flocking and following are important behaviours, any handling that involves separating or disrupting groups of sheep will cause difficulties for both the sheep and handler (Hargreaves & Hutson, 1997). Sheep run faster through races 1.5m wide than races 0.5m wide because they can move as a group rather than being restricted to a single file (Franklin & Hutson, 1982c; Hutson & Hitchcock, 1978).

Sheep move easier on non-slip surfaces. Compared to less steep angles, it takes sheep longer to move up or down when the incline is greater than 30^o. If the ramp is narrow (0.5m wide) and the incline is 30^o or greater, the sheep take longer to move down the ramp than they take to move up the ramp (Hitchcock & Hutson, 1979b). Lighting that causes shadows causes difficulty, but contrasts in light do not have a major influence on sheep movement (Hitchcock & Hutson, 1979a). Franklin and Hutson (1982a, b) found no benefit in using either olfactory stimuli or sheep vocalizations to encourage sheep to move along a race. An electrical stimulus is also not useful when attempting to move sheep in a race. McCutchan and Freeman (1992) found that when sheep were given an electric shock, 29% of the group moved forwards, 13% did not or could not move, and 58% were forced backwards or moved backwards. Groups of sheep move faster through a race that has solid sides than when a race has open sides (Hutson & Hitchcock, 1978). However, Hutson and Hitchcock (1978) found that the effect of the angle of the race (0^o to 135^o) on the speed of movement through the race was less clear and depended on the width of the race.

Hargreaves and Hutson (1997) recommended that the "materials used to construct handling facilities should not make loud or alarming noises" when used. Sheep move most readily towards other sheep or the exit rather than to aversive stimuli (e.g. humans, dogs, treatment sites or an apparent dead-end). Franklin and Hutson (1982c) found no significant effect of using live decoy sheep, or mirrors, on the time taken for a complete group of sheep to move along a race. A live decoy sheep decreased the latency of sheep to leave a pen and enter a race, whereas a model sheep reduced the flow of sheep along a race. Although the sheep appeared to be attracted towards a mirror placed at the end of the race, they were hesitant to move past it.

Research recommendations: Further research on the components of handling systems that are stressful for sheep and measures that can be used to mitigate the stressful effects of handling. Examples of handling systems that should be evaluated include: lamb cradles used for tail-docking and castration; flip cradles for artificial insemination or foot trimming; and automatic squeezes.

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2. ACCELERATED LAMBING

Conclusions:

1. **Although there are several potentially negative effects of accelerated lambing on the welfare of both ewes and lambs, there is little scientific evidence that has demonstrated that sheep are likely to suffer more in an accelerated lambing system than in a conventional once a year lambing system.**

2. **An analysis of the potential welfare issues associated with accelerated lambing suggests that many problems can be avoided with a higher level of management, e.g. breed selection, maintenance of ewe body condition, care of newborn lambs to ensure that they receive adequate colostrum/milk and protection from cold conditions, and extra supervision and care if aspects of sheep reproduction occur during hot conditions.**

3. **The main effect of accelerated lambing that is likely to put the welfare of the lambs at risk is the lower birth weight in lambs born in autumn or winter compared with traditional spring lambing.**

4. **The main effect of accelerated lambing that is likely to put the welfare of ewes at risk is the reduced time for post-partum and post-lactation recovery.**

5. **Adoption of an accelerated lambing system can result in changes in the health control measures required to minimise the risk of disease.**

Background: Accelerated lambing (also called frequent lambing) is a method used to increase the number of lambs born in a flock by increasing the frequency of lambing to more than once a year. It is not a natural system of reproduction. Under natural conditions, ewes are seasonally polyestrous; they begin to cycle when day length decreases in the fall. After mating, sheep have a gestation period of around five months. This means that most lambs are born in the spring. If the weather conditions are good, lambing at this time provides favourable conditions for lamb survival.

It is possible to induce ewes to lamb every 7.2-8 months by artificially manipulating the reproductive cycle of sheep. However, the timing of lambing outside of the natural season may not coincide with ideal thermal conditions during lambing or ideal nutrition from pasture for the ewe before and after lambing. Accelerated lambing seeks to increase the productivity of the ewe by reducing the normal time (about 4 months of the year) when it is not pregnant or lactating. The two main accelerated systems are: three lambing periods in two years (i.e. potentially lambing every 8 months) and five lambing periods in three years (known as the Cornell Star System, i.e. potentially lambing every 7.2 months) (Fisher, 2001). Three lambing periods in two years requires an average lambing interval of eight months, or 1.5 lambings per ewe per year. As described by Martins (2011), this system can be achieved using a “fixed mating and lambing schedule such as May mating/October lambing, January mating/June lambing and September mating/February lambing. It can also be modified slightly to 7-7-10 or 7-8-9-month intervals to fit climatic, management and feed resources.” Five lamb crops per ewe every three years can be achieved using five lambing periods in each year. In this system, there are three separately managed groups in the flock; breeding and pregnant ewes and the rams, lambing and/or lactating ewes and their lambs, and growing lambs (market and replacements) (Martins, 2011).

Reproduction in sheep can be controlled by artificially inducing estrus, ovulation, and fertilization. Accelerated lamb production or out-of-season breeding requires selection of appropriate breeds which have maternal traits that provide sufficient maternal care for the lambs. Progesterone-based treatments are a common method of inducing estrus in non-cycling ewes. However, it is also possible to induce estrus by treatment with melatonin or by housing the ewes in a light-tight building and controlling the photoperiod (e.g. Cameron et al., 2010). Non-cycling ewes can also be stimulated to ovulate by the sudden introduction of a ram or 'teaser'/vasectomised ram. Artificial insemination (vaginal, cervical, trans-cervical, and laparoscopic or intra-uterine) could also potentially be part of a controlled breeding programme. For example, laparoscopic artificial insemination can be used to undertake out-of-season breeding when seasonal effects on ram semen production and libido reduce the effectiveness of natural mating (Gourley & Riese, 1990). However, if breeds with naturally aseasonal estrus patterns are used (e.g. Dorset), accelerated lambing systems are not dependent upon the use of hormones or light control (Smith, 2006).

Unfortunately there have been no specific studies on the welfare of sheep in early accelerated lambing systems compared with traditional systems (Fisher, 2004). The literature has been reviewed by Fisher (2004) to assess the welfare implications, and by Smith (2006) to assess the health implications, of accelerated lambing.

Literature sources that did not aim to assess welfare, but compared accelerated lambing with conventional lambing using factors, such as biological performance, health, etc. were evaluated. However, the results found in individual studies were likely to have been dependent not only on whether accelerated lambing was used, but also on other aspects of the management of the sheep, e.g. breed, nutrition, age at weaning, climate and health.

The relationships between biological performance, e.g. measures of reproductive success and measures of growth, and animal welfare are complex (Keeling et al., 2011). As many farm animals have been selected for their reproductive potential, failure to reproduce might be indicative of a welfare issue, such as a general reduction in fitness or debilitation, an underlying disease or especially in females, a disruption of the complex endocrine events necessary for reproduction due to the presence of a stressor. However, reduced reproductive success might equally arise because of reproductive management that is unrelated to factors likely to impact on welfare, such as breeding during the anovulatory season. As accelerated lambing requires different reproductive management strategies than those used in conventional lambing, the relevance of measures of reproductive success to evaluate the welfare implications of each lambing system is limited. In addition, excessive reproductive success has the potential to cause problems, such as loss of body reserves in ewes, to meet the needs of multiple fetuses and the associated post-partum lactation requirements for suckling multiple lambs. Therefore, when evaluating the potential welfare implications of accelerated lambing versus conventional lambing, limited use has been made of measures of reproductive success, as it is not possible to interpret their relevance in relation to animal welfare.

Potential welfare issues associated with accelerated lambing: Potential welfare issues for the lambs, ewes and rams were identified from literature sources and are summarised in Table 2. The approach taken followed standard methods of welfare evaluation and assessment, such as that used Dwyer (2008) to evaluate welfare issues associated with neonatal lambs. The Five Freedoms provided by the United Kingdom (UK) Farm Animal Welfare Council (FAWC, 2009), provide a framework to present an initial evaluation of the potential welfare issues.

Table 2: Potential welfare issues associated with accelerated lambing.

Issue [a]	Reference	Potential effect [b]	Potential welfare consequence [c]
Lower birth weight in lambs born in autumn or winter compared with traditional spring lambing.	Fisher (2004); Jenkinson et al. (1995)	Increased lamb mortality from 1. greater heat loss (increased surface/body mass ratio)	Exposure to adverse environmental conditions would result in discomfort and suffering
		2. increased risk of starvation (due to decreased vigour)	Increased risk of thermal discomfort and hunger
		Decreased risk of dystocia from oversized lamb	Reduction in pain and discomfort to ewe and lamb
Lower milk production from ewes lambing in autumn or winter compared with traditional spring lambing.	Fisher (2004)	Reduced growth rate in lambs	Depends on magnitude of reduction as to whether it might be associated with insufficient feed intake resulting in hunger or in a general debilitation affecting biological fitness
Difficulty in aligning the energy demands of ewes during late pregnancy and lactation with feed supply, when pasture is not available.	Fisher (2004)	Less milk available to lambs.	Increased risk of thermal discomfort and hunger
		Ewes more susceptible to pregnancy toxaemia	Suffering as a result of 'sickness'
Lambing during cold conditions	Fisher (2004)	Increased risk of hypothermia and mortality in lamb	Increased risk of thermal discomfort
		Increased difficulty in providing care for ewes and lambs	If inadequate care, risk of pain, discomfort, thirst and hunger
Lambing during hot conditions		Increased risk of heat stress	Increased risk of thermal discomfort
		Increased water requirement for lactating ewes	Thirst in ewes and lambs, hunger in lambs
Reduced time for postpartum and post-lactation recovery of ewes and/or recovery under hot conditions	Hansen & Shrestha (2002); Goulet & Castonguay (2002)	Potential for decreased feed intake and decreased recovery of body condition	Potential for general debilitation affecting biological fitness and subsequent milk production
Spreading lambing over more than one period.	Fisher (2004); Smith (2006)	Increased availability and quality of labour to provide adequate care	Reduced risk of pain and discomfort

Issue [a]	Reference	Potential effect [b]	Potential welfare consequence [c]
		If a disease or management problem occurs, not all lambs are at risk at the same time	
If accelerated lambing requires indoor lambing	Stafford & Gregory (2008)	Protection from adverse weather	Reduced risk of thermal discomfort
		Easier supervision and assistance	Reduced risk of pain and discomfort
		Close proximity can assist bond formation between ewe and her lamb(s)	Reduced risk of hunger in lambs
		Increased risk of mastitis especially on straw at high stocking densities	Pain and discomfort to ewes. Increased risk of hunger in lamb
		Increased risk of perinatal infection in unhygienic conditions	Increased risk of pain and discomfort
		Increased risk of mismothering due to interference	Increased risk of hunger in the lambs
		Decreased risk of predation	Reduced risk of pain and discomfort
Early weaning of lambs	Dwyer (2008); Sowińska et al. (2001)	Increased stress and possibly increased risk of disease	Increased stress and possibly increased risk of pain, discomfort and sickness
Use of invasive procedures on the ewe e.g. laparoscopic artificial insemination, as part of controlled reproduction	Fisher (2004); Stafford et al. (2006)	Handling stress, discomfort and risk of disease	Stress and fear associated with handling. Pain and discomfort from procedure and disease
Vasectomising rams for use as 'teaser' rams	Matthews (1990)	Handling stress and discomfort	Stress and fear associated with handling. Potential for pain and discomfort from procedure
Increased use of electroejaculation of rams to monitor semen production	Damián & Ungerfeld (2011)	Stress	Stress and discomfort
Use of rams for natural mating more frequency and out of season	Matthews (1990)	Loss of body condition and increased potential for heat stress	Potential for general debilitation affecting biological fitness. Increased risk of thermal discomfort

[a] Identified from a review of the literature and first principles, i.e. the fundamental concepts or assumptions on which animal welfare assessments are made. These arise from the FAWC 5 freedoms and a knowledge and understanding of biological principles, including physiology, psychology, behaviour and health.
[b] Identified from a review of the literature and first principles
[c] Identified using first principles.

Health issues: If lambing indoors is required, independent of whether lambing is accelerated, there is potentially an increased risk of certain diseases (Ridler, 2008). Ridler (2008) cautioned that housing increased the risk that the following diseases could occur in lambs: coccidiosis;

Escherichia coli endotoxemia (watery mouth); postpartum bacterial infections, such as navel infection and polyarthritis; and cryptosporidiosis. Benoit et al. (2009) found significantly greater lamb mortality (18%) in an organic accelerated lambing system (3 lambing periods/2 years) compared with that in an organic once a year lambing system (12%) ($P<0.05$) and a greater peri-natal mortality (up to 10 days of age) of 14% in the accelerated lambing system compared with 10% a once a year lambing system ($P<0.01$). Although not statistically different, the lamb mortality after 10 days of age due to conditions such as arthritis, endotoxemia and pneumonia was 5% in the accelerated lambing system and 3% in the once a year lambing system.

Accelerated lambing can result in a narrower age range of lambs within the same lambing period. This has the potential to assist in the control of coccidiosis. It reduces the risk that later-born lambs are exposed to increased oocyst numbers in the bedding and provides an opportunity to replace bedding after one batch of lambs has been weaned and before the arrival of the next group of ewes to lamb (Smith, 2006). That said, Benoit et al. (2009) found more coccidia in lambs in an organic accelerated lambing system than in an organic once a year lambing system ($P<0.05$).

Smith (2006) considered that a disadvantage of several lambing periods each year is the continuous presence of disease-susceptible sheep in a facility. For example, contagious ecthyma (orf) might disappear from a flock that lambs once a year, but persist where there is a steady flow of new, susceptible lambs. Smith (2006) also cautioned against the temptation to mix, ewes with poor body condition or small lambs, from previous lambing groups, with sheep from management groups associated with subsequent lambings. In many cases, Smith (2006) considered that the cause of the poor body condition was likely to have been chronic infectious disease. Mixing of the sheep rather than operating an 'all-in, all-out' policy could result in the spread of disease to other groups. Another potential problem identified by Smith (2006) was in relation to grazing management to control parasites. If lambing occurred once a year it was possible for all of the lambs to be turned out onto relatively worm-free pasture. However, if several batches of lambs were produced per year, and if fresh pasture was not available for each batch, they could be exposed to pasture contaminated with strongyle eggs from previous groups. Benoit et al. (2009) found some evidence to support this suggestion. They found significantly greater numbers of strongyles in the digestive tract of ewes and lambs in an organic accelerated lambing system than in an organic once a year lambing system ($P<0.05$).

Nutrition: In an accelerated lambing system, the ability of ewes to recover from the previous lambing and lactation, before they are mated again can be affected by several factors, including nutrition, body condition and breed (Goulet & Castonguay, 2002). Goulet and Castonguay, (2002) compared the effects of mating after a 75 days post-partum period with mating after a 90 days post-partum period. They found that after the longer period, the ewes were in a better body condition score at mating (3.1 versus 2.7) ($P<0.01$), but by the time of lambing, there was no significant difference in body condition score. There was also no significant effect of the length of the post-partum period before mating on the weight of the lambs at birth. Matthews (1990) recommended that ewes used for accelerated lambing should be kept in good to excellent body condition throughout the year and to have a body condition score of 3 to 3.5 before breeding. In Canada, Cameron et al. (2010) demonstrated that it was possible to maintain an average ewe body condition score (at the time of breeding, 5 weeks before lambing, and at lambing) of 3 in ewes managed in an accelerated lambing system, whereas the score in ewes managed in a conventional system was 2.5 ($P<0.001$).

Culling of ewes: "Depending on breed type and culling strategy, accelerated lambing can lead, but does not necessarily lead to shorter productive lives of ewes than annual lambing" (Nugent & Jenkins, 1992). However, where this occurs, it appears to be due to culling for reproductive reasons rather than because of physical or disease reasons (Nugent & Jenkins, 1992). In Canada, Cameron et al. (2010) did not find a significant difference in the culling rate of ewes in an accelerated lambing system (8%) compared with a conventional system (7%). Similarly, in Mexico, Rodríguez et al. (1998) found no effect of lambing system on the ewe culling rate.

Lamb body weight and thermal environment: In Canada, Cameron et al. (2010) found a lower birth weight in lambs born in an accelerated lambing system (3.4kg) compared with a conventional lambing system (4.1kg) ($P<0.001$). A similar effect has been recorded in studies in other countries (Gül & Keskin, 2010; deNicolo et al., 2008). Benoit et al. (2009) found a significant interaction, between lambing system and time of year when lambing occurred, on lamb birth weight. One study in Canada, did not find a significant effect of season of birth, on lamb mortality in an accelerated lambing system (Fahmy, 1990). However, if lambing occurred indoors, this would have reduced the seasonal influence of potentially adverse weather conditions. Further work is required to identify the biological significance, in cold Canadian conditions, of the lower birth weight of lambs born from ewes in an accelerated lambing system.

If a newborn lamb with low body weight had greater difficulty coping with cold than a larger lamb, it would be at greater risk of hypothermia and mortality. Mellor and Stafford (2004) considered that the effect of hypothermia on neonatal lambs represented a mild to moderate welfare issue. They considered that hypothermia was likely to be painful and distressing until the lamb's core temperature fell to such an extent that cerebral function was depressed. However, when it was attempting to maximise heat production, the lamb would have been physiologically challenged e.g. vigorous muscular shivering, and this could have resulted in distress due to exhaustion. The maximum heat production that a lamb can produce as it attempts to maintain body temperature in response to increased heat loss to a cold environment is termed 'summit metabolism'. Heat loss is proportional to surface area and the surface area to body weight ratio increases as the body weight of a newborn lamb decreases (Eales & Small, 1980). Alexander (1962) showed that during summit metabolism, the rate of heat energy produced per body weight by young lambs was approximately constant at all body weights. Therefore, summit metabolism per unit of surface area increased with increasing body weight. The implication of this is that heavier lambs are more likely to maintain their body temperature under conditions of high heat loss than lighter lambs. However, Eales and Small (1980) showed in a smaller breed of lambs, that summit metabolism per unit body weight increased as body weight decreased so that summit metabolism was directly proportional to surface area. In this type of lamb, the rate of energy consumption per unit body weight in small lambs will be higher than in a larger lamb maintained under similar conditions. Therefore, these authors suggested that any interruption in the milk supply will have a more acute effect on the ability of smaller lambs to maintain body temperature in cold conditions than it would in larger lambs.

Growth of lambs: Benoit et al. (2009) found a lower growth rate from 0 to 70 days in lambs from an organic accelerated lambing system (235g/day) compared with an organic once a year lambing system (258g/day) ($P<0.05$). However, this effect was influenced by the season when lambing occurred. A similar effect has also been recorded in other studies (Gül & Keskin, 2010).

Early weaning: Artificial weaning involves separation of the ewe and its lamb and a major change in diet. Weaning can be stressful for both the lamb and the ewe. Napolitano et al. (2008) suggested that early weaning of lambs was detrimental to their welfare, but these authors did not produce strong evidence as to whether the earlier time necessary for weaning in an accelerated lambing system was any worse for the welfare of the lambs than the later weaning time in a conventional system. It has been suggested, e.g. Dwyer (2008), that early weaned lambs are at greater risk of disease than later weaned lambs. Although this is possible, the evidence for this is not strong. However, Sowińska et al. (2001) found a greater cortisol response in ewes when their lambs were removed for 15 hours at 50 days of age than when they were removed for 15 hours at 100 days of age. Pérez-León et al. (2006) showed that the stress experienced by ewes at the time of weaning, as a result of separation from their lambs, could be partially mitigated by hormonally inducing them to exhibit estrus, in the vicinity of rams, on the day of weaning. This suggests that the practice of hormonal induction of estrus on the day of weaning that is often a part of an accelerated lambing system, might actually reduce the stress in the ewe that occurs following separation from her lambs.

Research recommendations: Comprehensive evaluation of the welfare implications of accelerated lambing in Canada relative to traditional systems. Outcomes relevant to welfare should include the: effect on lamb mortality by season and inter-lambing interval, longevity of the ewe and disease rates associated with lambing and lactation events, and effects on lamb diseases. The comparison group should be matched by age of ewe and season of birth in annual lambing systems.

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3. METHODS OF ON-FARM EUTHANASIA OF SHEEP

Conclusions:

1. **The correct use of a penetrating captive bolt stunner on the top/front of the head will result in immediate loss of consciousness and when followed by either exsanguination or pithing, the sheep will die without recovering consciousness. However, depending on the way the stunner is used, some sheep might not immediately lose consciousness. In one study, a captive bolt stunner was shown to produce an effective stun in 94% of the sheep. However, greater problems occurred in horned rams (only 84% were effectively stunned). Poor marksmanship resulting in the bolt causing insufficient damage to the brain was responsible for all cases of ineffective stunning. Although some sheep will die as a direct result of the use of a normal penetrating captive bolt stunner, an additional procedure ensures that the sheep dies and there is no risk of partial or full recovery of sensibility. The use of a captive bolt stunner in the poll position does not always result in immediate loss of consciousness. If pellets or a bullet from a firearm have sufficient penetration of the skull to cause extensive damage to the brain; this will cause immediate loss of consciousness.**

2. **Exsanguination (bleeding-out) without prior stunning does not cause immediate loss of consciousness. In one study, it took 14 seconds for the brain of anesthetized sheep to stop responding to visual stimuli. In addition, it is likely that a sheep would experience pain during and after the neck incision for exsanguination.**

3. **Blunt trauma can cause extensive brain damage to lambs. An impact to the frontal region causes more brain damage than one to the temporal or poll regions. Other than the use of a non-penetrating captive bolt stunner, there have been no reports on the effectiveness of blunt trauma to cause in a consistent manner, immediate loss of consciousness and death in lambs.**

Background: A sheep farmer/producer is required to undertake on-farm euthanasia of sheep to prevent or avoid suffering, e.g. when either treatment or transport for slaughter for human consumption is not an appropriate option. Development of a suitable on-farm euthanasia plan (e.g. Ontario Ministry of Agriculture, Food and Rural Affairs [OMAFRA], 2011a) that includes identification of suitable endpoints and decision trees (e.g. OMAFRA, 2011b), methods of euthanasia and staff training should be part of the overall flock health management program (Turner & Doonan, 2010).

There are numerous ways of killing sheep, but only a few methods are practical options for use by individual producers who periodically have a requirement to euthanize limited numbers of sheep at any one time. There is a considerable body of literature available that provides guidance on how to euthanize sheep, and these are either included within the reference list or in Appendix 1 at the end of this report. These are useful sources of practical information and have been used to place the scientific information on methods of euthanasia in context.

Many reports provide approaches on how to evaluate the welfare implications of different methods of euthanasia. The AVMA (American Veterinary Medicine Association) (2007) when evaluating methods of euthanasia used the following criteria to assess the welfare implications of each method:

1) ability to induce loss of consciousness and death without causing pain, distress, anxiety, or apprehension
2) time required to induce loss of consciousness
3) reliability, and
4) irreversibility

In addition, they considered the following criteria as they have implications on the practicality of the methods:

5) safety of personnel
6) compatibility with requirement and purpose
7) emotional effect on observers or operators
8) compatibility with subsequent evaluation, examination, or use of tissue;
9) drug availability and human abuse potential
10) compatibility with species, age, and health status
11) ability to maintain equipment in proper working order, and
12) safety for predators/scavengers should the carcass be consumed.

There are no reports of scientific studies that used the above criteria to evaluate in a systematic manner, the various methods available for the euthanasia of sheep. The potential options for on-farm euthanasia and their relative merits using some of the criteria listed above are summarised in several sources and these are listed in Appendix 1.

Introduction: Blackmore (1993) considered that euthanasia methods caused death through three main methods: anoxia (lack of oxygen supply) of the central nervous system (CNS); chemical depression of neurones in the brain that are essential for life, e.g. those required to control breathing; and permanent physical damage to vital centres of the brain. The main method of causing anoxia of the CNS in sheep is exsanguination (bleeding out) as a result of cutting the major blood vessels in the neck causing a fatal loss of blood (hypovolemia). Gaseous methods to cause anoxia have not been used for euthanasia of sheep. Use of electrodes on the head to pass electricity through the brain to stun a sheep and then across the chest to pass electricity to stop the heart, thereby causing brain anoxia, is an effective means of killing. It is used in slaughter plants and during disease outbreaks where specialised equipment is available and large numbers of sheep need to be killed on one site. Chemical depression of neurones in the brain and death can be achieved by the use of anesthetic agents, e.g. barbiturates. The most common physical methods of euthanasia include shooting, captive bolt stunning and direct damage to the brain by a blow to the head.

There is a degree of consensus that intravenous barbiturate overdose administered by a veterinarian, use of a penetrating captive bolt followed by exsanguination (bleeding out) or pithing, and gunshot to the head are appropriate means for killing sheep (e.g. OMAFRA, 2011b). However, what is controversial is the acceptability of exsanguinating conscious sheep without prior stunning (e.g. Australian Code of Practice, Primary Industries Ministerial Council,

2006) and physical blunt trauma to the head of lambs (e.g. Primary Industries Ministerial Council, 2006; Humane Slaughter Association, 2008).

The correct use of captive bolt stunners for euthanasia is also a topic that has been debated. A traditional penetrating captive bolt stunner, such as that used in a slaughter plant, is not designed to kill sheep. If extensive damage to the brain is caused, its use will kill a sheep. However, it is only designed to stun sheep and to be followed by a secondary method, i.e. exsanguination or pithing that will kill the sheep. The recent introduction of captive bolt apparatus, with an extended bolt and a large charge, marketed specifically for euthanasia, provides an option for killing sheep without exsanguination.

Various research methods have been used to assess the welfare implications of the various methods of euthanasia. An understanding of the biological basis of these methods is helpful to appreciate the problems associated with their interpretation and hence understand some of the scientific controversy regarding various types of evidence presented for different methods of euthanasia. The ability of a euthanasia method to induce loss of consciousness and death without causing pain, distress, anxiety, or apprehension is an important criterion. The methods used to assess pain, and those used to assess fear and stress are considered in detail in other sections of this report. The reliability of a method to cause death without any possibility of recovery is an essential requirement. Death of a sheep usually occurs in stages as the various tissues progressively cease to function (Newhook & Blackmore, 1982). If an animal’s vital signs are assessed to determine whether each of the vital organs has ceased to function, the methods used to assess whether an animal is dead and will not recover are straightforward. However, as these organs progressively fail, what is more contentious is the determination as to the stage when the animal can be considered dead. The most reliable method is the cessation of a steady, rhythmic heartbeat and the absence of respiration (Woods et al., 2010). Other signs indicating that the animal is dead are the absence of a pulse, dilation of the pupils, lack of a corneal reflex and loss of capillary refill (Woods et al., 2010).

As long as the procedures used during a method of euthanasia ensure that the animal does not recover i.e. it dies, the main focus of research is to determine when the animal loses consciousness and whether the animal remains unconscious until it dies. The methods used to determine consciousness are problematic. Although mammals are considered to have the neurophysiological and behavioural characteristics relevant to consciousness (Edelman & Seth, 2009), the philosophical dilemma as to whether animals can be considered to be ‘conscious’ resulted in the use of an alternative term ‘sensible’, i.e. if an animal is ‘insensible’ it is considered to be unable to perceive stimuli. If a method causes permanent insensibility that inevitably results in death with no possibility of recovery, the time taken for the onset of permanent insensibility is the relevant criteria to use when determining the welfare implications of a method rather than the time taken to die (Newhook & Blackmore, 1982). Ideally, a method of euthanasia would cause immediate insensibility. If one method took longer than another method to cause insensibility, the animal might experience pain, fear or distress for a longer period. A method for assessing insensibility practically may be useful during euthanasia to determine that an animal is insensible, but it might not be capable of detecting the time when the onset of insensibility first occurs. For example, a reflex such as the corneal reflex may be lost sometime after an animal is insensible (Rosen, 2004).

The neurophysiological research techniques that have been used to assess the onset of insensibility of animals are similar to those used in human medicine. The electrical activity of the brain can be recorded from electrodes on the surface on the head (generating an electroencephalogram or EEG) or the brain (electrocorticography or ECoG). The pattern of EEG recordings is different when an animal is conscious, unconscious and dead. However, the differentiation between the characteristics of an EEG recorded during various states of consciousness can be unclear and are open to interpretation (Shaw, 2002). In addition, to minimise suffering associated with some euthanasia methods, some recordings have to be made while the animal is anesthetized. However, a flat line or isoelectric EEG occurs when no brain electrical activity is recorded and is consistent with brain death. The time that an isoelectric EEG is first recorded is therefore useful for an unambiguous determination of brain death and the maximum time since the onset of the method that the animal might have been sensible. To estimate the time when an animal loses consciousness (i.e. before the start of an isoelectric EEG) the ability of the brain to perceive a discrete stimulus to the nervous system can be recorded as a discrete electrical activity (evoked potential) in the brain. The time when visual (light flashing) or somatosensory (nerve stimulation) evoked responses are abolished has been used to indicate the onset of insensibility (Shaw, 2002).

Intravenous administration of barbiturate: If undertaken by a veterinarian, this method meets all the welfare criteria listed by the AVMA. However, it does not meet some important practical criteria for on-farm use by a non-veterinarian, e.g. drug availability, human abuse potential and safety for predators/scavengers should the carcass be consumed. In addition, Peisker et al. (2010) reported that in pregnant ewes, both mid-gestation fetuses and near term fetuses still had a heart beat 25 minutes after the administration of intravenous pentobarbital. Although it is possible that a lamb fetus is aware and capable of suffering, it is also possible that a fetus is unconscious and awareness does not occur until birth (Mellor & Gregory, 2003). In any case, Peisker et al. (2010) considered that the fetuses in ewes that had been euthanised using pentobarbital may have been fetusthetised during hypoxia.

Exsanguination: In sheep, the main blood supply to the brain is from the external carotid artery, via branches of the internal maxillary artery (Baldwin, 1964). Drastic and rapid fall in cerebral blood flow after the main blood vessels on both sides of the neck have been severed can inactivate the cerebral cortex by depriving it of its blood supply, leading to a rapid hypoxia, loss of consciousness and death (Rosen, 2004). Sheep differ from cattle in that cattle also receive a blood supply to the brain from vertebral arteries that are not cut by a neck incision. Therefore, the time taken after exsanguination by a neck cut before the onset of insensibility is greater in cattle than in sheep. Anil et al. (2004) found in ewes killed by severance of all the blood vessels in the animal's neck with one knife cut that blood loss after 90s represented 4% of the animal's liveweight. Twenty-five percent of the blood loss occurred within 6 seconds, 50% within 14 seconds, 75% within 32 seconds and 90% within 56 seconds.

The following welfare issues have been considered in relation to exsanguination without prior stunning: (a) the possibility of undue stress during handling prior to exsanguination, (b) the possibility of pain during the neck incision and/or immediately afterwards (c) whether distress is caused by a sudden fall in blood flow to the brain and (d) whether sensibility is lost quickly enough following exsanguination (Anil et al., 2004; Mellor & Littin, 2004). If a sheep is already unconscious, exsanguination is a reliable method to kill the sheep without the possibility of suffering (Close et al., 1997).

Stress during handling prior to exsanguinations: Although there are no readily available studies on the stress caused by handling prior to exsanguination, in observations of 96 sheep in two slaughterplants undertaking religious slaughter without stunning, the time taken between manually restraining a sheep on its' side and cutting the blood vessels was about 4 seconds (Velarde et al., 2010).

Pain during and after neck incision: The throat or neck cut required for exsanguination can involve "skin, muscle, trachea, oesophagus, carotid arteries, jugular veins, other blood vessels, sensory nerves (including pain nerves), other nerves and connective tissue" (Mellor & Littin, 2004). As insensibility is not immediate, the pain from the cut causes the transmission of impulses to the brain (Mellor & Littin, 2004). It is thought that the severity of suffering is reduced if the knife is long and sharp and the cut is made quickly (Grandin & Regenstein, 1994; Mellor & Littin, 2004). However, studies in calves have produced evidence that the cut is likely to be painful (Mellor et al., 2009). Gibson et al. (2009a,b) found that a ventral-neck incision in calves caused EEG changes for 40 seconds that were quantitatively and qualitatively similar to those observed during dehorning of calves under what the authors described as minimal light general anesthesia (ketamine and propofol induction followed by 0.9% halothane), but without a local anesthesia nerve block.

Time to insensibility: In observations in two slaughterplants of 96 sheep that were held on their side for religious slaughter, the time between cutting the blood vessels in the neck, and the loss of rhythmic breathing was recorded as about 22 seconds (Velarde et al., 2010).

Blackmore (1984) observed that exsanguination in adult ewes by bilateral severance of carotids and jugulars caused a loss of ability to stand in 3-4 seconds, a loss in apparent coordinated attempts to stand after 8-9 seconds, pupillary dilation after 70-72 seconds, onset of clonic convulsions (uncontrolled jerking kicking movements) after 126-141 seconds and loss of corneal and palpebral reflexes after 200 seconds. In 1-week old lambs, exsanguination by bilateral severance of carotids and jugulars caused a loss of ability to stand in 2-3 seconds, a loss in apparent coordinated attempts to stand after 9-11 seconds, pupillary dilation after 56-114 seconds, onset of clonic convulsions after 68-158 seconds and loss of corneal and palpebral reflexes after 200 seconds (Blackmore, 1984). Newhook and Blackmore (1982) found in five conscious sheep that had their common carotid arteries and external jugular veins severed bilaterally, that the EEG became isoelectric after 20-43 seconds, but changes in the EEG suggested that they were insensible within 7 seconds. In five conscious 1-week-old lambs, the EEG became isoelectric after 10-25 seconds, but changes in the EEG suggested that they were insensible within 6.5 seconds. Gregory and Wotton (1984) found that if both carotid arteries and both jugular veins were severed, the time to loss of brain responsiveness as determined from the visually-evoked responses was 14±1 seconds, but when only one carotid artery and one jugular vein were cut it was 70±7 seconds and when both jugular veins, but no carotid arteries were cut it was 298±34 seconds. Blackman et al. (1986) using a dye in anesthetized 1-year-old sheep with an exposed cerebrum, showed that blood flow to the cerebrum stops after bilateral severance of the carotid arteries and jugular veins, but continues for at least 53 seconds if only one side is cut. In six sheep aged 6 to 12 months, Cook et al. (1996) found that after the blood vessels in the neck were severed there was an initial increase in the amplitude of the EEG, but after 9.5 ±2.1 seconds the amplitude quickly decreased and became isoelectric. Occasional short burst high amplitude spikes of less than 5 seconds duration were recorded for up to 180 seconds. The heart rate increased initially by 15±20 beats per minute but then decreased rapidly. The pupillary, corneal and palpebral reflexes were absent by 10 seconds after throat cutting. The responses to exsanguination are summarised in Table 3.

Table 3: Responses of adult sheep to bilateral severance of common carotid arteries and jugular veins.

Time after carotid arteries were cut (seconds)	Measurement	Reference
3-4	loss of ability to stand	Blackmore (1984)
7-20	changes in the EEG pattern	Newhook & Blackmore (1982)
8-9	loss in apparent coordinated attempts to stand	Blackmore (1984)
9-43	isoelectric EEG	Cook et al. (1996); Newhook & Blackmore (1982)
10-200	loss of pupillary, corneal and palpebral reflexes	Blackmore (1984); Cook et al. (1996)
14	loss of visually-evoked responses	Gregory & Wotton (1984)
22	loss of rhythmic breathing	Velarde et al. (2010).
70-72	pupillary dilation	Blackmore (1984)
126-141	onset of clonic convulsions	Blackmore (1984)

Captive bolt stunning: Captive bolt stunning requires that the operator closely approaches the sheep and holds the stunner in a precise position to ensure that an effective stun is caused by the bolt entering the brain (Baker & Scrimgeour, 1995). However, as shown by Gibson et al. (2012) accurate placement of the stunner on the head can be difficult in individually penned freely moving sheep. Unless a sheep is moribund, it will normally require some form of restraint (Baker & Scrimgeour, 1995). Restraint or shooting sheep in closely packed groups was recommended by Gibson et al. (2012).

Recommendations for the entry position and angle of entry of a captive bolt vary and depend on whether the sheep has horns. Grandin (2011) shows three angles of midline entry into the head of a sheep for a captive bolt to penetrate the brain: (1) a vertical angle aimed downwards from the top of the head towards the angle of the jaw, (2) a point on the forehead, just above the eyes and directed down the angle of the neck and (3) a point behind the top of the head directed from behind the sheep towards the throat.

Gibson et al. (2012) studied the effects of approaching a sheep from behind and using a captive bolt stunner to shoot polled ewes and rams on the midline at the highest point on the head whilst aiming towards the throat. Horned ewes and rams were shot on the midline between the base of the horns just caudal to the nuchal crest whilst aiming towards the back of the throat. These authors reported that the sheep lowered or angled the head downwards just before placement of the stunner. This changed the position of the 'top of the head', but shooting with the head in this position, was shown to cause effective damage to the thalamus and midbrain and was recommended for euthanasia.

A penetrating captive bolt pistol or stunner uses an explosive charge to drive a metal rod through the skull into the brain (Finnie, 1997). The type of charge used, and the maintenance of the equipment affect the bolt velocity. The cerebral injury produced by a captive bolt pistol may be fatal, but in most cases the sheep will only be stunned. The penetrative percussive effect is designed to produce a state of immediate unconsciousness, which persists until the animal is rendered permanently insensible (Finnie, 1993a). To prevent the risk of recovery, stunning requires an additional procedure to kill the sheep, i.e. exsanguination or pithing to destroy the brain. Pithing with a rod through the hole in the skull that was made by the penetrating bolt kills the animal by physical destruction of the brain and upper region of the spinal cord and avoids the need to exsanguinate (Butterworth & Wotton, 2005). The duration of unconsciousness induced by the stun should be longer than the sum of the time periods from the end of stunning to the start of the killing method and the time it takes for death to occur after exsanguination or pithing (Raj, 2008).

After effective captive bolt stunning, the sheep immediately collapses, respiration stops and there is no corneal reflex (Schütt-Abraham et al., 1983). A captive bolt produces insensibility by a combination of the concussive force generated by impact of the bolt with the skull and damage produced by passage of the bolt through the brain (Finnie et al., 2002). It is actually the pressure wave caused by high speed penetration of the bolt within the cranium that contributes most to stunning rather than the direct damage to brain tissue caused by the penetrating bolt. Daly and Whittington (1989) found that manual insertion of a bolt through a pre-drilled hole in the skull permanently stopped visually evoked responses in only one out of eight sheep, and none of the sheep had an isoelectric EEG within 320 seconds. In comparison, shooting a captive bolt through a pre-drilled hole in the skull caused immediate and continuous loss of visually evoked responses in four out of eight sheep, and a further three sheep lost visually evoked responses by 320 seconds. In five out of the eight sheep, the mean time until an isoelectric EEG was recorded was 48.5±13.0 seconds. After normal captive bolt stunning through an intact skull there was an immediate loss of visually evoked responses, and an isoelectric EEG was recorded in four out of eight sheep at a mean time of 76±17 seconds. Daly et al. (1986) found that after captive bolt stunning, visual and somatosensory responses were lost immediately from anesthetized sheep, and did not return during the subsequent 320 seconds recording period. In four out of five sheep that were conscious at the time of stunning and thus able to move their head, visually evoked responses were also lost immediately after stunning except for one sheep, where they lasted for 35 seconds, but did not reappear during the subsequent 192 seconds. The EEGs from these sheep were isoelectric 53±13 seconds after stunning. The responses to captive bolt stunning are summarised in Table 4.

Table 4: Responses of adult sheep to captive bolt stunning on the top of the head.

Time after stunning (seconds)	Measurement	Reference
0	loss of ability to stand	Gibson et al. (2012)
0	loss of rhythmic breathing	Schütt-Abraham et al. (1983)
0	changes in the ECoG pattern	Lambooy (1982)
0	loss of corneal reflex	Schütt-Abraham et al. (1983)
0-35	loss of visually-evoked responses	Daly & Whittington (1989) Daly et al. (1986)
53-76	isoelectric EEG	Daly & Whittington (1989) Daly et al. (1986)
6-890	cardiac arrest	Gibson et al. (2012)

Finnie et al. (2000) described the injury caused by using a penetrating captive bolt stunner on the top of the head of ewes without horns. A discrete hole in the skull was caused with skull fractures at the impact site and on the contralateral (basal) side of the head. The bolt caused a penetrating wound through the full thickness of the brain. Impact and contralateral contusions and subarachnoid hemorrhage were caused. Wide spread injury to axons, neurons and blood vessels were found in the brain. Finnie et al. (2002) considered that the combination of direct mechanical damage to the cerebrum, cerebellum and brainstem, and focal and diffuse injuries to pathways connecting these areas, would cause loss of consciousness.

The severity of the resulting brain damage from a captive bolt stunner can vary between individual animals (Finnie et al., 2002) and is dependent on the location and depth of the penetration of the brain. Lambooy (1982), using a captive bolt with a penetrating depth of 2.2cm only caused damage to the cortex of three sheep, but in a fourth sheep, a bone fracture caused damage to the deeper parts of the brain. The ECoG trace immediately showed wave changes that are associated with unconsciousness. A tonic phase lasted about 15 seconds after which the sheep relaxed. In contrast, the use of a captive bolt with a penetrating depth of only 0.5cm caused local hemorrhage. In one sheep the ECoG trace was not altered after stunning and in two sheep, there was a change in the pattern of the ECoG trace indicative of concussion. Twenty-one seconds after stunning, a fourth sheep had an ECoG trace indicative of insensibility.

The likelihood of the captive bolt stunner causing death before a secondary method is used to kill the sheep is thought to be increased if the apparatus has been designed specifically for euthanasia. Captive bolt apparatus designed for euthanasia use a heavy load charge and an extended bolt to penetrate deeply into the brain (Baker & Scrimgeour, 1995; Woods et al., 2010). The impact produced by a captive bolt stunner can cause traumatic damage to medullary centres resulting in immediate and prolonged apnoea (i.e. the sheep stops breathing) (Finnie et al., 2002). Finnie et al. (2002) found that anesthetized, but not mechanically ventilated, sheep stunned with a penetrating captive bolt (Schermer model with a No. 17 charge, although not stated the bolt length was probably a standard length designed for stunning in a slaughter plant rather than an elongated bolt designed for euthanasia), died within 10 minutes without regaining consciousness.

Stunning sheep in the poll position (immediately caudal to the occipital-parietal suture), i.e. in the back of the head, can cause effective stunning in some sheep, but ineffective stunning may also occur. As described by Finnie (1993a), a captive bolt used behind the poll can produce a large, deep, and well-defined hemorrhagic track with severe destruction and loss of neural tissue in many parts of the brain. Daly and Whittington (1986) found that sheep that had been stunned in the poll position lost visually evoked responses immediately, but in five out of eight sheep, visually evoked responses gradually returned after 49±5.9 seconds.

Gibson et al. (2012) reported on the consistency of the use of a penetrating captive bolt stunner to produce effective euthanasia without the use of a secondary method, i.e. exsanguination or pithing. Type of captive-bolt gun/cartridge combination, sex and presence of horns affected the percentage of sheep showing signs of ineffective stunning (Table 5). Although results are reported separately by sex and presence of horns, the results are not shown for each combination of captive-bolt gun/cartridge by sex and presence of horns.

Table 5: Influence of sex and presence of horns on the percentages of adult sheep that showed signs of ineffective stunning following the use of a captive bolt stunner† (adapted from Gibson et al., 2012 with permission from UFAW).

Sex	**Ewe**		**Ram**	
Presence of horns	Polled	Horns	Polled	Horns‡
Did not collapse immediately	1	1	2	9
Rhythmic normal breathing	2	1	2	14
Corneal reflex	3	1	3	12
Palpebral reflex	3	1	3	14
Eyeball rotation	5	1	3	7
Nystagmus	3	1	2	4
Absence of relaxed jaw	3	1	3	13
Categorised as ineffectively stunned§	**3**	**1**	**4**	**16**
No. of sheep	116	134	117	122

† The captive bolt was used on the midline and aimed towards the throat. For polled sheep it was placed at the highest point of the head. For horned sheep it was placed just caudal to the nuchal crest.

‡ The percentages of horned rams showing each of these signs indicative of ineffective stunning were significantly greater than those for polled rams, horned ewes and polled ewes.

§ The sheep were considered to have been ineffectively stunned if they showed rhythmic breathing or did not collapse immediately and/or if more than one of the following was present: positive corneal and palpebral reflexes, tight jaw muscles and eyeball rotation. Within the 6% of sheep classified as ineffectively stunned, 86% had a positive palpebral reflex and tight jaw, 79% had normal rhythmic breathing and a positive corneal reflex, 54% failed to collapse immediately, 46% had eyeball rotation and 32% showed nystagmus.

The percentage of sheep (polled and horned ewes and polled rams) showing ineffective stunning following the use of a .22 Cash Special with a 2.5g (grain) purple cartridge with a kinetic energy of 189J was 2%. The percentage of rams (polled and horned) showing ineffective stunning following the use of a .22 Cash Special Heavy with a 4g red cartridge with a kinetic energy of 306J was 6%. The percentage of horned rams showing ineffective stunning following the use of a .22 Cash Special with a 3g green cartridge with a kinetic energy of 234J was 20%. The percentage of horned rams showing ineffective stunning following the use of a .25 Cash Eurostunner with a 4g black cartridge with a kinetic energy of 412J was 16%.

Hemorrhage on the ventral surface of the brainstem was associated with effective stunning (Table 6). Thirty-two percent of sheep showing signs of incomplete stunning had hemorrhage on the ventral surface of the brainstem. In sheep showing signs of incomplete stunning, 39% had no brain hemorrhage, 46% mild, 14% moderate and 0% severe brain hemorrhage.

Table 6: Influence of sex and presence of horns on the damage caused to the brain of adult sheep by the use of a captive bolt stunner (adapted from Gibson et al., 2012 with permission from Universities Federation for Animal Welfare [UFAW]).

Sex	**Ewe**		**Ram**	
Presence of horns	Polled	Horns	Polled	Horns
Skull thickness (mm)	8	7	11	12
Bolt penetration depth (mm)	66	68	71	69
% of sheep				
Bad marksmanship resulting in insufficient brain damage†	18	7	17	37
Brain not penetrated at all.	1	1	3	15
Cavitation of the inner surface of the skull‡	50	60	53	37
Brain tissue observed to extrude from the hole in the skull caused by the captive bolt§	82	79	80	56
No. of sheep	116	134	117	122

†Bad marksmanship, i.e. where the trajectory and penetrative depth of the bolt either missed the brain completely or only caused superficial damage to the parietal, occipital lobes and cerebellum and completely missed the brainstem. This was associated with all (6% of the sheep) of the cases of ineffective stunning. In 79% of these cases, the brain was missed completely. Damage to the thalamus, midbrain, pons and occipital and parietal lobe was associated with effective concussion/stunning leading to death.
‡ No sheep in which the bolt had passed through the brain and caused cavitation on the inner side of the skull showed signs of incomplete stunning.
§ Eighty-seven percent of the sheep that showed signs of ineffective stunning had no brain tissue extruding from the hole in the skull caused by the captive bolt.

Other potential reasons for lack of effectiveness of captive bolt stunning that were identified by Grandin (2002) during observations of cattle in slaughter plants were poor stunner maintenance, insufficient charge or damp cartridge. These problems can reduce bolt velocity and hence the effectiveness of the stun to cause loss of consciousness.

Shooting: Longair et al. (1991) recommended using either a 0.22 calibre rifle with long-rifle mushroom (hollow point) shells or a 0.410 gauge shotgun with slugs or pellets to shoot sheep. These authors recommended that the "barrel of the firearm should be 3-5cm from the head if using a rifle, pistol or 0.410 gauge shotgun, or 1-2 m if using a larger gauge shotgun or rifle (e.g. a 0.308 rifle)". However, another source (OMAFRA, 2011b) recommend using a 0.22 calibre firearm, with long-rifle hollow-nosed ammunition or a 0.38 calibre firearm, 5-25cm away from the head. Longair et al. (1991) recommended that the head be secured with a halter, and food offered to the animal. For sheep without horns, they suggested that "The aim of the firearm should be from behind or from the top of the head at a point high up on the head an equal distance from the eyes and ears." "If the animals have horns, the approach should be from the rear, and the aim directed between the base of the horns towards the mouth. Alternatively, the firearm can be aimed from the front just above the eyes on the midline, shooting towards the spine."

Finnie (1993b) shot adult sheep from a range of 3m by a 0.22 calibre firearm using a single bullet fired at the temporal region of the skull to produce a right-to-left transverse wound to the brain through the temporal lobes. He used either a high velocity, round-nosed bullet (Winchester "Superspeed" 0.22 LR) or a lower velocity, hollow-point bullet (Winchester "Subsonic" 0.22 LR). The bullet caused laceration and crushing of neural tissue and created a hemorrhagic primary wound track with secondary tracks caused by bone fragments. The high-velocity bullet caused a perforating wound with both entry and exit wounds, in eight out of 10 sheep. The lower velocity bullet only caused a penetrating wound, which in some sheep did not completely penetrate the entire brain. It was retained within the skull in seven sheep and in soft tissues on the contralateral side of the head in three sheep. "The slower, hollow-point bullets also tended to fragment upon impact, whereas the majority of the higher velocity projectiles remained intact." The neuropathological changes were described as consistently severe and were considered to have resulted in rapid death. "Death was attributed, in part, to the laceration and crushing produced by missile penetration of the brain with the formation of a permanent wound cavity and, more particularly, to the widely disseminated effects of stretch injuries to neural elements and blood vessels caused by the large temporary cavity. There was also significant distortion and displacement of the brain in these sheep, and the mechanism of death was probably an acute elevation of intracranial pressure with brainstem compression."

Finnie (1993b) stated that the degree of brain damage caused by a gunshot wound was largely dependent upon the velocity of the bullet. "The kinetic energy of the bullet is transferred to the brain to produce a large temporary cavity which exists for only microseconds, but its diameter is much greater than the permanent cavity. The marked temporary cavitation produced by high-velocity bullets, with transient displacement and stretching of tissue, causes shear and rupture of blood vessels and nerve fibres and is the main cause of injury beyond the wound track in soft tissues. It is the widespread effects of the large temporary cavity that appear to be chiefly responsible for a fatal outcome in missile injury to the brain, unless vital structures are damaged by tissue destruction in the immediate vicinity of the wound track." Puskas and Rumney (2003) found that when a variety of different types of firearms and ammunition (including a ACP Colt Government Model Pistol with 0.45 ca. Remington Solid Point ammunition and a muzzle velocity of 270 m/s, a LR Smith & Wesson Revolver with 0.22 calibre Remington Yellow Jacket Hollow Point ammunition and a muzzle velocity of 366m/s, a 12 gauge Winchester Shotgun with Winchester Super X Hollow Point ammunition and a muzzle velocity of 457 m/s and a Lee Enfield No. 4 Rifle with Imperial 0.303 British ammunition and a muzzle velocity of 838m/s) were used to shoot dead sheep in the head, the degree of skull fracturing and cracking increased with muzzle velocity. Muzzle velocity is the velocity of the projectile at the moment it emerges from the muzzle. This velocity depends on the charge, the mass of the bullet, and the length of the barrel. The charge is the quantity of propellant contained in a round and is usually measured in grains (1 grain = 64.8mg) (Baker & Scrimgeour, 1995).

Finnie (1994) found that a cartridge (Winchester SSG loading, containing 18 pellets) fired from a "Remington" Model 870 12-gauge shotgun at the temporal region of the head of a sheep resulted in more severe cerebral damage as a result of multiple wound tracks caused by individual pellets, or fragments than that caused by a 0.22 calibre firearm. However, Finnie (1994) considered that both types of weapon caused sufficient penetration of the brain to cause the rapid unconsciousness that was observed after the sheep were shot. Blackmore (1985) used a 'Niven humane killer' to fire a variety of types of ammunition. Conventional solid bullets with charges of 2, 2.8 and 3 grains passed completely through the head of dead sheep. Penetration of the head and brain of dead sheep was caused by projectiles weighing about 10g consisting of (a) 130 lead pellets in an acrylic tube or (b) 5 or 10 lead discs in a polyethylene sleeve, that were fired using either a 2 or 3 grain charge. In addition, six sheep shot in the frontal region with charges of up to 168mg collapsed immediately with a period of tetany (or tonic contraction during which the body becomes rigid) lasting 7-12 seconds and then mild clonic movements for 50 seconds. Pedal reflexes could be evoked for up to 60 seconds. There was 'satisfactory' skull penetration and wide distribution of pellets (Blackmore, 1985). However, Blackmore et al. (1995) found that shooting sheep in the poll area through the upper cervical region of the vertebral column (near the occipito-atlantal junction at the base of the skull) with a 0.22-inch calibre rifle using solid lead bullets from a range of about 1 m "did not necessarily transmit sufficient percussive forces to higher brain regions to produce immediate insensibility". In one sheep, the bullet passed through the spinal cord causing fractures and extensive subdural hemorrhage around the base of the medulla and spinal cord. The EEG pattern was similar to that recorded before the sheep was shot, and visually evoked responses were present for at least 120 seconds (after which time the sheep was shot with a captive bolt). In another sheep, the bullet passed through the occipital condyles. The EEG pattern changed after the sheep was shot and became isoelectric after about 20 seconds. Visually evoked responses were lost immediately.

A summary of the responses of adult sheep after different methods of killing is shown in Table 7.

Table 7: Summary of the time (s) at which various responses of adult sheep occurred after different methods of killing[†].

Measurement	Exsanguination	Captive bolt stunning to the top of the head	Shooting	Punctilla spinal section followed by exsanguination after 130 seconds	Decapitation
loss of ability to stand	3-4	0	0		
changes in the EEG/ ECoG pattern	7-20	0		135	8
loss of struggling	8-9			37	
loss of visually-evoked responses	14	0-35			
isoelectric EEG	9-43	53-76		178	20
loss of rhythmic breathing	22	0		77	
pupillary dilation	70-72				51-87
onset of clonic convulsions	126-141		12		

[†] For references see Table 3 for exsanguination, Table 4 for captive bolt stunning, Blackmore (1985) for shooting and Tidswell et al. (1987) for comparative information on: punctilla and decapitation (methods not recommended for euthanasia).

Blunt trauma to the head: A manual blow delivered to the head of a neonatal lamb, using blunt objects or swinging the animal's head against a hard surface (wall or pillar) is a potential method for euthanasia (Raj, 2008). However, no systematic studies on the effectiveness of this method in lambs have been reported. Blackmore (1993) considered that gross physical damage to the brain could induce immediate insensibility, but lack of training, and human error could lead to distress and pain in some animals. Whiting et al. (2011) euthanized young piglets by swinging a 227g ball pien/peen hammer with a hemispherical head onto the head of restrained piglets. A correctly applied blow resulted in massive skull damage and convulsion within seconds. Unless the piglet was vocalising, "an unconscious convulsing piglet was difficult to differentiate from a conscious brain-injured piglet struggling in response to pain". Out of 50 piglets, one returned to consciousness and five failed to die. In many cases repeated blows were used to ensure that the piglet was killed rapidly. This method of euthanasia was not favoured by the operators.

The amount of brain damage caused by trauma to the head is related to the severity of the impact. In ewes, a maximum force of >6kN applied to the lateral side of the head is required to cause a skull fracture and extensive macroscopic signs of brain injury, such as subarachnoid hemorrhage, contusions and laceration of the cortex (Anderson et al., 2003). Impact forces result from contact between the head and an object. Inertial or acceleration-deceleration forces are the result of head movement immediately after impact and cause movement of the brain within the skull. In general, contact forces lead to focal surface phenomena, including fractures, hemorrhages and contusions, while inertial forces lead to more diffuse pathology (Duhaime, 2006; Finnie, 1997). Vigorous movement of the head of 7- to 10-day-old lambs, without impact, can cause focal subdural hemorrhage and diffuse histological changes in the brain (Finnie et al., 2010). Trauma to the head of 4- to 5-week-old lambs can cause contusions/bruising and hemorrhage in the brain (Finnie, 1997; Finnie, et al., 1999). Finnie et al. (2001) found that a mushroom-headed, non-penetrating stunner used on the frontal region of 4 to 5-week-old lambs caused a depressed skull fracture in all of six lambs, whereas its use on the lateral side of the skull caused a skull fracture in five out of 10 lambs and when used in the occipital or poll region it caused a skull fracture in four out of eight lambs. Macroscopic hemorrhage was found in various sites of the brain in all lambs. Macroscopic impact contusions were found in all lambs with a frontal impact, eight out of 10 lambs following temporal impact, and five out of eight lambs with an occipital impact. Contralateral contusions were present in all lambs with a frontal impact, two out of 10 lambs following temporal impact, and five out of eight lambs with an occipital impact.

Research recommendations:

Comprehensive evaluation of the welfare implications of different methods of euthanasia of sheep.

The effectiveness of blunt trauma to cause in a consistent manner, immediate loss of consciousness and death in lambs of various ages and weights).

The effectiveness of captive bolt apparatus with an extended bolt and a large charge to kill sheep.

The effectiveness of different methods of shooting i.e. type and calibre of weapon and projectile, and position on head of entry wound to kill sheep.

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4. FLOORING TYPES

Conclusions:

1. **A wet and warm floor surface increases the risk of foot rot compared with a dry surface.**

2. **Some results indicate that unshorn sheep do not show a preference for lying on a particular type of floor or bedding, while others have shown that straw is preferred over wooden slats.**

3. **The thermal conductivity of a particular floor type is important to sheep that have been recently shorn and straw and wooden slats are preferred over expanded metal floors and rubber mats.**

4. **Recently shorn sheep will reduce their lying time if the floor surface is too cold in order to conserve heat.**

5. **Animals fed a concentrate-only diet and housed on slatted floors show increased abnormal behaviours such as bar-biting and wool eating compared with sheep with access to straw.**

6. **The effective perimeter length of a pen is important, as sheep prefer to lie next to a wall.**

Introduction: While sheep are often raised in extensive pasture environments or in dry lots, in some situations and environments, sheep are kept indoors during the winter or year round. Buildings are often not insulated. Different types of flooring may be used in these buildings, and certain types of welfare issues may arise with these types of flooring.

Effect on nutrition: The ingestion of straw bedding can in some circumstances provide nutritional benefits. If sheep are kept on slatted floors they are dependent on the diet offered and do not have the opportunity to supplement their diet by eating straw bedding. For example, Crosby et al. (2004) and Day et al. (2006) reported higher liver copper concentrations in lambs on slatted floors than in lambs that were able to eat straw bedding.

Effect on foot health: The sole and heel bulb account for the largest area of the weight-bearing surface of the hoof in ruminants, yet the weight of the animal is normally borne on the claw surface of the hoof. The claw wall is hard and strong and built specifically to transfer the weight of the animal onto the ground. The softer sole and bulb also bear weight as well as distribute it to the ground surface. With heavy usage, the claw wears down and if it is worn flat, the sole will bear more weight and will therefore wear faster, causing the sole to thin (Shakespeare, 2009). Uneven or abrasive surfaces have been known to increase the wear of the claw (Shakespeare, 2009) and cows housed on concrete had increased rates of claw wear (Vanegas et al., 2006). Hard surfaces have the potential to cause joint damage in sheep. In experimental conditions, where sheep were walked daily on concrete and housed on tarmac, after 2.5 years, there was evidence of fibrillation of the knee joint (damage) that was not found in sheep walked on wood chips and kept on pasture (Radin et al., 1982). There was no evidence of severe osteoarthritis, a condition that has been found in cattle and swine housed on concrete floors, but there was some indication of early osteoarthritis as well as strengthening of the bones (Radin et al., 1982).

Sheep housed on concrete floors with straw bedding were not found to contract ovine foot rot under dry conditions and rarely under wet conditions if the temperature was cool and the feet were not injured (Cross, 1978). Similar results were seen under these conditions even if the animals were exposed to other sheep with foot rot (pen contact) or if freshly collected exudate was rubbed into scratches made on the foot (exudate) (Table 8). Over half of the sheep with scratches on their feet and kept under warm, wet conditions developed foot rot (Cross, 1978). Adequate drainage of floor surfaces may therefore be necessary to reduce the occurrence of foot rot.

Table 8: Influence of environmental factors on the transmission of ovine foot rot (Adapted from Cross, 1978).

Moisture	Temperature (°C)	Exposure to foot rot	Foot injury	Number of exposed feet	Number of feet diagnosed with foot rot
Dry	>10	Pen contact	None	32	0
Wet	>10	Pen contact	None	60	1
Dry	>10	Exudate	Scratches	16	0
Wet	>10	Exudate	Scratches	46	25
Wet	<10	Exudate	Scratches	14	1

O'Toole (1963) reported the results of lambing ewes (55 to 73kg) on wooden slats (6.4cm wide and 4.8cm deep) with a gap between adjacent slats of either 1.3 or 1.9cm. When placed on the slats, the ewes showed some initial signs of lameness, but almost no signs of foot rot were observed. The slat width of 6.4cm was described as satisfactory and negligible slipping by the ewes was reported. The 1.3cm gap between the slats was insufficient to prevent the free passage of manure and rejected silage. The 1.9cm gap between the slats was required to keep the slats clean, but was reported to be sufficiently narrow to be safe for newborn lambs (3.7 to 4kg) and for weaned lambs (30 to 34kg). Berge (1997) provided recommendations on slat design for sheep housing. Slats made from Scandinavian spruce and pine coated with epoxy filled with dry sand when wet was reported to provide excellent surface characteristics. A slat width of between 5 and 10cm and a gap between adjacent slats of 1.8cm for newborn lambs and 2.5cm for adult sheep were recommended. At temperatures below -20°C, manure was reported to tend to clog the slots and at low temperatures a wet ration resulted in more clogging and a slicker floor. A report from the United States (US) on the use of galvanised, expanded, flat sheet metal with a mesh size of 1.9 x 4cm for sheep was cited by Berge (1997) as providing a suitable surface.

Effect on udder health: Mastitis occurred at a higher incidence in ewes housed on expanded metal floors over 'natural' flooring (excreta and food remains) and slatted wood (43.6%, 35.0%, and 21.4% of ewes respectively). Despite this, in the first four days of lactation, most mastitis cases occurred on natural floors and the fewest number of cases occurred on the expanded metal floor (Indreb, 1991). Teat injuries occurred more often on expanded metal floors (Indreb, 1991). The majority of *Escherichia coli* cases (6 of 12) of mastitis were found on natural floors. Mastitis due to *E. coli* is rare in sheep, and thus these results should be considered in this context. The authors concluded that the general health of ewes was best on natural floors, but the reason for this conclusion is not known.

Cleanliness of the floor: A wooden slatted floor was found to retain some fecal pellets and not maintain its cleanliness as anticipated (Lupton et al., 2007). The feces were generally squashed and forced through the slats by the feet of the lambs (Lupton et al., 2007). Woven steel wire floor was found to improve the ability of the feces to fall through, which also maintains the distinct fecal pellet shape which is needed if the manure is to be sold to gardeners (Lupton et al., 2007).

Rubber mats have low absorption capacity, and quickly become wet and dirty (Færevik et al., 2005). The wetness of a surface impacts the thermal conductivity of the material, which together with the poor cleanliness likely decreases the appeal of the material for resting. The thermal resistance of sawdust, for example, is reduced by a factor of six when it is wet (Gatenby, 1977). As stated above, wet surfaces can lead to problems with diseases such as foot rot.

Effect on production: Lambs reared in barns on above ground wooden slats or woven wire floors produced leaner carcasses and heavier, more uniform and visually cleaner fleeces than lambs raised on pasture or in a feedlot (Lupton et al., 2007). There was no significant difference in growth rate found in lambs raised on straw bedded floors compared to galvanized expanded metal flooring (Crosby et al., 2004) or plastic slatted flooring (Day et al., 2006). Feed intake also was not different, despite the addition of fresh bedding every second day that could have been an additional fibre source for the lambs (Crosby et al., 2004).

EFFECT ON BEHAVIOUR:

Flooring material preferences: Group housed ewes did not show a preference for any specific flooring materials in two-choice tests between solid wood, mats, expanded metal floor or straw (Færevik et al., 2005). The first ewe of a group to lay down after feeding preferred wooden floor to expanded metal floor, straw to wooden floor and straw to expanded metal floor, but no preference between wooden floor and rubber mats was evident for the first ewe lying down after feeding (Færevik et al., 2005). In other results, Gordon and Cockram (1995), found a significant preference of one-year-old rams for straw bedded floors over wooden slats. Some habituation was observed with wooden slats, as the amount of time spent lying on slats in the second 24 hour period increased from the first 24 hour period (Gordon & Cockram, 1995). Rams housed on wire mesh floors with access to plastic mats spent significantly more time lying on the mat than on the wire mesh (McGreevy et al., 2007). Lying off the mat was significantly reduced when the mat was returned after a period without it. The percentage of time spent lying peaked on the first day the mat was returned compared to percentage of time spent lying when the mat was first introduced or in days following reintroduction (McGreevy et al., 2007).

While unshorn ewes appear to place less importance on the softness of the floor than recently shorn ewes, as seen by preference testing by Færevik et al. (2005), shorn ewes significantly preferred a wooden floor to an expanded metal floor, straw to wooden floor and straw to expanded metal floor, as well as tending to prefer wooden floor to rubber mats (Færevik et al., 2005). Similar results were found by Hansen and Lind (2008), where only after shearing did lambs use double bunks with wooden slatted floors as much or slightly more than expanded metal floors. The thermal conductivity, while appearing to have little importance to unshorn sheep, seems to have great importance to shorn animals, at least for the first 3 weeks following shearing, likely due in part to the thick fleece present on unshorn ewes limiting the loss of heat (Færevik et al., 2005; Hansen & Lind, 2008) and possibly the lack of a cushioning effect provided by fleece. Ewes showed a clear preference for lying next to a wall (98.2% of observations lying), and observations of lying in the middle of the area were almost exclusively on straw (Færevik et al., 2005). The effective perimeter length affects the lying preference of sheep and a minimum of 0.9m per ewe has been suggested (Jørgensen & Bøe, 2009). In slatted floored pens, solid wood platforms could help to increase the effective perimeter length in a pen without increasing its size but can become covered in feces and urine, which could lead to wool, claw or skin contamination (Jørgensen & Bøe, 2009). Wooden platforms, if kept clean and dry may thereby improve the comfort of sheep housed indoors on slatted floors, although the advantage is seen largely from the increased space to lie next to a wall (Jørgensen & Bøe, 2009).

COMFORT AROUND RESTING

Heat loss: Conductive heat loss from sheep is determined largely by the ground temperature, the depth of fleece and nature of the insulation material beneath the sheep (e.g. straw, wood shavings, wet or dry sawdust) and is fairly unaffected by the immediate microclimate (Gatenby, 1977). When a sheep is lying down 20-25% of the surface area is in contact with the ground. Depending on the proportion of time which the animal spends lying down, conduction can be an important contributor to heat loss (Gatenby, 1977). In comparison to lying, a sheep that is standing has only 0.5% of its total surface area contacting the ground. The proportion of the time spent lying can be influenced by weather conditions, food supply and social habits (Gatenby, 1977). Sheep may lose 2-3MJ/day (up to 30% of minimum heat production) by conduction when lying on cold, poorly insulated surfaces (Gatenby, 1977). Conduction may be an important route of heat loss in housing facilities, and cold stress can therefore be aggravated by conduction (Gatenby, 1977).

The length of fleece is suggested to be more important in determining heat loss while lying than the nature of the substrate the sheep lies on (Gatenby, 1977). This was suggested after the pattern of heat flow through 3.3cm of fleece to grass or to concrete surfaces was found to be similar (Gatenby, 1977).

Duration of resting: Sheep kept indoors on slatted floors (mostly wire mesh) spent 2-3 hours more lying down than sheep on pasture (Bøe, 1990). This was probably due to the increased time spent foraging on pasture and not to the comfort level of the lying surface.

Before shearing, sheep housed on slatted wire mesh floors in an uninsulated barn spent significantly shorter time lying than sheep housed in insulated barns on similar floors (862.1 minutes/day and 917.2 minutes/day) (Bøe, 1990). Lying time in the uninsulated barn also positively correlated with the outside ambient temperature, whereas this correlation was not seen in the insulated barn (Bøe, 1990). After shearing, lying time was reduced by nearly 40% and no significant difference in the lying time between insulated or uninsulated barns was observed (Bøe, 1990). Lying time was also correlated with outside temperatures in both barns

(Bøe, 1990). By twenty-five days after shearing, the duration of lying had returned to approximately the same length as before shearing, which the author presumed was because of a combination of increased insulation from growing wool, acclimatization, and increasing environmental temperature (Bøe, 1990).

Ability to perform natural behaviours: Lambs fed a pelleted diet in a barn on raised wooden slats or raised woven wire floors were not observed wool biting or fighting for dominance (Lupton et al., 2007). Sheep housed in straw bedded pens spent significantly more time lying, moving, eating hay, nosing straw and ruminating than sheep individually housed in stalls (e.g. experimental crates) with slatted floors (Cooper & Jackson, 1996). In comparison, sheep housed in slatted individual stalls spent significantly more time eating concentrate, rearing, drinking and performing abnormal oral activities such as bar-biting, slat chewing and wool eating than the sheep housed on straw in a group (Cooper & Jackson, 1996). These abnormal oral activities performed by sheep on slatted floors fed a concentrate-only diet may act in place of foraging activities such as eating hay or nosing straw (Cooper & Jackson, 1996). This suggests that concentrate alone does not entirely meet the nutritional needs of sheep, likely due to the lack of long stem fibre which is important in the functioning of the digestive tract (Cooper & Jackson, 1996) and an environment void of these types of substrate deny the animal appropriate foraging opportunities. Supplementing concentrate-fed, housed Merino sheep with straw significantly reduced the frequency of wool biting and wool damage (Vasseur et al., 2006)

Research Recommendations:

The effect of flooring types on foot and leg health.

There is little research on the relationships between bedding, flooring type and the risk of mastitis.

Specifically, more research is needed on slatted flooring (effect on feed intake, lying times, foot health and thermal comfort of nursing and weaned lambs, as well as adults).

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5. NEONATAL CARE UP TO AND INCLUDING WEANING

DYSTOCIA

Conclusions:

1. **Dystocia increases the risk of lamb mortality and can delay the performance of important behaviours such as suckling.**

2. **Although there has been minimal research directly on sheep, dystocia is likely to cause significant pain in ewes during and perhaps after parturition.**

3. **There are a variety of factors that can increase the risk of dystocia, such as birth weight and litter size, as well as relative fetal oversize. Consideration of these factors and adjusting management requirements may help to reduce the incidence and severity of dystocia cases.**

Introduction: The welfare of both ewes and lambs can be compromised through difficulty at birth, also known as dystocia. Their ability to perform their natural behaviour that is required to fulfil essential functions can be affected by dystocia.

The incidence of dystocia is somewhat varied, but Dwyer (2003) found that 21.2% of 524 Suffolk or Scottish Blackface lambs required some assistance at birth. Most lambs that were malpresented required assistance, and yet some (11.4%) correctly presented lambs also required assistance (Dwyer, 2003).

The evaluation of the impact of dystocia is often measured using lamb mortality. In many circumstances mortality rates can provide a way of assessing standards of husbandry. However, if death is quick and without suffering, it is not a welfare issue, but when it is prolonged and associated with feelings such as sickness, pain and fear it is a welfare concern (Broom, 1988). As discussed by Mellor and Stafford (2004), the ability of neonatal lambs to perceive suffering associated with several aversive outcomes of dystocia, that might proceed death, such as breathlessness, hypothermia, hunger, sickness or pain might be mitigated by any associated hypoxaemia, hypothermia, drowsiness, sleep and/or unconsciousness.

As discussed by Cockram and Hughes (2011), dystocia can cause considerable pain, discomfort and health risks to both the ewe and the lamb. Some consequences of dystocia for newborn animals include direct physical trauma, delayed passive antibody transfer and subsequent bacterial infections. Veterinary procedures, the use of analgesia (Scott & Gessert, 1996) and antibiotics, and hygienic practices can reduce the adverse welfare implications associated with obstetrical problems (Scott, 2005). Further research is required on the welfare implications of dystocia; however, the delay in performing natural behaviours has been recorded to a certain extent.

There is a considerable amount of literature on risk factors for dystocia, and these factors may provide insight into practices that can help to alleviate the occurrence of this problem, thereby minimizing the number of animals which experience dystocia.

Risk factors of dystocia: There is a wide variation in the reported risk factors for dystocia. While some factors are repeated in several studies, others are contradictory. One potential reason for this is the wide range of sheep breeds which were studied. Certain breeds may be genetically predisposed to dystocia due to one reason over another. Another possible discrepancy between studies is the criteria for when assistance was given to the lambing ewe, i.e. when she was determined to require manual delivery or veterinary assistance. It is likely that there was at least some variation between studies in the criteria for when to provide assistance or veterinary assistance, which could cause some discrepancy in the discussion of the risk factors.

Dystocia risk has been found to be highest in triplet-bearing ewes; with triplet dystocia the risk of lamb mortality is 9% greater than for twins (Everett-Hincks & Dodds, 2008). The increased incidence of dystocia in increased litter sizes is in line with the increased incidence of malpresentation at birth (Speijers et al., 2010). Conversely, in other studies, single-born lambs were found to be significantly more likely to require assistance at delivery than twins or multiple lambs (Dwyer & Bünger, 2012). This is believed to be at least partially due to over-feeding ewes pregnant with singles resulting in increased birth weight. However, there is little scientific examination of this risk factor. In summary, single-born lambs have an increased risk of dystocia due to increased birth weight while increased litter sizes increase the risk of dystocia due to malpresentation.

The age (including experience and parity) of the ewe can affect the incidence of dystocia. For example, Dawson and Carson (2002) found that one-year-old ewes required assistance at lambing more often than two or three-year-old ewes. Dwyer and Bünger (2012) found that 55% of 2-year-old ewes lambed unassisted compare to 67% of ewes over 2-years-old. Speijers et al. (2010) found that the odds ratio for dystocia decreased with the age of the ewe. Although lambs born to 3-year-old ewes had a higher risk of dystocia compared to ewes 2, 4, 5 or 6-years old, this increased risk of dystocia in 3-year-old ewes is likely due to an increased prevalence of multiple births (Speijers et al., 2010). A restrospective study of 2 to 6-year old dams by Everett-Hincks and Dodds (2008) also found that dystocia rates were greatest in lambs born to 3-year-old dams. There are a number of factors involved (Smith, 1977) and the relationship between ewe age and dystocia requires further investigation.

No effect of lamb sex on dystocia was found over several breeds of sheep but there was a significant effect of sex for Suffolk lambs (Dwyer, 2003). Male lambs required assistance more often than female lambs (Dwyer & Bünger, 2012; Everett-Hincks & Dodds, 2008), which can be at least partially accounted for by the increased birth weight seen in male lambs. Males also tended to be malpresented more frequently which could be due to differences between the sexes in prenatal behavioural devlopment, particularly in breeds, which have been selected for production traits (Dwyer & Bünger, 2012).

As male lambs were heavier than female lambs and increasing the litter size decreased the lamb weight, it is difficult to separate the effects of weight and lamb sex. Lamb weight was found to be significantly higher in cases of dystocia than in unassisted births (Cagnetta et al., 1995). Unassisted lambs were significantly lighter than assisted lambs overall, and yet weights did not differ between lambs requiring different levels of assistance (i.e. minor assistance, major assistance or veterinary assistance) (Dwyer & Bünger, 2012). In both Suffolk and Scottish

Blackface lambs, heavier lambs had significantly longer labour and male Scottish Blackface lambs also had an increased labour length; these factors possibly increased the number of lambs given assistance in the study by Everett-Hincks and Dodds (2008). The incidence of dystocia started to increase once the birth weight of the lamb increased above 4kg, and being oversize was found to be the predominant cause of dystocia in single lambs (Speijers et al., 2010). Heavier lambs also had a higher frequency of malpresentation than lighter lambs and an increased weight was associated with a higher proportion of lambs presented head first with one or both legs retracted (Dwyer, 2003). Lambs presented with one leg retracted were also found to be significantly heavier than those presented with both legs back (Dwyer, 2003). In other results, lambs that were 0.5 to 1kg above the overall mean weight of the other lambs in the study, regardless of litter size, had a lower mortality risk due to dystocia (and also a lower mortality risk from starvation and exposure during the first 3 days after birth), and triplet lambs that were 2kg lighter than the mean had the greatest mortality risk to dystocia (Everett-Hincks & Dodds, 2008). Ewe nutrient intake and weight fluctuations throughout gestation can impact the birth weight of the lamb and thus impact its risk of dystocia. This will be covered in greater detail in the following subsection on *Neonatal Survival*.

There is considerable evidence, e.g. Olson et al. (1987), that pregnant ewes are unlikely to experience significant problems associated with either thermal regulation, health or lambing ability at air temperatures as low as -10^{o}C. In the Olson et al. (1987) study lamb mortality rate at birth was not greater at -10^{o}C than at temperatures of 10 and 15^{o}C. However, there is some evidence that the energy demands on pregnant ewes that do not receive adequate nutrition and are exposed to cold conditions can result in increased lamb mortality (Blaxter, 1957). Everett-Hincks and Dodds (2008) referred to two proceedings in their discussion in which the authors suggest that weather conditions in late pregnancy influence the energy balance of the ewe, particularly those carrying twins or more, and that this may influence lamb viability at birth. It has been suggested that weather conditions during late pregnancy influence the energy balance of the ewe when nutritional requirements are great and in some cases may not be met (Everett-Hincks & Dodds, 2008). This energy imbalance is thought to affect the vitality and survival of the lamb (Everett-Hincks & Dodds, 2008) and its ability to cope with the harsh climate it may encounter (Coronato, 1999). The survival of the offspring to at least two months of age was negatively correlated with the heat loss, assessed by a formula using temperature, wind speed, time of wet fleece, fleece depth and percentage of overcast sky during the two weeks preceding lambing in Patagonia (Coronato, 1999). This correlation was stronger than the heat loss assessed during the period of lambing itself (Coronato, 1999). Although this author emphasised the importance of the climatic conditions before lambing, the average daily conditions that the ewes were exposed to were all above 0°C with winds under 4 m/second.

Triplet lambs born to ewes with maternal behaviour scores lower than 3 (see Table 9 for description of scores) also had an increased risk of death to dystocia, whereas single born lambs were not affected by the maternal behaviour score of the dam (Everett-Hincks & Dodds, 2008).

Table 9: Maternal behaviour scores of dams recorded at tagging of the lamb (Adapted from O'Connor et al., 1985).

Maternal Behaviour Score	Description
1	Ewe flees at the approach of the shepherd, shows no interest in the lambs, and does not return
2	Ewe retreats further than 10m but comes back to her lambs as the shepherd leaves them
3	Ewe retreats to such a distance that tag identification is difficult (5 to 10m)
4	Ewe retreats but stays within 5m
5	Ewe stays close to the shepherd during handling of her lambs

Breed has a significant impact on whether ewes require assistance at delivery. Significantly more ewes giving birth to purebred Texel lambs required assistance at delivery and ewes giving birth to purebred Suffolk lambs required assistance more often than ewes giving birth to Scottish Blackface lambs or Mule (Scottish Blackface x Border Leicester) x Texel lambs (Dwyer & Bünger, 2012). Ewes giving birth to Texel lambs were also much more likely to require veterinary assistance at lambing (Dwyer & Bünger, 2012).

There appears to be some variation in the dystocia incidence between ewe breeds depending on the sire of the lamb (Carson et al., 2001). It was found that the proportion of ewes that required assistance when lambing was higher in Blackface ewes than Cheviot ewes when the sire of the lamb(s) was a Texel ram, which is suggested to be due to the incompatibility of the lamb size and pelvic size of the ewe (Carson et al., 2001). Relative fetal oversize was the most common suspected cause of dystocia necessitating caesarean operations in ewes in a field study of 137 caesarean operations over 3 years (Scott, 1989). It was also found that the proportion of Blackface ewes that were crossed with Blackface sires that required lambing assistance was lower than the proportion of Cheviot ewes crossed with Cheviot sire (Carson et al., 2001). Dystocia was significantly lower in purebred Blackface ewes mated to Blackface rams than those mated to Lleyn, Cheviot or Texel rams (Speijers et al., 2010). In other results, a higher proportion of Suffolk x Cheviot ewes lambed without assistance when compared to Blue-faced Leicester x Blackface and Texel x Blackface ewes (Dawson & Carson, 2002). Blue-faced Leicester x Blackface, Texel x Blackface and Texel x Cheviot ewes all had a similar proportion of ewes requiring assistance (Dawson & Carson, 2002). A greater proportion of ewes that were crossed with a Suffolk ram required assistance than ewes crossed with a Texel ram (Dawson & Carson, 2002). While in some cases the incidence of dystocia between breeds can be attributed to the lamb weight differences, it has also been suggested that the presentation of the lamb may also be a cause (Carson et al., 2001). Speijers et al. (2010) found that the differences between sire breeds in the proportion of dystocia caused by large lambs was in line with their differences in lamb birth weight. There was also a significant effect of sire breed on dystocia that was caused by lamb malpresentation which was independent of birth weight (Speijers et al., 2010). Consideration and matching of the sire and ewe breeds to each other may help to reduce the incidence of dystocia. Welfare problems may also occur if breeds are not matched to their managment requirements; for example, data has shown that the Suffolk breed, which is generally managed intensively, requires considerable human labour input at lambing time, and if labour in these flocks is reduced, there is likely to be a large increase in lamb mortality rate and thus reduced lamb welfare (Dwyer & Lawrence, 2005).

Effect on mortality risk of the lamb: In extensive systems, the majority of lambs' deaths are attributed to two causes, dystocia from prolonged or difficult birth or the starvation-mismothering-exposure complex (SME) (Nowak & Poindron, 2006). In one study, most lambs which were able to stand, but subsequently died had gone through an above average length of labour (Arnold & Morgan, 1975). Lamb birth weight generally demonstrates a U-shaped distribution with survival; mortalities from starvation and exposure decrease as lamb weight increases, while mortalities due to dystocia increase with birth weight (Dwyer, 2003). Lambing difficulty score (from 1 to 4, score 1= no assistance at lambing, 4= very difficult manual delivery, including veterinary assistance) has tended to be associated with lamb mortality rate between birth and 7 weeks of age (Speijers et al., 2010). Every increase in lambing difficulty score more than doubled the likelihood of lamb(s) dying within 24 hours of birth (Speijers et al., 2010). Scales et al. (1986) found that 5% of lambs born, died after dystocia, a mortality rate which increased to 15.7% if it is assumed that lambs that were assisted would have died without assistance. This effect of dystocia on mortality is stronger in single-born lambs, as their heavier birth weights predispose them to dystocia and birth trauma (Speijers et al., 2010).

Effect on latency to perform behaviours: Any assistance given to deliver lambs slowed the time to initial righting movements performed by the lamb after delivery, such as raising the head and pushing up onto the knees (Dwyer, 2003). Interestingly, correcting the position of the lamb before the ewe delivered the lamb on her own did not affect the lamb behaviours in comparison to unassisted lambs (Dwyer, 2003). Lambs that required a full manual delivery were significantly slower than all other lambs to perform all neonatal behaviours and a smaller number were seen playing within the first three hours of birth (Dwyer, 2003). Lambs that required assistance at delivery or undergo a difficult birth process can, without human intervention, have delayed suckling (Dwyer, 2003; Dwyer & Bünger, 2012). Lambs that required a manual delivery were also less active than lambs with a less difficult birth in the first three days after birth (Dwyer, 2003). Lamb birthing difficulty could result in trauma, either physical injury or hypoxia, which could be the factor affecting the lamb's development in the postnatal period (Dwyer, 2003). A delay in standing or grooming of the lamb by the ewe was also associated with a long labour (Arnold & Morgan, 1975).

Summary: Dystocia requiring assistance to deliver lambs increases the risk of lamb mortality – not only at the time of birth but also in the early neonatal period. The major causes of dystocia are maternal: foetal disproportion and malpresentation. Dystocia due to maternal: foetal disproportion can be due to: inappropriate breed selection, breeding poorly grown ewe lambs and/or overfeeding ewes carrying singles. Malpresentation can be the result of high birth weight but also increases when multiple births occur. Dystocia can result in pain and damage to the lamb, which will interfere with normal nursing behaviour; and pain and damage to the ewe which may interfere with the ewe's ability to properly mother the lamb(s) and may lead to mismothering. To reduce welfare issues due to dystocia, the following points are important to consider: proper gestational ewe nutrition to assure appropriate birth weights (i.e. avoid underfeeding of ewes carrying multiples and overfeeding of ewes carrying singles); proper selection of breeds to ensure lambing ease; timely and appropriate intervention when malpresentation occurs; culling of ewes with a history of lambing difficulties; protection from inclement conditions in the periparturient time; proper nutrition of ewe lambs to ensure good body size at the time of lambing.

Research recommendations:

Implications of dystocia on pain and maternal care.

Implications of supervision of lambing on the risk of dystocia. For example, effect of frequency of observation, group size, criteria for intervening on lamb survival and ewe comfort. More research on criteria for when to intervene should also be studied (e.g. how long after the fetal membranes have broken should one intervene).

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NEONATAL SURVIVAL

Conclusions:

1. **Selection of sheep suited to the management practices is important, as both intensive and extensive lambing systems have potential welfare concerns**.

2. **Lamb mortality rates vary greatly due to many factors involved. Lambs born to larger litters have the highest risk, and increased surveillance of these and any other high risk lambs may help to reduce the mortality rates.**

3. **The starvation-mismothering-exposure complex is the most common cause of death of lambs, and is multi-factorial. Addressing all factors will minimise losses from this complex.**

Introduction: Farm management practices are very diverse, and management of lambing is no exception to this. On one end of the spectrum there is intensive lambing where the sheep are under constant supervision and human intervention is a regular occurrence. On the other end of the spectrum, sheep are left in 'natural' environments with little human involvement (Fisher & Mellor, 2002). These two extremes represent two different welfare considerations. In intensive systems, sheep are monitored closely and any problems or difficulties are addressed, thereby reducing suffering, yet this can disrupt natural behaviours and may cause some fear responses in the ewe. It is important that the environment be constructed to reduce this disruption. In extensive systems, the sheep have less human intrusion and can behave 'naturally', but there is reduced opportunity to avoid unnecessary pain and death if problems arise. In general, animals which are kept extensively are selected heavily both naturally and artificially for their ability to raise a lamb with minimal human intervention.

Parturient ewes will often seek isolation, a behaviour which is often interrupted in intensive farm situations due to high stocking rates and concentrated lambing patterns (Fisher & Mellor, 2002). This isolated birth site may decrease the chance of interference by other ewes or lambs. Bonding occurs at the birth site, and ewes that spend longer time at this site are less likely to become separated from their lambs (Alexander et al., 1983). Although natural movement does not seem to affect the ewe-lamb bonding process, forced movement of ewes in labour is disruptive because the focal point of the birth site is removed (Fisher & Mellor, 2002). Human disturbance during lambing may cause ewes to move from the birth site, particularly if they are unaccustomed to the presence of the shepherd.

Because the presence of humans can inhibit or delay parturition which in turn increases the risk of dystocia, and disturbance at birth can compromise ewe-lamb bonding and therefore lamb survival, the degree of shepherding has to be adapted to the situation (Fisher & Mellor, 2002).

Factors affecting lamb mortality: Improper neonatal care (i.e. care of newborn lambs), can affect all aspects of welfare, but the most obvious effect of poor neonatal care is lamb mortality. Lamb mortality is suggested by Dwyer (2008) to be considered a clear predictor of welfare, where high neonatal losses are synonomous with poor welfare. Lamb mortality is presumed to be associated with levels of suffering by the animal, however a review by Mellor and Stafford (2004) concluded that this generalization is not always appropriate and the level of suffering will depend on the cause of death. Mortality due to breathlessness and hypothermia have been rated as mild to moderate welfare concerns, as the factors which lead to death also dull the consciousness of the lamb, thereby likely reducing the level of suffering felt by the lamb (Mellor & Stafford, 2004). Mortality due to hunger, sickness and injuries has been rated as moderate to severe welfare concerns (Mellor & Stafford, 2004). Although in many cases some causes of death result in higher levels of suffering before death than others, the adoption of management practices that reduce mortality rates, are likely to improve the welfare of the surviving lambs.

Lamb mortality rates vary across countries, production systems, and breeds of sheep, and have been noted to commonly range from 15-25% worldwide (Nowak et al., 2008). Gama et al. (1991) reported preweaning mortality varying from 19.6% to 27% between different breeds, and yearly and accelerated lambing systems. Mortality at birth or within the first 24 hours of life has been noted to range from 20 to 63% of total preweaning mortality, emphasising the importance of surveillance at lambing (Gama et al., 1991).

Lamb mortality rate varies with breed of sheep, parity of the ewe, litter size and season of birth (María & Ascaso, 1999). Analysis of pre-weaning mortality of a population of over sixteen thousand lambs born over a five year period by Gama et al. (1991) showed that much of the variation between individuals and maternal breeds came from differences in litter size and birth weight relative to the size of the ewe. Lambs from more prolific breeds (Finnish Landrace (FL) and FL crosses) were better able to survive to weaning than Rambouillet, Targhee and Suffolk lambs with common litter sizes or similar ratio of birth weight to mature size of the ewe (Gama et al., 1991). At any given litter size, total mortality rate before weaning was lower in more prolific breeds (FL and maternal composite breeds) than in Suffolk and Targhee lambs (Gama et al., 1991). This difference widened as litter size increased, primarily because a greater increase in mortality rate in the first 24 hours of life was seen with increased litter size in Suffolk and Targhee breeds (Gama et al., 1991).

Lamb mortality rate in first parity ewes has been found to be significantly higher than in adult ewes (María & Ascaso, 1999). Other results have found that lamb mortality rate is lowest for ewes lambing between 1 and 3 years of age and increased in older ewes (Gama et al., 1991). The same authors found that the mortality rate in an accelerated lambing system was highest in ewes near 3 years of age and lowest in younger and older ewes. However, when these effects were adjusted for litter size and birth weight, the effect of ewe age became less evident (Gama et al., 1991).

Lamb mortality rate is also higher in triplet litters than in single or twin births (María & Ascaso, 1999). Larger litter sizes in paternal lines lambing once a year were associated with a quadratic increase in lamb mortality rate, i.e. the rate of increase in mortality increased with increased litter size (Gama et al., 1991). Starvation has been noted as the major cause of death in large litters, while respiratory disease is the major cause of death in small litters (Gama et al., 1991). For some breeds, perinatal lamb mortality rate (i.e. mortality at birth and during the first 24 hours after birth) was higher for twins and triplets than for single born lambs. (Gama et al., 1991). The effects of litter size on mortality rate can be mediated through the effects of birth weight and there is some variation between breeds (Gama et al., 1991).

Although results vary, lamb mortality rate is often found to be lowest in autumn lambing flocks, which is generally when the litter sizes are the smallest as well. It is clear from these results that lambs from large litter sizes are at greatest risk for mortality early in life, probably due to a combination of factors. Increased surveillance and/or human intervention (e.g. feeding, penning) for these larger litters has the potential to decrease the level of mortality.

Birth weight effects on mortality: Birth weight has been found to be the best predictor of lamb mortality from birth to weaning, where lambs of intermediate weight for each breed had the lowest mortality rate (Gama et al., 1991). The optimum birth weight, where mortality rate is lowest, varies among breeds. Gama et al. (1991) found the optimum birth weight was 4.4kg for Finn lambs, 6.4kg for Targhee, 8.0kg for Suffolk lambs, 5.6kg for Dorset and 5.9kg for Rambouillet lambs. Total mortality rate from birth to weaning increased with weights above or below this optimum birth weight. Smaller lambs are likely weaker at birth which may impede the lambs ability to obtain adequate milk from the dam, predisposing them to diseases as well as starvation. Mortality rate increased with higher birth weights due to deaths within the first 24 hours after birth, likely due to dystocia because of the incompatibility of the lamb and ewe size (Gama et al., 1991). Conversely, mortality rate from 1 to 60 days of age decreased with heavier birth weights in all breeds examined, except one, in which starvation deaths increased (Gama et al., 1991).

The birth weight of the lamb can be affected by the ewe’s nutritional status. Overfeeding young ewes to maximise growth and fat deposits restricts the growth of the lamb and can lead to premature births (Wallace et al., 2006). A high-energy intake has been found to be the primary cause of this, as opposed to the protein levels in the diet (Wallace et al., 2006). In contrast, a low plane of nutrition in early pregnancy increased the prolificacy of one-year-old ewes, but led to higher lamb mortality rate in the first six weeks (Muñoz et al., 2009).

The weight gain of ewes in the last six weeks of pregnancy has been correlated significantly (r^2= 0.92 and 0.95) with the birth weight of single lambs and twin lambs (Scales et al., 1986). A 10 kg increase in ewe weight during the last six weeks of pregnancy led to a 0.46kg increase in birth weight of single lambs and 0.52kg increase in individual lamb birth weight in twins (Scales et al., 1986). Mature ewes fed corn or dried distillers grains tended to have larger lambs at birth than ewes fed haylage (Radunz et al., 2011). These changes did not affect ewe performance or lamb weaning weights. Deaths due to dystocia increased with increased weight gain in the ewe, particularly in single lambs, while deaths due to starvation showed corresponding decreases with increased ewe weight (Scales et al., 1986).

Nutrient restrictions during the last part of gestation results in lambs which are nearly 1 kg lighter than lambs from ewes fed a high nutrient level (Tygesen et al., 2008). Ultrasonic scanning to determine fetal numbers can be used to group ewes for feeding according to the number of fetuses (White & Russel, 1984; Russel, 1985). If twin bearing ewes are separated out and given supplementary feeds during late pregnancy this can improve the survival rates for their twin lambs (Waterhouse, 1996). Increasing the amount of feed offered to the ewe during the second half of gestation can increase both fetal weight and brown adipose tissue (Budge et al., 2000). For a newborn lamb to maintain homeothermy before it ingests colostrum it must metabolise its brown fat energy reserves and increase muscular activity by shivering. Fat reserves are disproportionately low in small lambs and in lambs being born from ewes that had been undernourished during pregnancy. Lambs with poor fat reserves have reduced chances of survival (Nowak & Poindron, 2006).

Starvation-Mismothering-Exposure (SME) complex: The SME complex is a common cause of death of neonatal lambs born in extensive environments (Broster et al., 2010); however this likely encapsulates a much larger variety of problems. These three causes of death can act independently, but often there is some association between them.

Hunger is a normal sensation which drives animals to seek and ingest food and is not considered to be a welfare concern unless food intake is inadequate or nonexistent for an extended period of time (Mellor & Stafford, 2004). Starvation will obviously be associated with severe hunger and reduced welfare. Starvation is a major cause of neonatal mortality in lambs, especially in large litters and can occur in up to 9% of lambs (Gama et al., 1991). Starvation occurs when the lamb does not ingest sufficient colostrum within the first 3 days after birth and especially during the first few hours after birth. There are a number of reasons for this including lamb health and vigor, inadequate milk supply, udder abnormalities or disruption in the lamb/ewe bond within the first 3 days of birth (Dennis & Nairn, 1970; Yapi et al., 1990). It has been found to be the largest single cause of death, accounting for 33.6% of all the lambs necropsied and nearly 50% of post-parturient deaths (Dennis, 1974). The incidence of mortality caused by starvation increased with litter size similarly across many breeds and for each additional lamb born, the mortality rate due to starvation increased by about 2.2%.

The behaviour of the ewe before, during and after lambing can affect lamb mortality, particularly under extensive conditions (Nowak, 1996). The maternal behaviour of the sheep, such as seeking shelter and forming a strong bond with their lamb, is affected by breed (Dwyer & Lawrence, 1998). Mismothering generally leads to death of the newborn through starvation, which may be exacerbated by cold exposure. Mismothering can be due to a variety of reasons related to the failure to form or maintain the ewe-lamb bond (Mellor & Stafford, 2004). The effects of mismothering such as starvation or predation can cause reduced welfare in lambs. Ewe behaviours which were found to directly affect lamb mortality rate were desertion and interest in the lamb of another ewe prior to birth of their own lamb, although most ewes lost interest in lambs of other ewes before the birth of their own lamb (Arnold & Morgan, 1975). The only four ewes that continued their attention to another ewe's lamb deserted their own lambs, all of these lambs subsequently died (Arnold & Morgan, 1975). As these results are based on a small number of animals, they should be interpreted with some caution.

Ewes moved from the birth site 30 minutes after the birth of their second lamb permanently deserted at least one lamb, whereas ewes penned at the birth site for six hours following parturition did not desert their lambs (Putu et al., 1988). The use of lambing cubicles that allow the ewe to leave but prevent the lambs from leaving the birth site kept the ewe together with all of her lambs, where without this the ewe may drift away with one or two lambs and desert the other (Gonyou & Stookey, 1985). Lambing cubicles also decrease the frequency of interference of a parturient ewe by other ewes, which also helps to decrease the occurrence of separation and stealing of lambs (Gonyou & Stookey, 1985).

Exposure alone is difficult to diagnose post-mortem, and was not found to be a significant cause of death (Dennis, 1974). These results were found in Western Australia, and temperatures would rarely, if ever, be comparable to Canadian winter temperatures, and thus may underestimate the risk of lamb mortality due to exposure. Metabolic rate in newborn lambs increases below environmental temperatures of 28°C, and at temperatures below 10°C, skin temperatures of the lambs' extremities fall below the trunk skin temperatures (Haughey, 1973).

Hypothermia often precedes death in lambs, but this reduced body temperature is not necessarily the primary cause of death, and hypothermia itself has several causes (Mellor & Stafford, 2004). Exposure to cold conditions can be considered the primary cause of death in healthy newborns. Lamb mortality rate was higher in lambs kept at 0°C or -10°C compared to those kept at 15°C or 10°C (Olson et al., 1987). Cold temperatures cause newborns to increase their heat production, but if the intensity of the environmental temperature is so cold that the heat loss from the body exceeds heat production, hypothermia can develop within 15-30 minutes and death can follow within hours (reviewed by Mellor & Stafford, 2004). Lambs born into a cold environment (0°C or -10°C) showed signs of moderate to severe muscular weakness, depression and difficulty or reluctance to suck (Olson et al., 1987). Cold-induced lesions in extremities have also been identified, which may add to the difficulty of standing and walking in these lambs (Olson et al., 1987). Hypothermia can also develop if the lamb has impaired heat production, which can be due to a number of causes such as placental insufficiency, immaturity at birth or starvation (Mellor & Stafford, 2004). Newborn lambs may also become hypothermic within minutes but then return to normal body temperatures as the increased heat production allows the lamb to compensate for heat losses. In other cases, lambs may become mildly hypothermic and remain in this state for several hours before improving or deteriorating for a variety of reasons such as decreased temperatures or a failure in heat production mechanisms. Cold-stressed lambs were found to have normal rectal temperatures, until the second day of life, when lambs kept at -10°C had declining rectal temperatures (Olson et al., 1987). Perirenal fat at 3 days of age was significantly reduced in cold-exposed lambs compared to lambs kept at warm temperatures (Olson et al., 1987) which may explain the reduction in rectal temperature as the fat reserves for heat production diminish. Newborns may also become hypothermic several hours after birth due to inadequate milk intake or very severe cold exposure (Mellor & Stafford, 2004).

Exposure is often confounded by starvation; Haughey (1973) found that 10 of 11 lambs which were prevented from sucking after birth and kept in rooms at 1°C died, many as early as 2 or 3 hours after birth. Nine lambs kept at the same temperature but allowed to suck their dams did not die, which implies that if lambs are prevented from sucking they are more vulnerable to cold conditions and more likely to die. Many lamb deaths have been noted to occur during or after wet weather, e.g. in one study 52% of lambs born on rainy days died (Arnold & Morgan, 1975). Nearly all lambs which died had depressed rectal temperature at 3 hours after birth, suggesting exposure played at least a partial role in the death of the lambs. Exposure to high temperatures can also cause lamb mortality, as walking in the open during the heat of the day was found to distress lambs that were 3 days or less old, before the lamb's homeothermic mechanisms are developed and often the lamb died from extreme fever and/or heart failure (Arnold & Morgan, 1975).

As described by Martin (2010), the risk of mortality due to hypothermia can be reduced by management procedures, such as: providing adequate shelter for newborn lambs; drying the lambs; fitting an insulated coat or jacket; supervision of the feeding of ewes and lambs; monitoring newborn lambs for hypothermia by routine use of an electronic rectal thermometer capable of measuring low body temperatures; if necessary providing colostrum via a stomach tube. If the lamb's temperature is extremely low e.g. <37^{o}C, it is necessary to deal with hypoglycaemia by the administration of an intraperitoneal injection of glucose solution to the lamb, and the lamb should be placed in a heated box maintained at 40^{o}C (Alexander et al. 1980; Eales, 1982; Eales et al., 1982a, b, 1984; Gregory et al., 1999; Robinson et al., 1986).

Importance of colostrum: When lambs are born they leave the sterile environment of the uterus and become exposed to the microorganism loaded environment. They are immunologically naive, therefore are extremely vulnerable to infectious disease until they have consumed adequate colostrum to provide passive immunity to infections (Dwyer, 2008). The ingestion and absorption of the colostral immunoglobulins is the most important source of protection against foreign bacteria for a neonatal lamb. Colostrum is ingested and then absorbed from the digestive tract and essentially provides the lamb with protection against disease, energy and other factors important for growth and development. For example, feeding colostrum can increase the summit metabolic rate of newborn lambs making them less susceptible to mortality in cold conditions (Eales & Small, 1981). The ability to absorb macromolecules without differentiation declines over the first 24 hours of the animal's life and is complete by 48 hours if not sooner (McMarthy & McDougall, 1953). This absorption also declines as the concentration of immunoglobulins which are ingested increases, likely due to competition for absorption.

In general, a higher level of immunoglobulins in the lamb is associated with a lower incidence of disease and mortality. Lambs that survived the neonatal period had higher levels of immunoglobulins and six out of seven lambs that died within the first week of life had low levels of immunoglobulins (Ahmad et al., 2000). The nutrition of the ewe can affect colostrum production (Mellor & Murray, 1985) and thereby lamb survival. Ewes fed a supplement (either a maize grain/soybean meal lick or whole maize grain) while grazing pasture for 14 days prior to expected lambing start date produced significantly more colostrum than those grazing pasture alone (Banchero et al., 2009). Supplemented ewes had lower levels of fat and protein but higher lactose levels. Immunoglobulin levels were not significantly different between the treatments, but tended to be higher in ewes that were not supplemented (Banchero et al., 2009). Lamb survival to 20 days of age was higher in groups that were supplemented on pasture.

Christley et al. (2003) in a UK study of indoor lambing flocks found that the serum immunoglobulin concentration was negatively associated with the risk of mortality between 2 and 14 days of age, i.e. a greater risk of mortality when the concentration was low. Increasing birth weight (after accounting for litter size) was associated with an increased serum immunoglobulin concentration in the lamb. Factors that were identified as reducing immunoglobulin concentration were: births 14 days after the start of lambing on a farm, increasing litter size and maternal mastitis. Management practices to ensure suckling can reduce the number of lambs that fail to receive adequate colostrum (McGuire et al., 1983). The importance of ensuring that newborn lambs receive adequate colostrum and the measures that can be taken to meet this requirement, were described by Mellor (1990). In the United Kingdom (UK), Binns et al. (2002) in an observational study recorded that 99% of sheep farmers gave colostrum to weak lambs and 98% gave colostrum to lambs not observed to suck (98%). "Seventy-five percent of indoor flocks used the dam's colostrum where possible, 56% used pooled colostrum from other ewes in the flock, and 32% used cow colostrum. The percentages for outdoor lambing flocks were 69, 50 and 27%, respectively." The provision of colostrum from other ewes to sick lambs occurred more often in flocks with a postnatal mortality ≤3% than in flocks where the mortality was >3%. Further research to increase understanding on how to ensure adequate colostrum intake and absorption of immunoglobulins would be beneficial.

Alternative sources of colostrum, such as bovine colostrum, can be used to supplement or replace ewe colostrum. However, it is important to be aware of issues with their use including risk of transmission of milk borne pathogens, e.g. *Mycobacterium avium* subspecies *paratuberculosis* (the cause of Johne's disease), bovine virus diarrhea virus, and bovine leucosis virus. Heating bovine colostrum at 60^{o}C for 2 hours can remove bacteria without affecting the immunoglobulin concentration (Godden et al., 2006). Of particular concern is the risk of cow colostrum anemia in which an unknown factor in bovine colostrum causes marked anemia in lambs (Nappert et al., 1995). There is no screening process to detect risky colostrum but pooling of bovine colostrum sources and early recognition and treatment of affected lambs will help to prevent mortality.

Summary: Lamb survival is governed by a complex interaction of environment and host factors. Risk factors and their interventions can be categorised under the following headings (with some overlap):

Hypothermia – due to excessive heat loss (environment) or by impaired heat production either through placental insufficiency (abortion diseases), hypoxia during birth; small birth weight most often accompanied by inadequate brown fat stores; preterm birth (abortion diseases); and finally starvation.

Mismothing – host factors (inappropriate breed or genetic line); first parity ewe lambs and inexperience; environmental factors – unable to bond due to restrictions from the environment.

Maternal Underfeeding – during gestation (inutero growth retardation and colostrum quality and quantity) and during lactation (milk supply)

Infectious Disease – during gestation (abortion) and post-lambing (septicemia, agents of diarrhea, mastitis)

Injuries and Predation – misadventure from improper environment; inadequate protection from the environment.

Adapted from Mellor and Stafford (2004).

Research recommendations:

Effectiveness of management procedures to reduce risk of mortality due to hypothermia and long term follow-up on health.

Effectiveness of management procedures to reduce risk of ill-health due to inadequate absorption of colostral immunoglobulins, including the effectiveness of colostrum replacement products for short-term and long-term health of the lamb.

Management systems to reduce mismothering. More research is needed on methods to improve ewe-lamb bonding and lamb survival.

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ARTIFICIAL REARING

Conclusions:

1. **If possible, it is beneficial for lambs to be reared by their dam so that they receive the benefits of maternal behaviour and normal suckling**.

2. **When lambs are separated from their mother, they can experience emotional stress.**

Introduction: Artificial rearing in the context of this report, refers to offering the lamb milk or a milk replacement but not nursing from an animal. In some situations, particularly on sheep dairies, lambs are separated from their dam at an early age (0-2 days) and offered milk replacer from a nipple apparatus (Napolitano et al., 2008). Lambs in this system may also be gradually transitioned from dam rearing to artificial rearing by having suckling access for part of the day (Sevi et al., 2003). Artificial rearing is also undertaken due to actual or anticipated mismothering (e.g. removing a triplet as routine practice). Lambs that are rejected by their own mother, or lambs from litters (e.g. triplets or quadruplets) that are unlikely to be raised successfully by their own mother may also be artificially reared (Nowak et al., 2008). A foster mother (a ewe that lost her lambs or a ewe with a single lamb that is capable of raising two), has been suggested to be a more appropriate method of rearing these lambs as they can provide the lamb with a social environment very similar to that which the lamb would have if it was raised by its own mother. However this has not been scientifically quantified (Nowak et al., 2008). Mismothering is often an issue when encouraging the ewe to adopt a lamb that is not her own, and the ewes' welfare may be impaired by restraint and/or confinement in order to successfully get her to adopt the lamb. (Nowak et al., 2008)

How milk is fed: Milk replacer can be fed in a variety of systems, such as with an automated lamb feeder that allows lambs ad libitum consumption of warm milk replacer, or feeding buckets with nipples (Bimczok et al., 2005). Bimczok et al. (2005) showed that lambs that were allowed to consume ad libitum amounts of milk had higher weight gains pre-weaning than other groups, but after weaning weight gains were lower than in lambs that were limit fed. The authors suggest that the lambs fed ad libitum milk replacer had a lower intake of concentrate and forage before weaning than those with limited milk replacer, which made the transition of the latter groups easier (Bimczok et al., 2005).

Watery feces were more often observed in ad libitum fed lambs than those fed by an automated individual dispensing unit or from a bucket (Bimczok et al., 2005). No other clinical signs were observed in most cases, and it was presumed to be due to the higher intake of milk replacer, with increased carbohydrates and protein entering the hindgut leading to a lower pH (Bimczok et al., 2005).

Abomasal bloat can occur in limit feeding situations – usually when a replacer product is fed infrequently (2 to 4 times per day) and the lambs engorge on a large amount of milk in a short period of time. Bloat can cause sudden death and is thought to be due to an overgrowth in the abomasum of gas producing bacteria when a large amount of carbohydrate substrate is available for growth. The incidence can be reduced by feeding cool (17-20°C) milk replacer ad libitum to encourage frequent small feedings (more like natural nursing); and/or acidifying the milk replacer using 0.05-0.1% formalin so that bacterial growth is inhibited (Gorrill et al., 1975).

Effect on health and productivity: Lambs removed from their dam at approximately two days of age, after they have consumed adequate colostrum, experience rapid changes in the composition of the milk due to the transition from maternal milk from the udder to a commercial milk substitute from a bucket (Napolitano et al., 2008). Feeding ewes' milk to lambs through a bucket helped to minimise the detrimental effects of artificial rearing on growth of lambs especially those due to nutritional changes, but few farms are able to source sufficient ewe milk at a reasonable cost to accomplish this (Sevi et al., 2003).

Antibody responses of artificially reared lambs can be affected by the age at which they are removed from their dam. Lambs separated from their mother at 2 days of age and given an injection of a foreign protein (keyhole limpet hemocyanin (KLH) in complete Freund's adjuvant), showed a significantly lower antibody titer 21 days after immunization than control lambs that remained with their mother (Caroprese et al., 2006; Napolitano et al., 1995). This difference was not noted in lambs separated from their mother at 15 or 28 days of age.

Gradual separation of 5-day-old lambs from their dam, during the daytime, but with access to milk replacer for 5 days, can decrease the growth rate of lambs compared with those that remain with their dam (Sevi et al., 2003).

Similar weaning weights were seen between single, mother-reared lambs and lambs fed, on average 1.1kg/lamb/day of milk replacer during the first month and 0.43kg/lamb/day during the second month (Béchet et al., 1989). Twin, mother-reared lambs had similar weaning weights as those fed 0.75kg/lamb/day of milk replacer during the first month and 0.25kg/lamb/day during the second month (Béchet et al., 1989). Growth rates were significantly higher in artificially reared than in mother-reared lambs when they were kept indoors. However, these differences disappeared when they were turned out to pasture at 6-7 weeks of age (Béchet et al., 1989).

Effect on stress levels and behaviour: Lambs fed artificially from a bucket cannot perform natural sucking related behaviours. Napolitano et al. (2008) proposed that this leads to the development of abnormal oral behaviours, particularly non-nutritive sucking, and yet this behaviour in lambs has not been researched to any extent. This type of behaviour is seen from the initial feeding of reconstituted milk until weaning. Non-nutritive sucking in lambs often involves sucking the navel or scrotum of pen mates and is usually performed while other lambs feed (Napolitano et al., 2008). The subject being sucked may be disturbed in their own milk ingestion and the animal performing the abnormal behaviour may ingest lesser amounts of milk (Napolitano et al., 2008). This behaviour may be reduced by feeding ad libitum. Naval sucking may increase the amount of navel infections in lambs that are being sucked (Napolitano et al., 2008).

Lambs left with their dams for up to 2 days to allow colostrum consumption and then abruptly removed experience noticeable emotional stress due to the separation from the mother and lack of maternal stimuli (Napolitano et al., 1995). The lambs also had a significantly greater plasma cortisol concentration 15 minutes after separation from their dam, but this response was no longer apparent 45 minutes after separation (Napolitano et al., 1995). Lambs have also be separated gradually from their dams after five days of age by separating them from their dams during the day and rejoining them during the night for another five days, after which they were fully separated from their mothers. These lambs showed behavioural, immunological and endocrine disturbances (Sevi et al., 2003). Gradually separated lambs showed more withdrawal behaviours in an isolation test in a novel environment than ewe reared or artificially reared lambs, which the authors suggest is due to lower vitality due to lower milk intake and emotional stress from the disruption of the mother/offspring bond (Sevi et al., 2003).

Lambs that are artificially reared respond similarly to ewe reared lambs when exposed to an open field test where they were isolated (Caroprese et al., 2006). This response did not differ whether the lambs had been exposed to a gentle handling procedure or not. As isolation is a stressful event for sheep, this result is not particularly unexpected.

Summary: Under some management situations, it is necessary to rear lambs artificially. This includes a dairy sheep situation or if a lamb is too weak to be raised by a ewe. Cross-fostering should be done if possible, understanding that there are situations when this is not appropriate. When deciding to have a lamb or lambs reared artificially, it is important to ensure that they ingest adequate colostrum. A feeding system that allows for proper ad libitum feeding through the use of a nipple feeding system, to allow for uninhibited sucking behaviour may help to prevent digestive disorders and non-nutritive sucking. Cleaning the feeding system thoroughly each day helps prevent the growth of pathogenic bacteria. Limit feeding systems require attention to proper feeding frequencies, prevention of non-nutritive sucking and prevention of abomasal bloat.

Research recommendations:

The welfare implications of artificial rearing versus normal suckling on behaviours in the group.

The welfare implications of methods used for cross fostering. For example, more research on lamb survival and growth of lambs that have been cross-fostered under different systems.

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WEANING (previously Early Weaning)

Conclusions:

1. **Stress responses of lambs weaned at 50 days of age are higher than those of lambs weaned at 100 days of age**.

2. **Abrupt weaning at any age before natural weaning is likely to cause stress. The natural bond between the ewe and the lamb weakens as the lamb ages, suggesting that later weaning poses less stress on the ewe and the lamb, but minimal research has been conducted to support this.**

3. **Weaning at an age of 28 days or earlier requires specific attention to the diet of the lamb as the rumen has not fully developed.**

Introduction: In sheep, natural weaning occurs when the ewe prevents her lamb(s) from suckling. Natural weaning generally takes place slowly, with the ewe completely preventing the lamb from sucking between 125 and 160 days of age, with some variation depending on the level of protein in the diet and the breed of sheep (Arnold et al., 1979). This natural weaning off of milk is not generally accompanied by immediate social separation which is a part of artificial weaning. Therefore, in sheep production, weaning involves both a change in the natural suckling behaviour as well as the social environment of the lamb. Weaning involves separation of the ewe and its lamb(s) and in many cases, a major change in diet for the lamb. There is not a specific age in the literature that is generally regarded as "early weaning" as opposed to "late weaning". Weaning often takes place when the lambs are about 3 months of age, although later-born lambs may be much younger if all lambs are weaned together (Nowak et al., 2008). In dairy operations, lambs are often separated from their dam at four weeks of age, or in some cases, shortly after birth, although these lambs would be reared artificially and not considered to be weaned. There is a limited body of research on weaning ages in sheep, and in most cases, two or more weaning ages are compared, although the younger ages may not always be considered "early weaning". The weaning ages used are presented in this section where possible to allow each study to be considered in context.

Effect on health and productivity: It has been suggested, e.g. Dwyer (2008), that early weaned lambs are at greater risk of disease than later weaned lambs. Although this is possible, the evidence for this is not strong.

Lambs begin to consume solid feed between 2 and 4 weeks of age. This consumption of solid feed stimulates rumen development and rumination begins at about 21 days of age (Walker, 1959, cited by Eadie, 1962). The pH of the rumen is a determining factor of the development of the rumen flora (Eadie, 1962) although the process is not entirely understood. Age does not appear to be as important as the consumption of solid feed in the morphological development of the rumen (Lane et al., 2000).

Research by Agriculture Canada (Ainsworth et al., 1987) has indicated that based on production results, lambs can be weaned as early as 21 days of age. Lambs weaned at this age typically lose weight or fail to gain weight during the first week after weaning, likely due to the under development of the rumen. This growth setback is essentially eliminated if weaning is delayed until 28 days of age. Ainsworth et al. (1987) proposed that weaning at 21 days represented an economic choice for lambs which are reared on artificial milk replacer, as the growth setback is less costly than the additional milk replacer required to prevent it. Lambs weaned at these early ages require high quality feed initially to ensure that performance is maintained. Although most lambs are able to adapt to weaning at 21 days of age, lambs less than 6kg benefit from an extra week on milk replacer (Ainsworth et al., 1987).

Production levels of lambs which are weaned early vary depending nutrient levels. Lambs weaned at 7, 10, 13, and 18 weeks of age grew equally well and had no significant carcass trait differences when the lambs were grazed on high protein pastures (Wardrop et al., 1960). Lambs weaned at 8 weeks of age and grazed on preflowering and flowering pastures conversely did not grow as well as unweaned controls, and had inferior carcass traits (Wardrop et al., 1960). Lambs weaned at 2 or 3 months of age performed similarly to lambs weaned at older ages when fed an alfalfa-grain pellet ration (Ruttle, 1971). Lambs can be switched to solid food as early as 28 days of age; however, the rumen has not fully developed and therefore, a growth delay is probable (Nowak et al., 2008). Therefore, nutrition following early weaning appears to be important, at least in the productivity of the lambs. It is not clear whether the nutritional adjustment at weaning caused the lamb to undergo significant stress, or if it is production alone that is potentially affected.

Affective states: Napolitano et al. (2008) suggested that weaning lambs at three months of age was detrimental to their welfare, but these authors did not produce strong evidence as to whether weaning at an earlier age was any worse for the welfare of the lambs than later weaning.

The number of high-pitched bleats by ewes and lambs increased significantly over baseline levels in the first hour of separation of ewes and lambs when they were separated for the first time at 3.5 weeks (Orgeur et al., 1998). Vocalizations occurred at an increased rate during the first 2 days after weaning, particularly in lambs (Orgeur et al., 1998). Ewes from which lambs were weaned abruptly had vocalisation rates that returned to normal levels on the second day after weaning, suggesting that they adapt to weaning more readily than lambs (Orgeur et al., 1998). Lambs separated from their mother at 20-22 days of age but kept with their biological twin vocalised less than those kept with a non-twin age mate (Porter et al., 1995). Twin lambs appear to have a sense of familiarity with one another and allowing twins to maintain contact at weaning may reduce the level of stress imposed.

Sowińska et al. (2001) found a greater cortisol response in lambs that were weaned at 50 days of age compared with those weaned at 100 days of age, suggesting that the earlier weaning caused a higher level of stress in lambs.

Pérez-León et al. (2006) showed that the stress experienced by ewes at the time of weaning at eight weeks, as a result of separation from their lambs, could be partially mitigated by inducing them hormonally to exhibit estrus, in the vicinity of rams, on the day of weaning. This suggests that the practice of hormonal induction of estrus on the day of weaning that is often a part of an accelerated lambing system, might actually reduce the stress in the ewe that occurs following separation from her lambs.

Summary: There can be benefits for disease control from weaning lambs at 50 to 60 days of age rather than leaving the lambs with the ewes for longer periods (e.g. to 100 days of age). Weaning at this age may assist with controlling exposures to specific disease pathogens. For example, it is difficult to manage exposure to pastures contaminated with gastrointestinal parasites while lambs are sucking ewes. Weaning may assist with reducing this exposure. There is little effect on lambs by weaning at 2 months of age, and there may be prudent reasons to manage ewes and lambs separately after this age. What is needed is more research into methods of lowering the stress on the ewes and lambs at weaning.

Research recommendations: The welfare implications of the age of lamb at weaning and the implications on both lamb and ewe performance. There is little to no research on the welfare implications of forced weaning, i.e. removal of ewes from lambs (or vice versa). Although natural weaning has drawbacks for disease control and rebreeding, the development of methods of more natural weaning should be studied in sheep. The welfare implications of the methods used for weaning after artificial rearing.

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6. PAINFUL PROCEDURES

INTRODUCTION

This review covers routine procedures which potentially cause pain in sheep, specifically tail docking, castration, and ear tagging. Other procedures such as electro-ejaculation, rectal biopsies and on-farm surgeries are considered to be veterinarian-only procedures, and are therefore not considered to be under the scope of this review. Appendix 2 contains summary tables presenting the results of various studies cited in this review.

Recognition and assessment of pain in sheep: Many management procedures performed on sheep are potentially painful, e.g. see list provided by Bath (1998). There is extensive literature that provides useful information on the assessment of pain in sheep following various procedures. However, the evaluation of pain in animals is difficult and ultimately subjective (Bath, 1998). Molony and Kent (1997) described animal pain as "an aversive sensory and emotional experience representing an awareness by the animal of damage or threat to the integrity of its tissues; it changes the animal's physiology and behavior to reduce or avoid damage, to reduce the likelihood of recurrence and to promote recovery." Importantly, Molony and Kent (1997) stated that "Because direct measurement of subjective experiences is not possible, assessment of animal pain is of necessity a value judgment relying on physiological and behavioral indices to provide indirect evidence of this particular mental state." In addition to review articles e.g. Molony and Kent (1997), Kent and Molony have produced a website http://www.vet.ed.ac.uk/animalpain/ that provides guidelines on the recognition and assessment of animal pain.

Mammals, such as sheep, are assumed to be able to experience some form of pain because they have the same neurophysiology for detecting damage and processing this information in their central nervous system as humans and they behave in situations that humans would find painful in similar ways to how a human would respond (Bateson, 1991).

A pain response is initiated by receptors (nociceptors) that respond to heat, pressure, and chemical stimuli and produce a signal that is transmitted to the brain; this process is termed nociception. The anatomic (nerve endings and nerve pathways) and chemical components needed for nociception are common to humans and animals. For animals or humans to perceive pain as an unpleasant emotional experience the brain must be capable of interpreting the sensory information that it receives (Robertson, 2002).

Bateson (1991) argued that many animals, e.g. sheep, have the following similarities with humans that make it likely that sheep are capable of experiencing pain:

> "1) Possession of receptors sensitive to noxious stimuli, located in functionally useful positions on or in the body.
> 2) Possession of brain structures analogous to the human cerebral cortex.
> 3) Possession of nervous pathways connecting nociceptive receptors to higher brain structures.
> 4) Possession of receptors for opioid substances found in the central nervous system, especially the brain.

5) Analgesics modify response to noxious stimuli and are chosen by the animal when the experience is unavoidable.
6) Responds to noxious stimuli by avoiding them or minimizing damage to the body.
7) Avoidance of noxious stimuli is relatively inelastic.
8) Response to noxious stimuli persists and the animal learns how to associate neutral events with noxious stimuli."

The behavioural responses that sheep show in response to procedures such as castration are similar to those shown by humans in acute pain, namely, vigorous and coordinated attempts to escape or to remove the source of intense stimulation. Associated physiological responses to acute pain occur in both humans and animals, including increases or decreases in blood pressure and heart rate, increased rate of breathing (gasping or panting), increased body temperature, sweating and increased muscle tone (Bateson, 1991). However, in some situations, some humans and some animals, may not show an acute response to pain, but instead show neural inhibition resulting in either normal or inactive behaviour e.g. immobility.

Measurements of the hypothalamic-pituitary-adrenocortical (HPA) system and the sympathetic adrenomedullary system are used to assess distress. "They do not measure pain, but provide an indication of how unpleasant the experience is emotionally and physically" (Mellor & Stafford, 2000). Changes in plasma endocrine concentrations e.g. cortisol, cannot definitively be used to assess pain as these responses also occur in many other situations (Bath, 1998). The plasma cortisol response after castration and tail docking often follows closely the time course of changes in posture and lamb activity (Kent et al., 1993). The relevance of these behavioural and physiological measurements in the assessment of pain following a procedure can be recognised by quantitative reductions in these responses when the procedure is undertaken after effective local anesthesia has been used to reduce nerve impulses from the site of the procedure. As the plasma cortisol concentrations after a procedure can be influenced by many factors, a useful way of quantifying and comparing the relative response to various procedures is to calculate the area under the response curve (integrated response), which combines magnitude and duration information (Rutherford, 2002).

Other useful physiological measurements include spectral changes of electroencephalograph (EEG) frequency that show changes in cortical electrical activity that might reflect the cognitive perception of pain (Barnett, 1997). Following a procedure, increased sensitivity to noxious stimuli, e.g. heat (hyperalgesia) or non-noxious stimuli e.g. light touch (allodynia) can occur at the site of injury and also at more distant sites (if there is continued activation of nociceptors in the injured area). Measuring the nociceptive threshold, i.e. the point at which a stimulus applied to a site elicits a response, can be useful in pain assessment (Rutherford, 2002).

As described by the work of Molony and Kent (1997), increased behavioural activity in an apparent attempt to reduce the pain, including restlessness, kicking, stamping, rolling, jumping, easing quarters, licking/biting at the site of damage, and tail wagging can occur after a painful procedure has been performed. A combined activity index of restlessness, rolling, foot stamping/kicking and easing quarters has been shown to be a useful indicator of pain resulting from rubber ring castration and tail-docking in lambs (Kent et al., 1998; Molony & Kent 1997). Following these active responses a lamb often changes its strategy to deal with the pain by changing from an active to a passive response to reduce the pain. As discussed by Molony and

Kent (1997) "A voluntary change in posture after castration may be the adoption of an immobile stance (statue standing) to avoid or reduce stimulation of hyperalgesic tissues." Other changes in posture can occur involuntarily e.g. after rubber ring castration there is a reflex response involving increased muscle tone resulting in a full extension of the hind limbs (see Wood & Molony, 1992).

Molony et al. (1993) suggested the following interpretations for behavioural changes in response to painful procedures:

> "1) An increase in restlessness generally indicates an increase in pain.
> 2) Lateral recumbency generally indicates more pain than ventral recumbency.
> 3) Extension, rather than flexion of the hind limbs indicates more pain.
> 4) More abnormality of standing and/or walking including ataxia, swaying and falling indicates more pain.
> 5) Standing still or lying still may reduce pain and at any particular time a lamb is considered to be suffering less pain when standing still than when moving about abnormally.
> 6) Behaviour rarely observed in the control group can be referred to as abnormal."

The severity of the responses of sheep to pain can also be assessed subjectively using qualitative rating scores. A numerical score can be allocated by reference to a set of descriptors or described using a visual analogue scale (Fitzpatrick et al., 2006). A score on a visual analogue scale is an estimate by an observer of the severity of pain that is recorded as a measured distance on a scale that represents a continuum of experience, from no pain to the most severe pain.

As discussed by Mellor and Stafford (2000) an understanding of the physiological and pathological responses to castration and tail docking can be useful when interpreting the results of studies that have compared various methods. Often there is a correlation between the amount of damage or injury and the duration and sensation of pain (Robertson, 2002). Castration and docking methods that cause immediate tissue damage (e.g. surgery, clamp and docking iron) initiate nerve impulses in pain pathways. The inflammation that develops after the injury causes additional pain (Mellor & Stafford, 2000). The response to tissue injury consists of a local inflammatory and a systemic (whole body) response e.g. an increase in the serum concentration of acute phase proteins, such as haptoglobin. The inflammatory response involves a series of vascular and interstitial tissue changes that increase blood flow to the affected area and result in redness, heat, pain, swelling and loss of function. The pain arises from the stimulation of nerve endings by cytokines and other mediators of inflammation (including histamine, prostaglandins and growth factors) that are released from damaged cells, peripheral sensory neuron terminals and inflammatory cells (Viňuela-Fernández et al., 2007). Some pain also comes from the swelling associated with the increased pressure of inflammatory exudates at the site of injury. Hyperalgesia can also occur following inflammation. Some methods e.g. rubber rings, cause an initial nerve response due to pressure on receptors. Once the constriction of blood vessels causes tissue damage, a second painful response occurs. The use of a clamp (e.g. burdizzo) to crush tissues is likely to damage the underlying nerves and interrupt the transmission of sensory nerve impulses distal to the crush. Surgical methods will cause an initial acute pain response from the incision that will be followed by the development of inflammation and associated pain.

Thermal cautery was once a common method in human medical practice to reduce hemorrhage, infection and pain. The use of thermal cautery in lambs might cause an initial pain response, but if the pain receptors are destroyed by burning, this could reduce the severity of pain that would otherwise have occurred following tissue damage (Mellor & Stafford, 1999; 2000).

Although there are likely to be some long-term consequences of castration and/or docking, such as chronic pain, hyperalgesia, phantom pain and neuropathic pain (Wood & Molony, 1992), these have not been studied in detail. "If chronic pain occurs, it may arise from slow resolution of inflammation in the damaged tissues, or from pathophysiological changes in pain thresholds or pain receptor input from healed tissues as occurs with hyperalgesia and phantom pain" (Mellor & Stafford, 2000).

Methods for improving welfare in relation to painful procedure:.

1) Find an alternative management solution that avoids the painful procedure.
2) Improve existing methods (Molony et al., 1997).
3) Reduce pain by using local anesthesia or pre-treatment with analgesics (Molony et al., 1997).
4) Develop new methods that cause no or reduced pain (Molony et al., 1997).
5) If possible, perform the procedure on a lamb at an age that causes the least pain or distress (Mellor & Stafford, 1999)
6) Use a method that involves minimal handling and restraint and returns lambs as quickly as possible to their dam (Mellor & Stafford, 1999).

Pharmacological methods to reduce pain responses to procedures (anesthesia and analgesia): Local anesthetic (LA) injections block nerve impulse transmission along affected nerves for the duration of action of the anesthetic, e.g. 2 hours for lignocaine (Dinniss et al., 1997) and 3 hours for bupivacaine (Molony et al., 1997). Some analgesia (pain control) can be produced in sheep using drugs such as the α2-adrenoceptor agonist xylazine (Grant et al., 1996; Scott et al., 1994). The analgesic non-steroidal anti-inflammatory drugs (NSAIDs) have the potential to reduce pain associated with inflammation (Graham et al., 1997). See Meintjes (2012) for a review of the use of analgesic drugs in animals.

In Canada, there are few veterinary versions of these drugs available. All are by veterinary prescription only and require withdrawals for slaughter. The following are licensed in food animals and are available by veterinary prescription. For local anesthesia, lidocaine HCl with or without epinephrine is the only product licensed for use in food animals (5-day meat withdrawal for sheep). No spray formulation is licensed for use in animals. Bupivacaine is a longer-acting local anesthetic with a narrow toxicity range and is not available for use in animals. Xylazine is available but is not licensed for use in sheep. Additionally, no NSAID is licensed for use in sheep. Those licensed for use in cattle include flunixine (intravenous [IV] use only in cattle), ketoprofen (IV or intramuscular [IM] in cattle), and meloxicam (IM or subcutaneous [SC] in cattle). All must be prescribed by a licensed veterinarian with a valid veterinary-client-patient relationship. Diclofenac and carprofen are not available for veterinary use in Canada. Information regarding one type of NSAID cannot necessarily be interpreted as true about another NSAID.

Age effects: There is no evidence that young lambs have a lower capacity to experience pain than older lambs (Mellor & Stafford, 1999). Newborn lambs are considered to be neurologically mature and sentient, and thereby capable of receiving noxious and other sensations and of suffering in response to painful procedures (Mellor & Diesch, 2006). However, a common recommendation in a number of countries has been that, if feasible, procedures, such as castration and tail docking, should be undertaken on lambs at as early an age as possible. The amount of tissue damage is likely to be greater and therefore, take longer to heal in older and larger lambs than in younger lambs (Stafford, 2007). Other pragmatic considerations for recommending procedures on younger lambs compared with older lambs include ease of handling and minimisation of production losses (Johnson et al., 2005). However, there are some other potential management influences of age on the timing of procedures that work in the other direction. For example, interruption of the intake of colostrum in lambs less than 1 day of age is undesirable. If kept in extensive systems and if undertaken before the lambs are 4-6 weeks of age, the disruption of the ewe-lamb bond caused by gathering of the sheep to enable procedures, such as castration and tail docking of the lambs, to take place could result in 'mismothering' (Thornton & Waterman-Pearson, 2002). In any case, if castration is to be performed, it is logical to undertake this procedure before the lamb reaches the age of puberty (Stafford, 2007). Although there has been a general belief that younger lambs would experience less pain after surgical procedures than older lambs (Johnson et al., 2005), the evidence for this is not strong. In addition, "developmental changes in newborn and growing animals could include changes in the sensitivity of components of the systems used to assess distress. Thus, demonstrating that a particular stimulus elicits similar responses in a distress index (e.g. cortisol) at different ages does not definitively demonstrate that the noxiousness of the experience did not change with age; nor do different responses indicate that changes in the noxiousness of the experience have occurred." (Mellor & Stafford, 1999). For example, the plasma cortisol response to either adrenocorticotropic hormone (ACTH) administration or rubber ring tail docking is greater at 8 weeks of age than at 1-week of age (Turner et al., 2006).

Guesgen et al. (2011) examined the effects of age and sex on pain sensitivity of lambs tested at 1, 3, 5, 7, 9 or 12 days of age. They recorded the latency of the lambs in sternal recumbency to respond to a thermal stimulus produced by a laser directed towards a shaved area on the hind-leg by withdrawing its leg. There was a significant interaction between age and sex in the response of the lambs. Latency to respond increased significantly with age in male lambs while female response latency decreased with age, but not significantly. These results suggest that between 1 and 12 days of age, males become less sensitive to pain with increasing age, whereas the pain sensitivity of females did not change significantly. If these results are confirmed by subsequent research, they suggest that it might be more appropriate to tail dock female lambs at 1-3 days of age than at 9-12 days of age, but to castrate and tail dock male lambs at 9-12 days of age rather than at 1-3 days of age.

Research recommendations: More multi-disciplinary, large-scale, multi-year, multi-factorial, well-controlled research projects with frequent observations/sampling are required to examine the short- and long-term, behavioural, physiological, health, and welfare implications of various painful procedures. Evaluation of effectiveness of anesthetic and analgesic drugs and their method of administration to reduce pain responses to procedures. This should include studies on the efficacy and safety of NSAIDS (e.g. due to their anti-prostaglandin nature, there may also be drawbacks to their use in very young animals). In addition, an evaluation of the use of injectable local anesthetic agents should examine the prevalence of adverse outcomes following their use in the ‘field’.

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TAIL DOCKING

Conclusions:

1. **Conclusions can only be tentative. The research evidence is capable of different interpretations. Caution is required when utilising the interpretations of the relative severity of pain from different methods of tail docking**.

2. **Rubber ring method**
   a. Physiological and behavioural evidence suggests that tail docking using a rubber ring is acutely painful. There is some pathological evidence that suggests that some pain might persist for several months.
   b. Tail docking using a rubber ring alone appears to more painful than tail docking using either rubber ring combined with a clamp or a hot iron alone.
   c. Tail docking using a rubber ring might be more painful than tail docking using a surgical method, but some of the evidence is contradictory.
   d. Use of local anesthesia at the site before the rubber ring is applied can reduce the signs of acute pain.
   e. The non-steroidal anti-inflammatory drug (NSAID) diclofenac can be beneficial in that it reduces the plasma cortisol response, but does not reduce behavioural signs of pain and is not as effective as local anesthesia. This particular NSAID is not available for veterinary use in Canada at this time.

3. **Combined ring and clamp method**
   a. Physiological and behavioural evidence suggests that tail docking using a combined rubber ring and clamp method is acutely painful.
   b. Tail docking using a combined rubber ring and clamp method appears to less painful than tail docking using only a rubber ring.
   c. Tail docking using a combined rubber ring and clamp method might be more painful than tail docking using surgery.

4. **Surgical method**
   a. Physiological evidence suggests that tail docking using surgery, i.e. cutting the tail off using a knife or scalpel - is acutely painful.
   b. Tail docking using surgery might be less painful than tail docking using a rubber ring, but some of the evidence is contradictory.

5. **Hot iron method**
   Other methods of tail docking e.g. rubber ring or surgery have acute physiological and behavioural responses that are not as apparent after docking using a hot iron.

6. **If there is a risk of flystrike, some studies have shown that tail docking can reduce the risk of flystrike to the tail.**

7. If the tail is removed completely (i.e. leaving 3 or fewer coccygeal vertebrae) there is an increased risk of problems compared with not tail docking. Lambs tail docked at the 4th tail joint had fewer problems than those that had been docked to leave a shorter tail length.

METHODS OF TAIL DOCKING

Rubber ring: An applicator is used to expand the diameter of a rubber ring that is placed on the tail. The ring contracts around the tail after it is released by the applicator. This is followed by a plasma cortisol response over the subsequent 3 hours (Graham et al., 1997; Lester et al., 1991). The lambs show restlessness, active behaviour, including foot stamping and head turning, and abnormal posture over the subsequent 1.5-3 hours (Graham et al., 1997; Grant 2004; Price & Nolan, 2001). The constriction produced by the ring reduces blood flow to the distal portion of the tail, swelling is evident through lesion scores and the tail becomes necrotic and sloughs off after about 26 days (Kent et al., 2000). Lambs docked with rubber rings are considered to be at a greater risk of tetanus due to the slow healing wound, however no clinical signs of tetanus were observed in lambs docked with rubber rings infected with *Clostridium tetani* (Cooper, 1966). As this is based on only one study, clinical experience would suggest that a proper vaccination program can mitigate the risk of tetanus. During the first two days after docking no significant increase in the serum haptoglobin concentration compared with controls has been found (Price & Nolan, 2001). The lesion heals after about 42 days (Kent et al., 2000). However, a neuroma and/or irregular innervation has been observed in a significant proportion of the tails of docked lambs when slaughtered at 4-6 months of age. This suggests that chronic pain or increased sensitivity may have been present after docking even though the wound had appeared to have healed superficially (French & Morgan, 1992).

Local anesthesia (LA): LA administered either subcutaneously (SC) or in the form of a pressurized aerosol 'freeze spray' applied at very close range to the dorsal surface of the site, or given epidurally before the application of a ring can reduce the plasma cortisol response over the subsequent 3 hours (Graham et al., 1997; Kent et al., 1998). The lambs also show reduced active behaviour and abnormal posture over the subsequent 3 hours (Graham et al., 1997; Kent et al., 1998).

Non-steroidal anti-inflammatory drugs (NSAID): Intramuscularly (IM) administrated diclofenac (not currently available in Canada for food animals) before the application of a ring can reduce the plasma cortisol response over the subsequent 3 hours, but did not significantly reduce the behavioural responses compared with lambs that were docked using a ring without NSAID or LA (Graham et al., 1997). Oral acetyl salicylate at a rate of 26mg/kg, dissolved in water, can reduce restlessness, active behaviour and abnormal posture during the first hour (Pollard et al., 2001).

Comparisons between tail docking using a rubber ring and other methods of tail docking:

Ring docking without LA in comparison with clamp and ring without LA
↑ plasma cortisol response over the subsequent 3 hours (Graham et al., 1997).
↑ restlessness, active behaviour and abnormal posture over the subsequent 1-3 hours (Graham et al., 1997; Lester et al., 1996).
Ring docking without LA in comparison with surgery without LA
↑ plasma cortisol response over the subsequent 3 hours (Graham et al., 1997).
↓ plasma cortisol response over the subsequent 3 hours (Lester et al., 1991)
↑ restlessness, active behaviour and abnormal posture over the subsequent 1-3 hours (Graham et al., 1997; Lester et al., 1996).
Ring docking without LA in comparison with hot iron without LA
↑ plasma cortisol response over the subsequent 3 hours (Graham et al., 1997).
↑ integrated pain score over 1.5 hours (Grant, 2004).
↑ restlessness, active behaviour and abnormal posture over the subsequent 3 hours (Graham et al., 1997).

Rubber ring and clamp: A ring is placed on the tail and a castration clamp (e.g. Burdizzo) is applied distal to the ring. There is a plasma cortisol response and increased abnormal postures over the subsequent 3 hours (Graham et al., 1997).

Local anesthesia: LA administered either SC or in the form of a 'freeze spray' to the dorsal area of the site or given epidurally before the application of a ring did not reduce the plasma cortisol response over the subsequent 3 hours compared with docking without LA (Graham et al., 1997).

Comparisons between tail docking using a clamp and a rubber ring and other methods of tail docking:

Clamp and ring docking without LA in comparison with ring without LA
↓ plasma cortisol response over the subsequent 3 hours (Graham et al., 1997).
↓ restlessness, active behaviour and abnormal posture over the subsequent 1-3 hours (Graham et al., 1997; Lester et al., 1996).

Ring and clamp docking without LA in comparison with surgery without LA
↑ abnormal posture over the subsequent 3 hours (Graham et al., 1997).

Surgical: The tail is cut off with a blade and hemostasis may or may not be used. If hemorrhage is not adequately controlled blood hemoglobin concentration 7 days after docking can be reduced (Wohlt et al., 1982). The wound can be cauterised using a hot iron to reduce hemorrhage. There is an elevated plasma cortisol response over the subsequent 4 hours (Lester et al., 1991).

Comparisons between tail docking using surgery and other methods of tail docking:

Surgical docking without LA in comparison with ring docking without LA
↑ plasma cortisol response over the subsequent 4 hours (Lester et al., 1991).
↓ plasma cortisol response over the subsequent 3 hours (Graham et al., 1997).
↓ restlessness over subsequent 1 hours (Graham et al., 1997; Lester et al., 1991).

Surgical docking without LA in comparison with hot iron docking without LA
↑ plasma cortisol response over the subsequent 4 hours (Lester et al., 1991).

Hot iron: Docking with a hot iron simultaneously cuts the tail and cauterizes the wound. There is no significant plasma cortisol response over the subsequent 3 hours compared with controls and no significant differences in restlessness, active behaviour or abnormal postures over the subsequent 3 hours compared with controls (Graham et al., 1997).

Comparisons between tail docking using a hot iron and other methods of tail docking:

Hot iron docking without LA in comparison with ring without LA
↓ plasma cortisol response over the subsequent 3 hours (Graham et al., 1997).
↓ integrated pain score over 1.5 hours (Grant, 2004).
↓ restlessness, active behaviour and abnormal posture over the subsequent 1-3 hours (Graham et al., 1997; Lester et al., 1996).

Hot iron docking without LA in comparison with clamp and ring without LA
↓ abnormal posture over the subsequent 3 hours (Graham et al., 1997).
Hot iron docking without LA in comparison with surgery without LA
↓ plasma cortisol response over the subsequent 4 hours (Lester et al., 1991a).

Response with increasing age: There is little evidence for an age effect on the behavioural and physiological responses to tail docking alone. However, there are some small effects on the responses to tail docking and castration (see below) and a potential influence of age of castration on the subsequent response to tail docking. McCracken et al. (2010) found that rubber ring castration of lambs at 1-day of age resulted in more abnormal standing and rolling during the first 0.5 hours after rubber tail docking at 1-month of age, than in lambs that had been castrated at 10-days of age. The Farm Animal Welfare Council (2008) could not identify a precise age above which a rubber ring should not be used for tail docking. However, as tail size increases with age over the first weeks of life, they considered that healing would take longer when larger tails were docked from older sheep.

Effect of tail docking on risk of fly strike: Sheep fly strike is a condition caused by blowflies that lay their eggs on sheep. When the maggots hatch they burrow into the flesh and poison the sheep with the ammonia that they secrete. The sheep show signs of irritation during the first two days after eggs are laid. Once fly strike has been initiated, further flies are attracted to the strike site, and the sheep can die within 3-6 days from the onset of the first strike (Morris, 2000). Fly strike can cause pain and suffering in sheep. Shutt et al. (1988) found increased plasma cortisol concentration in sheep with flystrike compared with controls. Management practices that have been used to reduce fly strike include strategic shearing, control of causes of diarrhoea and insecticide use (Sotiraki & Hall, 2012; Tellam & Bowles, 1997).

In a field study in the UK, of unshorn lambs 3-6 months old with a tail length of between 7 and 11cm, lambs with fly strike had more fecal soiling of the breech than controls and the feces of lambs with fly strike was wetter than controls (French et al., 1996). The effects of tail docking on mortality and blowfly strike were examined by French et al. (1994) in a controlled field trial, comparing over 3,000 docked and undocked lambs on seven farms. The incidence of blowfly strike was strongly and consistently higher in undocked than docked lambs (rate ratio 6, 95% confidence interval (CI) 3 to 12 for male lambs and 4, 95% CI 2 to 8 for female lambs). The incidence of fecal soiling of the breech was slightly higher in undocked lambs and was identified as an important independent risk factor for blowfly strike. Mortality was similar for docked and undocked lambs. In a field study in Australia, docking reduced fecal dag scores compared with undocked lambs and on one farm, lambs with undocked tails were three times at risk 95% CI 1.1 to 7.8) of being flystruck than sheep with docked tails (Webb Ware et al., 2000).

Tail length after docking: Many purebred breeders or show lamb producers have historically docked tails extremely short (almost completely removing the tail) in order to make the leg muscles appear larger. Some countries recommend that sufficient tail is retained to cover the vulva in the case of female sheep and the anus in the case of male sheep. One-week-old lambs that have their tail completely removed using a ring have a greater risk of rectal prolapse (8%) than lambs that were docked to a medium length 2.5 to 3.8cm (4%) and those docked to a long length 5 to 7.5 cm (2%) (Thomas et al., 2003). Vizard (1994) summarised earlier work in Australia that showed that the risk of flystrike was greater in sheep that had been docked so short that all of the tail had been removed, than in undocked sheep. However, if the tail has been docked at the 4th tail joint to leave a 10cm long tail, the risk of flystrike was apparently lower than in undocked lambs. Lambs that had been docked at the 2nd tail joint to leave a tail length of 5cm did not have a lower risk of flystrike compared with undocked lambs. Docking to leave a tail length of 10cm appeared to offer protection from flystrike to the tail, but no protection from flystrike to the breech area. A review of the literature on this topic by Fisher et al. (2004) identified the following information relevant to the length of tail that should be left after docking. There was no consistent influence of tail length on fecal dags, but some studies showed that sheep with a medium length tail (equivalent to covering the vulva of a ewe) had less fecal soiling than those where most of the tail had been removed. Studies were reviewed that identified that a medium length tail reduced both breech and tail strike compared with shorter tails. Six days after surgical removal, there was less wound infection if a long tail was left. Lambs with medium length tails showed good healing, whereas lambs with no tail healed poorly and short tails were intermediate. The incidence of vaginal prolapse in adult ewes was not affected by tail lengths ranging from 1 to 5cm. Longer tails were slower to shear and slower to crutch. In one study in New Zealand by Fisher and Gregory (2007), lambs tail docked using a ring had an increased risk of neuroma development if 78% or more of the tail had been docked (i.e. 2-6 vertebrae left in the tail, 6-13cm long at the time of slaughter) than if 54% of the tail had been docked (i.e. 4-10 vertebrae left in the tail, 15-23cm long at the time of slaughter), but they tended to have a lower fecal dag score. If 78% of the tail was docked (i.e. 4-6 vertebrae left in the tail, 11-13cm long at the time of slaughter) the number of lambs with a high fecal dag score was greater than when 90% of the tail was docked (i.e. 3-5 vertebrae left in the tail, 9-11cm long at the time of slaughter).

Research recommendations: Epidemiological studies of the role of tail docking and the length of tail docked in controlling flystrike. Although flystrike occurs in pastured lambs and sheep in Canada, no research has been published on the risks and mitigating effects of tail docking in relation to the risk of flystrike. Epidemiological studies of the health implications e.g. risk of fly strike or rectal prolapse, of the length of tail docked. Evaluation of the practicality of using a hot iron for tail docking under differing management systems.

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CASTRATION

Conclusions:

1. **Castration may not be necessary in lambs slaughtered at or before puberty, but certain management considerations are required.**

2. **Conclusions on pain responses to castration can only be tentative. The research evidence is capable of different interpretations. Caution is required when utilising the interpretations of the relative severity of pain from different methods of castration.**

3. **All methods of castration result in a response indicative of pain.**

4. **Rubber ring method**
   a. There is a marked physiological and behavioural response to rubber ring castration that is indicative of acute pain.
   b. Local anesthesia injected into the scrotal neck and cord or the testis can reduce this response.
   c. The non-steroidal anti-inflammatory drug (NSAID) flunixin can reduce this response.
   d. Until the scrotum falls off after about 4 weeks, it remains swollen and appears to cause behavioural signs of discomfort.

5. **Clamp method**
   a. There is a physiological and behavioural response to clamp castration that is indicative of acute pain.
   b. Local anesthesia injected into the scrotal neck and cord can reduce this response.

6. **Clamp and ring method**
   a. There is a physiological and behavioural response to clamp castration that is indicative of acute pain.
   b. Local anesthesia injected into the scrotal neck and cord or the testis can reduce this response.
   c. The response to the combined clamp and ring method appears to be less than castration by rubber ring alone, but greater than castration by clamp alone.

7. **Surgical method**
   a. There is a marked physiological and behavioural response to surgical castration that is indicative of acute pain.

METHODS OF CASTRATION

Rubber ring: Using an elastrator, a tight rubber ring is placed around the neck of the scrotum. This stimulates afferent activity in the superior spermatic nerve for at least 1.5 hours (Cottrell & Molony, 1995) and a change in the electrical activity in the brain as indicated by an increase in the median frequency of an electroencephalogram (EEG) (Johnson et al., 2005; 2009). The heart rate of the lambs decreases for about 4 minutes (Johnson et al., 2005). The plasma cortisol concentration rises during the hour after the ring has been applied, then decreases over the next hour (Kent et al., 1998) to reach baseline concentrations within 6 hours (Paull et al., 2012).

After the ring has been applied the lambs show a marked active behavioural response including foot stamping, kicking, easing quarters (abnormally lowering rear quarters while standing or attempting to keep quarters off the ground while lying) and restlessness that lasts for about 1 hours (Kent et al., 1998). During this time they may also lick the scrotal area and spend less time teat seeking (Paull et al., 2012). They show abnormal posture e.g. standing hunched or unsteadily, abnormal ventral lying with hind limbs partially or fully extended and increased lateral lying, for about 2 hours (Colditz et al., 2012; Kent et al., 1998; Paull et al., 2012).

The constriction of the blood vessels to the neck of the scrotum causes ischemia distal to the ring followed by necrosis. The structures distal to the ring including the testes fall off between 25 days (Mellema et al., 2006) and 35 days (Kent et al., 2000; Melches et al., 2007) after application of the rubber ring. Molony et al. (2012) reported that the scrotum had fallen off after 28 days in 25% of lambs that had been castrated using a rubber ring. Compared with control lambs, after the ring has been applied there is swelling of the scrotum (Kent et al., 2000) that is associated with a marked response to scrotal palpation during the first 6 hours (Melches et al., 2007) and this increased sensitivity can last for 8-12 days (Melches et al., 2007; Mellema et al., 2006). Molony et al. (2012) reported swelling of the scrotum after 10 and 14 days with severe swelling after 21 days. This swelling was accompanied by ‘easing quarters’ (i.e. shifting, easing or tensing of a limb or part of the body) that reached maximum frequency after 17 days and noticeable itching of the ‘quarters’ after 24 days. The skin surrounding the ring becomes red and ulcerated (Kent et al., 2000) and this is most apparent after 26 days, prior to the scrotum falling off (Molony et al., 2012). Sutherland et al. (2000) reported that the scrotum became swollen, moist and blue-green in colour after 1 week, dry and necrotic after 2 weeks, but there were no signs of infection during the 6 weeks after the procedure. After about day 9, localised infection can occur in some lambs (e.g. 12%) (Mellema et al., 2006). However, there are no reports of systemic effects e.g. no increases in rectal temperature or plasma haptoglobin concentration compared with controls (Colditz et al., 2012; Paull et al., 2012). In a survey in Scotland involving over seven thousand lambs, only one death was attributed to rubber ring castration and no cases of castration failure were reported (Hosie et al., 1996).

Effect of age: There is a possibility that the pain from castration with rubber rings could interrupt sucking, reduce the ingestion of colostrum and predispose to diseases such as watery month (Collins et al., 1985). Therefore, a common recommendation is not to castrate at less than 12 hours, preferably not before 24 hours of age (Eales, 1987).

Thornton and Waterman-Pearson (2002) reported that for the 3 days after rubber ring castration, there were significant increases in the frequency of abnormal postures and significant decreases in the frequency of lying in 4-6 week-old lambs that were not observed in 1 week-old lambs. In anesthetized lambs, capable of responding to noxious stimuli, but not experiencing pain, Johnson et al. (2005) found that castration using a rubber ring resulted in a greater increase in the median frequency of the electroencephalogram (EEG) in lambs 12 days of age than in lambs 29 days of age. In a subsequent study, Johnson et al. (2009), found that lambs aged 25-36 days of age showed a greater increase in the median frequency of the EEG than lambs aged 1-18 days of age and that lambs 36 days of age had a greater increase in the spectral edge frequency of the EEG than lambs aged between 1 and 33 days of age. Although these two studies are apparently contradictory, the authors suggested they indicate that cerebral sensitivity to noxious stimulation that was small at birth, developed over the first week of postnatal life, peaked at around 10-12 days of age and then reduced slightly in older animals.

The Farm Animal Welfare Council (FAWC) (FAWC, 2008) concluded that "A major problem with using rings on older lambs is the increasing size of the scrotum and associated structures which, when constricted by the ring, can give rise to chronic inflammation, sepsis and pain until the scrotum falls off and healing occurs. For this reason, lambs should ideally be castrated as soon as possible after they have formed a secure maternal bond but not before they are 24 hours old." "Consideration of the severity of lesions produced by ring castration and other effects must therefore limit the upper age or size of lambs on which rubber rings should be placed."

Local anesthesia (LA): Local anesthetic injected directly into the testis after rubber ring application can, within 2 minutes, reduce the afferent activity in the spermatic nerve (Cottrell & Molony, 1995). Although injection of LA into just the cord can (Kent et al., 1998) but does not always (Dinniss et al., 1997) significantly reduce the cortisol response, injection of LA into the scrotal neck and cord or the testis, 15 minutes before the application of a rubber ring, can reduce the plasma cortisol response over the subsequent 4 hours (Dinniss et al., 1997; Mellema et al., 2006; Thorton & Waterman-Pearson, 1999). Injection of LA into the cord and the neck can reduce active behavioural responses and restlessness over the first hour and abnormal postures over the first 2 hours (Mellema et al., 2006). Injection of LA into the cord, scrotal neck and testis can also reduce active behaviour and visual analogue scale (VAS) pain scores over the subsequent 8 hours (Thorton &Waterman-Pearson, 1999).

Non-steroidal anti-inflammatory drugs (NSAID): Although no significant effects were found after the administration of meloxicam just before the application of a rubber ring, subcutaneous injection of flunixin into the scrotum before the application of a rubber ring reduces the plasma cortisol response over the subsequent 6 hours and reduces active behavioural responses during the first hour. Both flunixin and meloxicam can reduce the occurrence of abnormal postures after rubber ring castration (Paull et al., 2012).

Comparisons between rubber ring castration and other methods of castratio:.

Ring castration without LA in comparison with clamp without LA
↑ abnormal postures over 4 hours (Dinniss et al., 1999)

Ring castration without LA in comparison with surgical castration without LA
↓ cortisol response over 4-6 hours (Colditz et al., 2012; Lester et al., 1991)
↑ abnormal lying over 12 hours (Colditz et al., 2012)
↑ restlessness over 1 hours (Lester et al., 1996)

Ring castration without LA in comparison with ring castration without LA followed by clamp applied distal to the ring
↑ cortisol response over 3 hours (Kent et al., 1998)
↑ restlessness and abnormal postures over 1.5 hours (Kent et al., 1998)

Clamp: A clamp (e.g. Burdizzo clamp or Ritchey Nipper) is applied across one spermatic cord for at least 5 seconds to crush the blood vessels and nerves and interrupt the blood supply to the testicle. The other cord is then crushed, but at a slightly lower or higher level to avoid a continuous line. To reduce the risk of failure the procedure can be repeated distal to the first crush, avoiding the pampiniform plexus. This crushing causes ischemia followed by necrosis and atrophy over 4-6 weeks (Mellor & Stafford, 2000). Crushing of the cord results in redness at the site of application and scrotal swelling for about 1 week (Bonelli et al., 2008). However, the activities of serum enzymes (alanine transaminase [ALT], aspartate transaminase [AST], lactate dehydrogenase [LDH] and creatine kinase [CK]) used to detect tissue damage are not significantly increased (Bonelli et al., 2008). There is an increased response to scrotal palpation during the first 6h (Melches et al., 2007) and this can last until day 3 (Thorton & Waterman-Pearson, 1999) or day 5 (Mellema et al., 2006). This procedure is done on older lambs, but usually under 90 days of age.

The plasma cortisol concentration is increased over the subsequent 2-4 hours (Dinniss et al., 1997, 1999; Mellema et al., 2006; Mellor et al., 1991; Molony et al., 1997). During the first 15 minutes there is greater restlessness, kicking, vocalisation and abnormal lying (Mellor et al., 1991). Over the first 3 hours more time is spent in abnormal postures and there is more trembling and easing quarters than in controls (Molony et al., 1997). During day 1, less time is spent lying down and more time is spent in abnormal postures (Thorton & Waterman-Pearson, 2002).

In a survey in Scotland involving over seven thousand lambs, only three deaths were attributed to clamp castration. In 11 out of the 15 flocks surveyed, clamp castration did not always result in successful castration (Hosie et al., 1996). In another study, the outcome of clamp castration was found to be unsatisfactory in 11% of lambs castrated during the first week of life and in 65% of the lambs castrated at 10 weeks of age (Stoffel et al., 2009).

Local anesthesia: Although for 2 hours there is still a greater cortisol response than in controls, injection of LA into the cord and the neck can reduce the cortisol response over the first 3-4 hours (Bonelli et al., 2008; Dinniss et al., 1997, 1999; Melches et al., 2007).

Comparisons between clamp castration and other methods of castration:

Clamp castration without LA in comparison with rubber ring without LA
↓ abnormal postures over 4 hours (Dinniss et al., 1999)

Clamp castration without LA in comparison with combined clamp and rubber ring castration without LA
↓ restlessness and active behaviour over 3 hours (Molony et al., 1997)

***Ring and clamp castration*:** Ring plus clamp castration involves placing a ring on the scrotal neck, proximal to the testes, immediately before or after applying a castration clamp once to each spermatic cord or after applying it once across the full width of the scrotum. Clamping durations vary e.g. 5 or 10 seconds (Mellor & Stafford, 2000). This procedure is followed by a plasma cortisol response over the subsequent 3 hours (Molony et al., 1997; Thorton & Waterman-Pearson, 1999). There is increased restlessness, active behaviour and abnormal postures than in control lambs (Molony et al., 1997), but less active behaviour and lower visual analogue scale pain scores than after the use of only a ring (Thorton & Waterman-Pearson, 1999). There is an increased response to scrotal palpation for at least 3 days (Thorton & Waterman-Pearson, 1999).

Local anesthesia: Local anesthetic injected directly into the testis; scrotal neck; or cord, scrotal neck and testis reduces the plasma cortisol response, and restlessness and active behaviour over the subsequent 1-3 hours (Dinniss et al., 1997, 1999; Molony et al., 1997; Thorton & Waterman-Pearson, 1999). Scrotal responses to palpation and mechanical stimulation are also reduced (Thorton & Waterman-Pearson, 1999).

Non-steroidal anti-inflammatory drug (NSAID): Intramuscular diclofenac 20 minutes before castration can reduce the plasma cortisol response and the occurrence of abnormal postures over the first 2 hours (Molony et al., 1997).

Comparisons between ring and clamp castration and other methods of castration:

> *Ring castration without LA followed by clamp applied distal to the ring in comparison with ring castration without LA*
> ↓ plasma cortisol response over 3 hours (Kent et al., 1998).
> ↓ active behaviour and lower visual analogue scale pain scores (Thorton & Waterman-Pearson, 1999)
>
> *Ring castration without LA followed by clamp applied distal to the ring in comparison with clamp castration without LA*
> ↑ vocalisation, restlessness and active behaviour (Molony et al., 1997)

Surgical castration: Surgical castration involves cutting the scrotum and underlying tissues to expose the testes which are then removed by tearing, cutting or twisting, with or without cautery, ligation or clamping (Thornton & Waterman-Pearson, 1999). Surgical castration is followed by a plasma cortisol response over the subsequent 4-12 hours (Lester et al., 1991; Colditz et al., 2012). The visual analogue scale pain scores and active behavioural responses are increased for 3 hours and the response to scrotal palpation is increased during the first day (Thorton & Waterman-Pearson, 1999). There is increased standing and abnormal standing postures over the subsequent 12 hours (Colditz et al., 2012). The rectal temperature is increased for 12 hours (Colditz et al., 2012), but there are normally no other clinical signs at this time (Al-Zghoul et al., 2008). Increased plasma fibrinogen concentration and increased serum activities of LDH and AST indicative of inflammation and tissue damage can occur during the first 3 days (Al-Zghoul et al., 2008), but do not always occur (Bonelli et al., 2008). On day 3, there can also be increased numbers of nucleated cells in the peritoneal fluid that are indicative of slight peritonitis (Al-Zghoul et al., 2008). If the cord is ligated there is a risk of infection (Bonelli et al., 2008). In a survey in Scotland involving over seven thousand lambs, only one death was attributed to surgical castration and no cases of castration failure were reported (Hosie et al., 1996).

Local anesthesia: LA injected into the scrotal neck, cord and testis of week-old lambs can reduce the plasma cortisol response to surgical castration (Thorton & Waterman-Pearson, 1999), but after LA was injected into the scrotal neck and cord of either 4-5-month-old (Bonelli et al., 2008) or 2.5 to 6-month-old surgically castrated lambs (Melches et al., 2007) there was a raised plasma cortisol response for 3-6 hours.

Comparisons between surgical castration and other methods of castration:

Surgical castration without LA in comparison with ring castration without LA
↓ lateral lying, abnormal ventral lying over 12 hours (Colditz et al., 2012)
↓ active behaviour over 1 hour (Lester et al., 1996) or 3 hours (Thornton &Waterman-Pearson, 1999)
↑ Statue standing, abnormal standing, abnormal behaviour over 12 hours (Colditz et al., 2012)
↓ visual analogue scale pain score over 3 hours (Thornton & Waterman-Pearson, 1999)

Surgical castration without LA in comparison with clamp castration without LA
↑ cortisol response over 6 hours (Colditz et al., 2012) or 9 hours (Melches et al., 2007)

Surgical castration with LA in comparison with clamp castration with LA
↑ cortisol response over 3 hours (Bonelli et al., 2008) or 9 hours (Melches et al., 2007)
↑ abnormal posture over 9 hours (Melches et al., 2007)
↑ response to scrotal palpation for 9 hours (Melches et al., 2007)

Surgical castration without LA in comparison with ring castration without LA followed by clamp applied distal to the ring
↓ active behaviour over 3 hours (Thornton & Waterman-Pearson, 1999)
↑ response to scrotal palpation for 9 hours (Thornton & Waterman-Pearson, 1999)
↑ visual analogue scale pain score over 3 hours (Thornton & Waterman-Pearson, 1999)

Surgical castration with LA in comparison with ring castration with LA
↑ immediate vocalisation and struggling (Melches et al., 2007)
↑ abnormal posture over 9 hours (Melches et al., 2007)
↑ response to scrotal palpation for 9 hours (Melches et al., 2007)

Callicrate band castration:This method is used on older lambs that are considered too big for ring castration, and is seen as an alternative to clamp castration. A rubber band is placed around the neck of the scrotum and a ratcheting device tightens the band so as to cause crushing of the cord and its contents. The callicrate bander allows for very tight application of the band and prevents loosening. Tetanus prophylaxis is important when using this method of castration. Callicrate banding and the pain associated with it have not been researched in sheep. However, in calves, its use without LA is associated with signs of acute pain (Stafford et al., 2002).

Is castration necessary? By removing or damaging the gonadal tissue, castration aims to disrupt spermatogenesis and steroidogenesis and, in particular, to prevent adult sexual activity. (Stoffel et al., 2009).

Potential reasons for castrating lambs:

1) to avoid indiscriminate breeding and maintain genetic control of breeding stock;
2) to avoid risk of injury as a result of sex-related behaviour and aggression;
3) to improve carcass conformation and quality;
4) to avoid carcass downgrading due to excessive ram characteristics;
5) to make shearing and crutching easier
(Fisher et al., 2010; Paull et al., 2009; Thornton &Waterman-Pearson, 1999).

However, if lambs reach slaughter weight before they reach puberty at about 5 months of age, castration may not be necessary. Lambs which are not castrated will subsequently require management practices in order to prevent accidental breeding. The age at puberty varies with several factors including breed and weight (Dickerson & Laster, 1975), and while the age at first estrus for most ewe lambs is 6-18 months, isolated cases of conception at 3-4 months have been reported (reviewed by Dýrmundsson, 1981). Ram lambs have successful mounting with ejaculation from 179-209 days of age (depending on breed, and body weight) (Belibasaki & Kouimtzis, 2000).

Although some management adjustments may be required to prevent accidental breeding, ram lambs produce a leaner carcass than wether lambs, and have an increased average daily gain and feed efficiency (reviewed by Field, 1971 and Seideman et al., 1982). Carcasses from rams and wethers differ little in grades, although ram carcasses are slightly tougher, this may be due to the leanness of the carcass (Field, 1971). When slaughtered at the same age, castrated rams have a similar carcass weight to those of intact rams (Fisher et al., 2010). As ram lambs increase in age and weight, the carcass becomes slightly less palatable, as the juiciness and tenderness decrease (Misock et al., 1976). Heavier/older rams do develop a stronger aroma, which may be characterised as “staggy” (Misock et al., 1976). Ram lambs which can be marketed and slaughtered at or before puberty should provide beneficial growth characteristics and few if any negative effects.

Research recommendations: Evaluation of welfare implications of using callicrate band castration in lambs at different ages. Evaluation of implications of not castrating lambs on sheep management, and carcass and meat quality.

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CASTRATION AND TAIL DOCKING PERFORMED CONCURRENTLY

In many cases, lambs are castrated and tail docked at the same time. Some of the responses to castration and tail docking performed concurrently are shown in Appendix 2, Table A.3.

Rubber ring castration and rubber ring tail docking: There is a raised plasma noradrenaline concentration over the first hour, and a plasma adrenocorticotropic hormone (ACTH) and cortisol response that is marked over the first 3 hours (Mellor et al., 2002; Peers et al., 2002; Sutherland et al., 1999), but lasts for 24 hours (Clark et al., 2011). Blood pressure and heart rate are also increased for 4 hours (Peers et al., 2002). There is increased active behaviour, abnormal posture and integrated pain score over the subsequent 1.5 hours (Grant, 2004; Kent et al., 1995) and increased restlessness for 3 hours (Molony et al., 1993). Price and Nolan (2001) reported that serum haptoglobin concentration over the first 2 days after the procedure was not significantly different from handled controls.

Local anesthetic (LA) administrated epidurally and to the spermatic cord, neck of the scrotum and testis (Wood et al., 1991), or to the scrotal neck alone, but not into the testis alone can reduce the plasma cortisol response (Sutherland et al., 1999). Wood et al (1991) reported that intravenous (IV) naloxone (an opioid antagonist) 50 minutes before the procedure did not significantly affect the plasma cortisol response over the first hour. Price and Nolan (2001) reported that the non-steroidal anti-inflammatory drug (NSAID) carprofen administered subcutaneously (SC) 0.5 hours before the procedure did not significantly reduce the active behavioural response.

Kent et al. (1993) and Molony et al. (1993) found that the maximum plasma cortisol concentration over the first 3 hours was significantly greater, but there was less restlessness behaviour in lambs 5 days of age than in 21 days and 42-day-old lambs.

Kent et al. (2004) reported that after this procedure was performed on 12-36 hours-old lambs, there was a 3.2% mortality over the subsequent 32 days. This was thought to have been mainly associated with septicaemia and joint-ill, even though tail and scrotal wounds appeared to be normal.

Comparisons between rubber ring castration and rubber ring tail docking and other methods:

Ring castration and ring tail docking without LA in comparison with ring plus clamp castration and ring plus clamp tail docking without LA
↑ maximum plasma cortisol concentration over 3 hours (Kent et al., 1995)
↑ restlessness and abnormal posture over 3 hours (Kent et al., 1995; Molony et al., 1993)
↑ restlessness and active behaviour over 2 hours (Kent et al., 2001)

Ring castration and ring tail docking without LA in comparison with ring plus clamp castration and ring tail docking without LA
↑ active behaviour over 2 hours (Kent et al., 2001)

Ring castration and ring tail docking without LA in comparison with ring plus clamp castration and ring plus clamp tail docking without LA

↑ plasma cortisol concentration over 3 hours (Kent et al., 2001)
↑ restlessness and active behaviour over 2 hours (Kent et al., 2001)

Ring castration and ring tail docking without LA in comparison with clamp castration and clamp tail docking without LA
↑ maximum plasma cortisol concentration over 3 hours (Kent et al., 1995)
↑ restlessness and abnormal posture over 1.5 hours (Kent et al., 1995)

Ring castration and ring tail docking without LA in comparison with surgical castration and surgical tail docking without LA
↓ plasma cortisol concentration over 4 hours (Lester et al., 1991a)
↑ restlessness over 1 hours (Lester et al., 1996)
↑ restlessness and abnormal postures over 3 hours (Molony et al., 1993)

Ring castration and ring tail docking without LA in comparison with ring plus clamp castration and hot iron tail docking without LA
↑ plasma cortisol concentration over 3 hours (Kent et al., 2001)
↑ restlessness, active behaviour and abnormal postures over 2 hours (Kent et al., 2001)

Ring castration and ring tail docking without LA in comparison with ring castration without LA
↑ active behaviour, abnormal posture and integrated pain score over 1.5 hours (Grant, 2004)
↑ restlessness over 1 hour (Lester et al., 1996)

Ring castration and ring tail docking without LA in comparison with ring tail docking without LA
↑ active behaviour, abnormal posture and integrated pain score over 1.5 hours (Grant, 2004)
↑ restlessness over 1 hour (Lester et al., 1996)
↑ plasma cortisol concentration over 4 hours (Lester et al., 1991a)

Ring and clamp castration and ring and clamp tail docking: There is a raised plasma cortisol concentration for 2-3 hours (Dinnis et al., 1997; Kent et al., 1993) and increased abnormal posture, active behaviour and restlessness during the first 2 hours after the procedure (Kent et al., 2001). Kent et al. (2004) reported that after this procedure was performed on 12-36-hours-old lambs, there was a 2.8% mortality over the subsequent 32 days. When conducted on 4-6 day-old lambs, Kent et al. (2001) did not find any significant differences in the cortisol or behavioural responses when this procedure was undertaken using either a Burdizzo clamp, a Ritchey Little Nipper clamp or a powered clamp. Molony et al. (1993) did not find any significant differences in the behavioural response (restlessness and abnormal postures) when this procedure was undertaken on lambs at 5, 21 and 42 days of age.

Comparisons between rubber ring and clamp castration and ring and clamp tail docking and other methods:

Ring and clamp castration and ring and clamp tail docking without LA in comparison with ring and clamp castration and ring tail docking without LA
↓ plasma cortisol concentration over 3 hours (Kent et al., 2001)

Ring and clamp castration and ring and clamp tail docking without LA in comparison with ring and clamp castration and ring tail docking without LA
↓ plasma cortisol concentration over 3 hours (Kent et al., 2001)

Ring and clamp castration and ring and clamp tail docking without LA in comparison with ring and clamp castration and hot iron tail docking without LA
↑ restlessness and active behaviour over 2 hours (Kent et al., 2001)

Ring and clamp castration and ring and clamp tail docking without LA in comparison with ring castration and ring tail docking without LA
↓ plasma cortisol concentration over 3 hours (Kent et al., 1995)
↓ restlessness over 1.5 hours (Kent et al., 1995)

Ring and clamp castration and ring and clamp tail docking without LA in comparison with clamp castration and clamp tail docking without LA
↓ plasma cortisol concentration over 3 hours (Kent et al., 1995)

***Rubber ring castration and hot iron tail docking*:** There is a plasma cortisol response over the first 4 hours (Lester et al., 1991), increased restlessness over the first hour (Lester et al., 1996) and increased abnormal lying over the first 4 hours (Paull et al., 2009). Paull et al. (2009) reported that the NSAID carprofen administered subcutaneously 90 minutes before the procedure did not have a significant effect on the plasma cortisol response, but did reduce the occurrence of pain-related behaviour over the first hour.

Comparisons between rubber ring castration and hot iron tail docking and other methods:

Rubber ring castration and hot iron tail docking without LA in comparison with surgical castration and surgical tail docking without LA
↓ plasma cortisol concentration over 4 hours (Lester et al., 1991a)
↓ restlessness over 1 hour (Lester et al., 1996)

Rubber ring castration and hot iron tail docking without LA in comparison with hot iron tail docking without LA
↑ plasma cortisol concentration over 4 hours (Lester et al., 1991a)

Clamp castration and clamp tail docking: There is a raised plasma cortisol concentration, increased restlessness and abnormal posture for 3 hours after the procedure (Kent et al., 1995).

Clamp castration and clamp tail docking without LA in comparison with ring and clamp castration and ring and clamp tail docking without LA
↑ maximum plasma cortisol concentration over 3 hours (Kent et al., 1995).

Surgical castration and surgical tail docking: There is a raised plasma cortisol concentration for 6 hours (Lester et al., 1991) and increased restlessness for 1 hour (Lester et al., 1996). Topical LA reduces the response to wound stimulation for 2 to 4 hours (Lomax et al., 2010).

Surgical castration with thermal cautery (used to prevent hemorrhage) and tail docking using a clamp and surgery followed by thermal cautery: There is a raised plasma cortisol concentration for 3 hours (Kent et al., 1993), but the restlessness and abnormal postures over the first 3 hours was not significantly different from handled controls (Molony et al., 1993).

Surgical castration and hot iron tail docking: When performed on 5-week-old lambs with a topical LA spray (Tri-Solfen) applied to the castration and tail wounds, the plasma concentrations of cortisol and haptoglobin were found to be raised for up to 48 hours and there was increased rolling for 1 hour (Paull et al., 2009). When the NSAID carprofen was administered subcutaneously 90 minutes before the procedure this reduced the plasma cortisol response at 6 hours and the behavioural response over the first hour.

Age effects: Kent et al. (1993) showed that lambs castrated and tail docked at 5 days of age (using rubber rings, surgery or rubber rings and Burdizzo clamp) had an earlier and greater plasma cortisol response than that in 21- and 42-day-old lambs. After rubber ring castration and tail docking of lambs at 5 days of age there was less restlessness during the subsequent hour than that in lambs aged 21 or 42 days (Molony et al. 1993). However, no other substantial differences were found between the behavioural responses of 5-, 21- and 42-day-old lambs. The integrated cortisol response, over a 4 hour period, in Dorset lambs, at 1-, 3-, 5- or 7-days of age, to rubber ring tail docking, combined rubber ring castration and tail docking, or the administration of ACTH, decreased with the age of the lamb (Mellor & Murray, 1989). However, this age effect was not found in Scottish Blackface lambs. These findings suggest that an age effect on cortisol responses to combined castration and tail docking could be due to developmental changes rather than necessarily due to a change with age in the response to pain. Although the behavioural responses of lambs to rubber ring castration and tail docking were similar in lambs at 5 days of age to those at 21 or 42 days of age, the increased restlessness after the application of the rubber ring in the older lambs may be significant in terms of a pain response.

Interpretation of results of research on tail docking and castration: The literature on castration and tail docking was reviewed. To assist with interpretation most emphasis was given to studies that examined castration and tail docking separately. The literature on this topic is extensive and difficult to examine. Due to variability between studies it was not possible to make satisfactory comparisons of different procedures between studies. However, within-study comparisons enabled the relative effects of variations in the procedures to be compared.

All procedures involve some handling and restraint that is likely to cause some stress (Mellor & Stafford, 1999). Only statistically significant findings were reported e.g. between treatment/post-treatment and pre-treatment that were greater than that found in handled controls (that were not subjected to a procedure such as castration or tail docking) or between different methods of undertaking the procedure. As the interpretation involves use of different types of information it is possible that different reviewers interpret the results in different ways.

Therefore, published reviews of the literature by others have been included in this review so that comparisons can be made in the interpretation of the results.

Mellor and Stafford (2000) used the integrated plasma cortisol responses to rank the severity of various procedures to cause distress. The behavioural and pathological responses were not considered in this ranking. Surgical methods of castration and/or docking were considered to cause the most distress. Most ring and ring plus clamp methods of castration plus docking or castration, used without a local anesthetic or systemic analgesic, were ranked next in severity. Ring plus clamp castration when the clamp is applied for 10 seconds across the full width of the scrotum distal to the ring in lambs aged no more than 1 week received the least severe ranking. Docking using a ring and clamp in a similar manner received the same low severity ranking.

Molony and Kent considered that active behaviours such as kicking, rolling and restlessness are exhibited by lambs suffering unavoidable pain, whereas immobile postures (statue standing, dog sitting, and reduced activity) indicate the avoidance of at least some pain. Immobile postures were considered to minimise the stimulation of sensitised tissues and they suggested that by standing still the lambs would experience less pain than when moving about (Kent et al., 1995; Molony et al., 1993). Molony et al. (2002) analysed a range of responses to different forms of rubber ring castration and tail docking and concluded that changes in the incidence of active behaviours and the time spent in abnormal postures appeared to be reliable indicators of the severity of acute pain resulting from rubber ring castration and tail docking in young lambs.

The Farm Animal Welfare Council (2008) produced a detailed report on the welfare implications of castration and tail docking. Although the report does not include citations, it reviewed research up to 2004. Their interpretation included the following findings on the welfare implications of each method of castration:

1) all methods of castration cause pain and distress;

2) it is difficult to interpret the behavioural responses of lambs castrated using one procedure compared with a different procedure as necessarily indicating a more severe response. For example, lambs castrated using a rubber ring show active behavioural responses and adopt abnormal postures whilst those castrated surgically appear to minimise movement to reduce pain from their wound;

3) castration using a rubber ring is painful at all ages;

4) surgical castration causes more distress than other methods;

5) the clamp and ring method reduces the acute pain response in the 3 hours following castration using just a rubber ring; and

6) LA can be effective in reducing the acute pain response to castration.

Their interpretation included the following findings on the welfare implications of each method of tail docking:

1) cortisol responses indicate that the pain and distress associated with tail docking by rubber ring, clamp and heated docking iron are generally less severe compared with those associated with most methods of castration;

2) injection of LA into the tail can reduce the pain associated with all methods of docking;

3) no evidence to indicate that the pain response in lambs less than 1 week of age docked using a rubber ring is less than that of older lambs;

4) in comparison with castration using rubber rings, cortisol responses after rubber ring tail docking are less severe;

5) behavioural and cortisol responses to surgical tail docking are greater than those after other methods; and

6) the cortisol response after hot iron docking is similar to that after rubber ring docking.

Hosie and Dwyer (2006) considered that all methods of castration cause varying degrees of acute pain. LA can control some of the pain from castration. They interpreted the literature to indicate that castration using surgical or clamp (Burdizzo) methods appeared to give rise to less *chronic* pain than either the rubber ring or the combined rubber ring and clamp method.

Sutherland and Tucker (2011) interpreted the literature on tail docking as indicating:

1) tail docking causes acute pain as measured by physiological and behavioural changes;

2) due to the procedure-specific nature of the behavioural response it is difficult to directly compare the severity of different methods;

3) all tail-docking methods resulted in behavioural changes that are indicative of acute pain, particularly the rubber ring and the surgical methods;

4) cortisol concentrations increase after ring application and remain elevated for 1–2 hours compared to control-handled lambs;

5) cortisol concentrations increase after surgical tail docking and remain elevated for up to 4 hours, but return to baseline values by the third day after docking;

6) cauterizing the wound after severing the tail reduces the cortisol to levels similar to that of control-handled lambs; and

7) in some situations, local anesthetic and analgesia can alleviate the pain caused by tail docking.

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IDENTIFICATION METHODS AND TEETH GRINDING

Conclusions:

1. **Ear tags result in an inflammatory response due to the wound which is created when they are inserted.**

2. **The severity of ear lesions, as well as other complications, can be minimized with correct positioning, regardless of the type of ear lesion.**

3. **Tags that are readable from a distance or electronically are more suitable in order to circumvent handling of the ear until the inflammatory response had subsided.**

4. **Metal loop tags result in more severe and persistent ear lesions than those found with other ear tag types.**

5. **Teeth grinding is ineffective and can cause acute and chronic pain.**

Introduction: If it is necessary to mark a sheep for permanent identification, the ear can be tattooed, tagged, notched or hole-punched (Primary Industries Standing Committee, 2006). Individual animal identification is necessary for good record keeping on animal health and productivity. The Canadian national identification program requires mandatory ear tags for any animal leaving the farm of origin. Therefore, nearly all sheep will, at some point, require an ear tag. Branding is rarely performed on sheep, and very little research exists on this procedure in small ruminants. Although it provides a permanent identification method, it can be assumed to cause significant pain (Whiting, 2005). Ear notching is also a potentially painful method of identification, and has been shown to cause acute pain in piglets (Leslie et al., 2010), but has not been investigated in sheep.

Ear tagging: Ear tagging has received little attention in the scientific literature, despite being a common management practice which often produces a behavioural response from the animal. Although puncturing the pinnae of the ear through the tagging process would be expected to produce some pain, Grant (2004) suggested that the pain is too small to be measured using the methods used to detect pain due to other procedures such as tail docking and castration (e.g. tail wagging, posture changes). Four to six week old lambs which were ear tagged showed no postural or behavioural differences after they were ear tagged compared to lambs which were only handled (Grant, 2004).

The reaction to the application of an ear tag varies somewhat between types of ear tags. Lambs tagged using single flap tags (one piece flexible polyurethane ear tag with a single flap; Fearing Anchor 1 tag, Fearing International Stock Aids) vocalised and/or shook their head more often following insertion, and these tags were also recorded as being difficult to insert than other types (i.e. metal loop tag, lambtag, double flex tag, golf-tee tag and plastic loop tag) (Edwards et al., 2001). These tags also had the largest incidence of hemorrhages and created the largest hole.

The location of the ear tag is important, as it can be important for both immediate and longer term pain and infection. The most common location that ear tags were found in animals at a slaughter house was in the middle of the ear on either the front or the back edge of the ear (Edwards & Johnston, 1999). In this case, the location did not have any effect on the occurrence of ear lesions found (Edwards & Johnston, 1999). The location of the ear tag and the type or material of the tag can interact; metal or plastic loop style tags that are positioned in the caudal middle of the ear have an increased likelihood of damage to the ear margin (Edwards & Johnston, 1999). Because the application of the ear tag can introduce bacteria to the site, tags placed too close to the base of the ear can result in the point of insertion being covered by a blood clot, thereby giving an anaerobic environment which bacteria may grow in (Aslani et al., 1998).

Ear tags often cause some type of lesion of the ear. Nearly 94% of ear tags which appeared to have been recently applied (shiny and bright with no signs of wear) to the ear of sheep in a slaughterhouse had associated lesions in the ear (Edwards & Johnston, 1999). Edwards et al. (2001) found that the severity of ear lesions in ewes increased during the first two weeks after the ear tag is inserted, but then declined, depending on the type of tag. By the 20^{th} week after the ear tag was applied, all lesions, except those caused by the metal loop tags, were almost completely healed. In lambs, five weeks after insertion, ear tags were generally associated with minor or no ear lesions (Edwards et al., 2001).

The type of ear tag used affects the amount and severity of lesions in the ear. For example, metal loop Ketchum style tags (a lightweight aluminum tag) were associated with the lowest proportion of major hemorrhages after insertion (Edwards et al., 2001) and caused slight damage in 29% of the ears, moderate damage in 27% and severe damage in 2% of the ears which had this type of tag (Edwards & Johnston, 1999). Hemorrhage at insertion was most common when the tag used was single flap ear tags (one-piece, flexible polyurethane ear tag) (Edwards et al., 2001). Alternatively, metal style loop tags were over 18 times as likely to be associated with major lesions in the ears of ewes than lambtags (a two-piece rigid plastic ear tag), single flex (plastic, flexible ear tag) or golf tee (two part polyurethane ear tag) ear tags (Edwards et al., 2001). Lambtags had the lowest risk of producing severe lesions in the ears of lambs, with the metal loop tag being 63 times as likely to produce major ear lesions (Edwards et al., 2001). Both metal and plastic style loop tags cause more damage to ears in both the number of ears with lesions and the severity of the lesions (Edwards & Johnston, 1999).

Teeth grinding/trimming: Grinding or trimming of incisors to improve food intake in ewes with ‘broken-mouth’ is not effective (Denhold & Vizard, 1986; McGregor, 2011; Spence et al., 1986). In addition, this procedure has the potential to cause pain during the procedure (as indicated by raised plasma cortisol concentration). As dental pulp is exposed this can result in infection and subsequent pain (Denhold & Vizard, 1986).

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7. SNOW AS A WATER SOURCE

Conclusions:

1. **Sheep have a basic thirst motivation to ingest water and water is essential for many processes within the body.**

2. **Sheep have efficient physiological mechanisms to deal with periods of water restriction and are able to withstand higher levels of water deprivation than humans. However, their welfare will deteriorate if they do not have adequate water intake.**

3. **There is insufficient scientific information to make any firm conclusions on the welfare implications of providing snow as the only source of water for sheep. The limited information available did not indicate any severe difficulties when only snow was provided as a water source However, further studies are required to evaluate the welfare implications in a range of conditions, e.g. when there is a greater than normal requirement for water intake from factors such as the type of diet, lactation and health problems. The implications of snow density on the ability of sheep to ingest snow and the factors affecting snow intake require study.**

4. **Clean, powdered snow appears to be preferred to hard, crusty or dirty snow.**

Introduction: The quality and quantity of available water can have a significant impact on sheep. Unrestricted access to snow as a sole source of water for sheep has received very little attention in the scientific literature. In an effort to present information as to whether snow is an adequate source of water for sheep, and if there are circumstances when this is not true, we have presented literature on aspects of water consumption and requirements, as well as some research regarding other species consuming snow as a water source. Much of this research was done many years ago, and while some aspects are likely to hold true, the methods of acquiring scientific data have improved vastly over recent times, and these early studies do require some caution while interpreting the results.

Why do sheep need to consume water? Animals have a basic thirst motivation to obtain water. Water can be supplied to sheep from three sources; drinking water, water in feed and metabolic water (i.e. water generated by the biochemical processing of digested nutrients). Because of water's critical role in life, animals have evolved behavioural mechanisms to balance water losses through drinking (National Research Council [NRC], 2007). Specific water requirements are difficult to determine because of the many factors involved. When animals are offered water ad libitum, water intake is often assumed to represent water requirements. It is possible that the requirements to satisfy thirst or drinking motivation could exceed those necessary to maintain body functions.

Water is a main constituent of the body, particularly in young animals. As animals develop and mature the water content of the body declines from approximately 80% of mass to about 55-80%. Water is used in the body for a variety of functions such as a dissolving agent for cell components, absorption, circulation and excretion. Water within the body transports heat, hormones, ions, nutrients and metabolites (NRC, 2007). Water is an essential part of metabolic processes, in anabolism water is removed from molecules to generate larger molecules and in catabolism, water is used to break bonds to create smaller molecules to be used for other purposes. Water is also a main factor in determining the tension or turgor of cells and tissues (Kamphues & Schulz, 2002). Water is directly or indirectly required for saliva and other secretions from the digestive system, as well as to make possible processes such as swallowing, respiration and transport through the gastrointestinal tract.

Water is also a significant component of other products, particularly milk and urine (Kamphues & Schulz, 2002). Urine production is critical in aiding elimination of metabolic toxins. In response to water restriction sheep have a good ability to produce highly concentrated urine. Insensible water losses also occur by evaporation through breathing, sweating, drooling and licking (NRC, 2007).

Criteria for assessing the implications of water restriction on the welfare of sheep: If the provision of snow as the only source of water results in a restriction in the water intake of sheep, some criteria are required to evaluate the potential impact of any water restriction on the welfare of the sheep. Some of these criteria were described by Cockram and Mitchell (1999) in relation to water restriction during transportation. One extreme criterion could be to evaluate whether sheep can survive with only snow as a source of water, i.e. to assess mortality rates. Another possibility would be to try and determine if sheep show signs of suffering with only snow as a source of water, e.g. do they show behavioural or physiological signs of distress. A third possibility would be to determine whether the sheep show either clinical or physiological evidence of dehydration, e.g. assess clinical signs and changes in blood and body composition indicative of dehydration. Another possibility would be to determine whether the sheep make significant physiological changes in order to conserve body water or redistribute body water in response to water restriction. The behaviour of the sheep when presented with water could also be used to determine the degree of thirst that the sheep might show after various periods of water restriction. However, it some circumstances, is possible that a sheep could be thirsty, but the motivation to perform another behaviour, such as eating, could be stronger than the motivation to drink. Thirst in humans is associated with dryness of the mouth and throat (Fitzsimons, 1972), but we cannot automatically assume that sheep perceive thirst in the same way as humans. Although the passage of water over oropharyngeal receptors can temporarily inhibit drinking in water deprived sheep, drinking is mainly controlled by other factors such as the degree of hydration of rumen contents (Bott et al., 1965) and receptors in the interstitial fluid (Park et al., 1986). It is a reasonable working assumption that a dehydrated animal that eagerly seeks out and consumes water is thirsty (Fitzsimons, 1972); however the onset of drinking may not always be a reliable indicator of the development of a negative water balance. This is because most drinking occurs when there is no current water deficit, but allows the animal to anticipate its future water requirements. This secondary drinking is affected by environmental conditions, circadian rhythm, pattern of feeding and diet (Fitzsimons, 1972). However, primary drinking is an emergency response to a deficit of body fluid and occurs at any time of the day or night. Ruminants can withstand greater dehydration than most monogastric mammals (Cole, 1995). This capacity is related to their ability during dehydration to use the water present in the rumen (Silanikove, 1994). For the first 2 days that sheep are without feed and water, the water absorbed from the alimentary tract is likely to be sufficient to prevent dehydration (Hecker et al., 1964). In sheep, the homeostatic responses to dehydration that act to conserve body fluids, include stimulation of thirst and increased secretion of vasopressin with subsequent reduction in urinary water excretion (McKinley et al., 1983). Even at environmental temperatures of up to 32^{o}C, the plasma volume can be maintained in Merino sheep without access to drinking water for at least 3 days (MacFarlane et al., 1961). If dehydration continues, the extracellular fluid volume decreases, sodium is retained and plasma osmolality increases. As discussed below, another early sign of inadequate water intake can be a decline in dry matter intake.

The literature on snow consumption by sheep as a source of water: The only quantitative study of the physiological and production effects of providing snow as the only water source for sheep was conducted by Degen and Young (1981). Eight Suffolk-cross ewes, each nursing a ram lamb, were kept in a field and were individually offered 2kg of dehydrated alfalfa pellets daily. The lambs were given access to a concentrate creep feed. After snowfall during the 4th week of lactation provided permanent snow cover, the ewes were divided into two groups matched for live weight and lambing date and thereafter until the l4th week of lactation one of the groups was denied water and had access only to snow in the field as their source of water. The second group continued to be offered weighed amounts of water during this period. Due to the small group sizes, this study errs towards not finding a difference. The mean maximum air temperature was only above freezing between 4 and 6 weeks of lactation when it was 0.5^{o}C and between 10 and 12 weeks of lactation when it was 0.9^{o}C. From 4 to 14 weeks of lactation, the water intake (kg/day) from sheep kept on snow (ranged from 2.86 to 3.47) was significantly less than that from ewes with access to water (ranged from 4.28 to 4.56). There was no significant difference between the groups in feed intake. There was no significant difference in the milk yield between the two groups. During this time, milk yield was calculated as between 1.33 kg/day at 6th week of lactation and 0.64 kg/day during 14th week of lactation. However, the effects of providing snow as the only water source were not studied during the times of maximum lactation, e.g. before the study commenced during the 2nd and 4th weeks of lactation the milk yield was 1.47 kg/day. At the 6th, 8th, 10th, 12th and 14th week of lactation, there was no significant difference between the groups in the plasma osmolality. The maximum osmolality in the group provided only with snow was 299 mosmol/kg. This value is below that found in dehydrated sheep and is considered to be normal. Although less useful as an indicator of dehydration in sheep, the packed cell volume was not significantly different between the two groups. There was no significant difference between the two groups in the live weight of the suckling lambs or in their packed cell volume. Degen and Young (1981) provided the following anecdotal comments: "The ewes that were denied water readily accepted snow within 24 hours and no unusual or distressed behavior such as bleating was noted. After a few days on treatment, the snow ewes ingested snow immediately after the feeding period whereas the water ewes nursed their lambs. On occasion the water ewes were observed to eat snow as well." "The snow ewes consumed an average of 3.15 kg/snow per day. At an average snow temperature of -10^{o}C found in this experiment it would require 1.70 MJ to melt this snow and raise its temperature to body temperature of 39^{o}C. The water ewes consumed an average of 3.47kg water at 10^{o}C and an additional 0.90kg snow per day. This would require 0.91 MJ to melt the snow and raise all the water to body temperature."

This study therefore did not identify any clear harmful effects of providing snow as the only source of water during a time when the ewes were lactating and therefore during a period of heightened water requirements. However, some caution is required when interpreting the welfare significance of the results from this study. The fact that the sheep provided with snow as the only water source did not die is significant, but sheep can 'survive' for prolonged periods without any source of water (MacFarlane et al., 1961). Further studies of production practices that are typical of Canadian conditions are required.

Evidence of the ability of sheep to survive with just snow as a water source is provided by field studies of wild ruminants. Wild ruminants that live in snow covered areas where the temperature is below freezing for several months of the year have to ingest snow and ice to survive (Crater & Barboza, 2007; Geist 1971).

In the study by Degen and Young (1981), the lower water intake of ewes provided only with snow than that found in the ewes that had access to water might suggest that snow did not provide sufficient water e.g. to completely satisfy motivation to drink. However, without testing the motivation of the sheep to drink by offering them drinking water, this is speculative. The anecdotal comment that sheep provided only with snow immediately went to ingest snow after feeding might suggest that these sheep did not have the same reserves of water in their rumen as the sheep that had access to drinking water. After feeding, the rumen osmolality rises. Therefore depending on the relative amounts of dry food and volume of water in the rumen, it is possible that after feeding, the rumen osmolality was greater in the sheep with access to only snow than in those with access to drinking water and they had a more immediate requirement for water intake than the ewes that had access to water and were able to nurse their lambs after feeding. The plasma osmolality values and the absence of an effect of restricting water access to snow alone are significant findings. Although it can take more than two days without access to any form of water before signs of dehydration are apparent in sheep (Hecker et al., 1964; Silanikove, 1994), if the sheep did not have sufficient access to water to maintain plasma volume, an increase in plasma osmolality would have been apparent.

The only other report in the scientific literature of providing snow as a water source for sheep was by Weeth et al. (1959). Pregnant sheep were divided into a group that received only snow as a source of water and a group that had access to water while penned on snow. The sheep were then fasted for 6 days. These authors reported as an anecdotal comment, that the snow, which was described as wet and loose, was readily consumed by the sheep. There was no mortality. Ewes that had only snow as a source of water did not lose more body weight than those that had access to water. The authors reported that there was no evidence that the source of water affected the packed cell volume.

Temperature of ingested water: Water intake can also vary with the temperature of the water which is offered (Kamphues & Schulz, 2002) and this temperature in relation to the environmental temperature. The low temperature of consumed snow could potentially have an adverse effect on rumen metabolism and also on body temperature. For example, Brod et al. (1982) showed that 2L of water, at a temperature of about 0^{o}C, placed directly into the rumen of a sheep caused a fall in ruminal temperature of 6^{o}C and it took 1.8 hours to regain normal rumen temperature. This temperature fall caused a non-significant temporary suppression of microbial activity (as shown by a reduced pH and reduced concentrations of volatile fatty acids and ammonia nitrogen). A similar reduction in ruminal temperature was observed by Crater and Barboza (2007) in muskoxen following either drinking cold water or ingesting snow. However, the slow rate at which water entered the rumen following the consumption of snow was considered to reduce the negative impact of increasing the temperature of the cold water.

When do sheep become dehydrated? Water deprivation causes a physiological adaptation to maintain circulatory blood volume and reduce hyperosmolarity of body fluids (Igbokwe, 1997). A 75% reduction in water intake has essentially the same affects as complete water deprivation (Purohit et al., 1973). Once sheep have their water intake reduced below 25% of their requirement, total body water, total blood and plasma volumes, and the extracellular, intracellular and interstitial fluid volumes begin to decrease (Purohit et al., 1973). Water deprivation through infrequent and/or inadequate watering can lead to production losses through loss of body weight, decreased milk production, abortions and death (Igbokwe, 1997).

Ewes given no access to water besides that available from pasture (i.e. dew and guttation – water exuded by leaves of grass) and rainfall, lose much less water through feces and urine than ewes supplied with supplementary water (Brown & Lynch, 1972). Ewes given access to water weighed about 4kg heavier than those without, and lambs born to these ewes also had heavier birth weights than those without water (Brown & Lynch, 1972). Australian research showed that in October, lactating ewes without water ate 700-1250 g of organic matter per day while lactating ewes with access to water ate 1320-1710g of organic matter. In November, the lactating ewes without access to water ate 530-830g of organic matter per day and lactating ewes without water ate 980-1800g (Brown & Lynch, 1972). Dry ewes without water ate 960g of organic matter per day in October, while those with water ate 920g per day. In November, dry ewes with water ate 960g per day while those without ate 700g per day of organic matter (Brown & Lynch, 1972). Sheep without access to supplementary water have been observed licking dew from wire fences and appeared to 'mouth' the grass for water, but the lack of free water did not affect the number of lambs born, lamb mortality, milk production, blood constituents, or total grazing time. It appeared ewes not given water between rainfalls (when rainfall is common) can adjust their water expenditure, except when water expenditure associated with lactation corresponds with moderate or high heat loads (Brown & Lynch, 1972). Ewes without access to water reduced their grazing time between 0600 and 1800 hours when compared to those with access to water (Brown & Lynch, 1972).

When do sheep have increased or decreased water requirements? Water requirements are based on a physiological need and vary between individuals, but the quantification of this is exceedingly difficult, even if the environmental conditions are considered. Water requirements can be calculated within a range, if body weight is known, where total water intake (TWI) is approximately 107-146mL (g)/kg $BW^{0.75}$ (NRC, 2007). Animals will continue to function normally for an extended period with some water intake restriction, which makes it difficult to determine or develop a minimum requirement.

The main factors influencing water intake of production animals were surmised by Kamphues (2000, cited by Kamphues & Schulz, 2002). Climatic conditions such as high temperature and humidity and their diurnal variations impact water intake through the need for thermoregulation and evaporation through the respiratory tract. However, in conditions where snow is present on the ground for a prolonged period, the temperature would be close to or below freezing. In these circumstances, unless the sheep were exercised, increased water would not be lost by thermoregulation involving increased respiration rate or sweating. High physical strain increases water intake due to breathing frequency and sweat, as well as energy release.

Feed factors: Feed composition such as the contents of electrolytes, protein and sulphates impacts the renal excretion, elimination of urea or uric acid and enforced fecal water losses. Diets high in salt, sulphates or protein lead to an increase in water intake (Kamphues & Schulz, 2002). Sheep that have restricted access to water, but have access to food are at a greater risk of developing dehydration sooner than those that do not have access to food (Ternouth, 1968). The water available in the feed also affects the required free water intake. Pregnant ewes fed silage drank less water than those fed hay (numbers not given), but the TWI of silage fed ewes was still 1- 2kg of water per kg of dry matter intake (DMI) more than ewes fed hay during the same period (Forbes, 1968). TWI was also greater when ewes were fed cubed dried grass compared to hay (2.19kg water/kg dry matter versus 1.62kg water/kg dry matter; Forbes, 1968).

Feed intake can impact water intake significantly and vice versa, as can be represented by the formula described by Forbes (1968), where

$$TWI = 3.86DMI - 0.99$$

An animal consuming feed with lower moisture content will drink more water than if it was consuming a diet with higher moisture content. Nutrient digestibility by animals fed dry grass was higher when the total water intake was the same as animals fed fresh grass, compared to those which had water intakes restricted at 50% of this level (Fujihara, 1988). Restricting water intake decreased digestibility of crude protein and crude fat (Fujihara, 1988). Feed intake may noticeably decline if water intake is restricted.

Animal factors: Species, age, breed and the stage of production will all impact the level of water intake. With regard to species, size of animals varies considerably and comparisons are usually made as water intake related to dry matter intake (Kamphues & Schultz, 2002). Species also differ widely on water efficiency, particularly in the ability to concentrate urine (Kamphues & Schultz, 2002). Water deposition through growth, perspiration and milk formation increases the required water intake due to the contents deposited as well as the energy required to do so and the resulting increased feed intake. Water intake can be increased through enforced water losses due to diseases, especially those causing diarrhoea or kidney diseases which cause increased water loss or impair urine concentration, or if an animal has a significant fever. Dehydration may occur when water losses from diarrhea are significant. In some cases this fecal water loss exceeds the water released from the urine.

Young animals have a higher percentage of water in the body than adults, generally between 70 and 85% at birth (Kamphues & Schultz, 2002). Young animals are less efficient at concentrating urine than their adult counterparts which means they must have a higher water intake as well. Lambs before weaning require approximately 195ml of water/kg $BW^{0.75}$ for maintenance and for growth, an additional 8ml/g BW average daily gain (NRC, 2007). Young animals (i.e. lambs) just after the suckling phase generally have a high water intake as well (Kamphues & Schulz, 2002).

Gestating ewes have greater water intake than non-pregnant ewes, and twin-bearing ewes in late pregnancy can consume up to 212% of the water intake of non-pregnant ewes (Forbes, 1968). This heightened water consumption is above and beyond the net water flow to the fetus and the increased energy demand of pregnancy as well as increased urinary excretion are thought to cause this increased water intake (NRC, 2007) During late gestation (last 21 days), the water to dry matter intake ratio increased, while overall dry matter intake decreased (Davies, 1972). Ewes in the last 21 days of pregnancy that were carrying one lamb drank less than ewes carrying twin lambs (Davies, 1972). At term, the TWI/DMI of sheep carrying one lamb is estimated at 4.3-5.2L/kg, whereas for sheep carrying twins the estimate is 7-8L/kg (NRC, 2007).

Lactating animals have increased water requirements over and above that which can be accounted for in milk production (Forbes, 1968). In week two of lactation, after correcting for milk yield, lactating ewes still had water intake 148% that of non-lactating ewes. This value remained higher than dry ewes until week 5 of lactation. In one study, lactating ewes suckling twin lambs consumed more water than those suckling singles, despite similar dry-matter intake levels (Davies, 1972). However in another study (Forbes, 1968) neither dry-matter intake nor total water intake varied between 11 ewes raising single or 4 raising twin lambs.

Breed of animal has an influence on the amount of water intake by an animal, at least under warm temperatures. Certain breeds well adapted to warm climates seem to balance water requirements at a more economical level (Schoeman & Visser, 1995). However, it has not been determined if this is also true at cold temperatures. Fleece length can also impact the water intake of an animal (McMeniman & Pepper, 1982).

The literature on snow consumption by other species: Many wild herbivores will go through periods without access to open water during cold winter periods and must consume their required water through snow consumption. Domestic species such as cattle (Degen & Young, 1990a, b; Young & Degen, 1991) and horses (Dieterich & Holleman, 1973; Mejdell et al., 2005) have been shown to manage well with snow as a water source, although cattle will choose water when given the choice (Degen &Young, 1984). Horses given access to open water after access to snow showed very little interest in water, and not all animals drank (Mejdell et al., 2005).

There appears to be a period of adaptation in cattle when first denied access to water sources other than snow. Steers denied access to water for the first time showed some bellowing and searching, and began consuming snow at approximately 35 hours after water was denied but then consumed snow readily and switched from snow to water and vice versa without any evident distress (Young & Degen, 1980). Mature cattle showed no hesitation to eating snow by the 5^{th} day after access to water was denied; however some water was available during the second and third day from snow melt (Young & Degen, 1991). In the following year, the cattle with previous experience consuming snow as a water source showed no hesitation to do so again (Young & Degen, 1991). Sheep have been noted to readily accept snow as a water source within 24 hours without any abnormal or distressed behaviour (not quantified; Degen & Young, 1981), but it was not specified if the animals had previous experience utilising snow as a water source (either as the sole or supplemental source of water).

Animals which utilise snow as their water source may adopt slightly different eating habits than those with access to open water. Growing beef calves with access to snow as their only water source ate their feed slower than those with access to water; alternating feeding periods and snow ingestion (Degen & Young, 1990a). This differs from animals with access to open water, which generally drink once or twice a day. If cattle are forced to consume snow in a short period, they have a decreased water intake and rumen volume (Degen & Young, 1984).

WHAT FACTORS AFFECT THE ABILITY OF SHEEP TO OBTAIN ENOUGH WATER FROM SNOW CONSUMPTION

Weather conditions: On warmer days cows were dispersed over the field and snow consumption was prolonged much more than on colder days (below -20°C), when cows huddled together in areas sheltered from the wind (Young & Degen, 1991). Provision of windbreaks in the winter might be beneficial in improving the motivation of sheep to move to areas containing snow.

Amount of snow: If the sheep are confined and not kept in range conditions, the amount of snow available could restrict the availability of water. The amount of water contained in a snow pack depends on the snow depth, area and density. After the snow falls its density increases due to gravitational settling, wind packing, melting and recrystallization (United States Department of Agriculture [USDA] National Resources Conservation Service [USDA NRCS]).

Type of snow: Observations by Geist (1971) of wild sheep suggest that they can paw soft snow to access underlying vegetation (and presumably also ingest some snow), but when snow melts on the surface during the day then compacts and freezes rock hard at night, the sheep cannot access it.

The process of melting and refreezing changes the microstructure of snow. Water is held between the grains and the snowpack becomes compacted. When the water refreezes the snow becomes denser increasing in hardness and strength (Langham, 1981). The density of snow ranges from about 70 to 95 kg/m^3 when fresh, to about 280 kg/m^3 after wind action. After consolidation partly into ice, the density can be about 500 kg/m^3 (McKay & Gray, 1981). If a period of melting, during which some water drains away, is followed by a period without melting, the density can be about 370 kg/m^3 (Goodison et al., 1981).

Pregnant cattle appeared to prefer to consume clean snow which could be scooped with a circular motion of the tongue similar to grazing, while trampled, wind-blown or crusty snow tended to be avoided (Young & Degen, 1991). Cattle (Young & Degen, 1980) and sheep (Butcher, 1973, cited by Young & Degen, 1980) also seem to prefer consumption of snow that is in powdered form.

Research recommendations: The welfare implications of providing snow as the only source of water for sheep.

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APPENDIX 1: ADDITIONAL SOURCES OF ADVISORY INFORMATION ON EUTHANASIA OF SHEEP

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APPENDIX 2: SUMMARY OF EXAMPLES OF RESEARCH ON TAIL DOCKING AND CASTRATION

Table A.1: Response to various methods of tail docking.

Procedure	Age	Behavioural Response	Physiological Response	Reference
Using a rubber ring (TR); using a rubber ring and a clamp (TRB); using a docking iron (TIR); surgically (TK)				
Docked with rubber ring (TR)	28-37 days		Cortisol response was the same as TIR, lower than TK	Lester et al., 1991
	Approximately 21 days	Total active behaviours significantly greater than TRB, TIR, and controls. Main behaviours were restlessness, foot stamping and head turning. More time spent in abnormal postures than controls.	Mean peak cortisol greater than TRB, IR and controls.	Graham et al., 1997
	28-37 days	Significantly higher restlessness scores[1] than controls, TR and TIR. Lambs spent more time lying than controls in first 90 minutes. High proportion of lateral lying during first 30-90 minutes post-treatment.	Cortisol increased in response to treatment, peaking at approximately 30 minutes and reaching pre-treatment levels at approximately 180 minutes post-treatment.	Lester et al., 1996
	5-8 days	Higher REQ score[2] than controls and higher incidence of head turning.	Cortisol response peaked at about 30 min post-treatment and returned to pre-treatment levels at about 120 minutes.	Kent et al., 1998
Docked with rubber ring and clamp (TRB)	Approximately 21 days	Active behaviours similar to controls and TIR More time spent in abnormal postures than controls	Mean peak cortisol higher than controls.	Graham et al., 1997
	5-8 days	Lower REQ score[2] and less total time spent walking abnormally than TR.	Lower plasma cortisol concentration increases than TR.	Kent et al., 1998
Docked with docking iron (TIR)	28-37 days		Cortisol response was same as TR, lower than TK.	Lester et al., 1991
	Approximately 21 days	Active behaviours similar to controls and TRB.	Mean peak cortisol similar to controls.	Graham et al., 1997
	28-37 days	Restlessness scores[1] were similar to controls and TK, and lower than TR. Standing/walking and lying behaviours were similar to controls.	Cortisol increased in response to treatment, peaking at approximately 30 minutes and reaching pre-treatment levels at approximately 150 minutes post-treatment.	Lester et al., 1996

Procedure	Age	Behavioural Response	Physiological Response	Reference
Using a rubber ring (TR); using a rubber ring and a clamp (TRB); using a docking iron (TIR); surgically (TK)				
Docked surgically (TK)	28-37 days		Significantly greater cortisol response than TR or TIR.	Lester et al., 1991
	28-37 days	Restlessness scores[1] were similar to controls and TIR, and lower than TR. Standing/walking and lying behaviours were similar to controls.	Cortisol increased in response to treatment, peaking at approximately 30 minutes, remaining above pre-treatment levels throughout the observation period. A small secondary peak was also seen at 120 minutes post-treatment.	Lester et al., 1996
	3-5 weeks		No rise in plasma levels of pro-opiomelanocortin-derived peptides of β-endorphin above controls at 15 minutes or 24 hours post-treatment. Plasma cortisol concentrations increased above control levels at 15 minutes post-treatment, but were not different from controls at 24 hours post-treatment.	Shutt et al., 1987
All methods			Cortisol response ranking (greatest to lowest): Surgical at 4-5 weeks. Ring at 4-5 weeks. Iron at 4-5 weeks. Control handling at 4-8 weeks. Ring at 3 weeks. Ring during first week. Iron at 3 weeks. Ring and clamp (10 seconds) at 3 weeks. Ring and clamp (10 seconds) at 1 week. Ring at 3 weeks plus NSAID (before). Ring at 3 weeks plus LA (before). Ring, with or without clamp (10 seconds) at 1 week plus LA (after). Control handling, first week.	Mellor &d Stafford, 2000 (review)

[1]Number of times lamb stood up and laid down in first 60 minutes.
[2]Sum of incidences of restlessness, rolling, stamping, kicking and easing quarters.

Table A.2: Response to various methods of castration.

Procedure*	Age	Behavioural Response	Physiological Response	Reference
**Using a rubber ring (CR); surgically (CK); using a rubber ring and a clamp (CRB); using a clamp only (CB), and short scrotum with rubber rings (SS)]*				
Castrated with rubber ring (CR)	28-37 days		Cortisol response significantly higher than control and lower than knife	Lester et al., 1991
	28-37 days	Restlessness scores[1] were higher than controls and CK. Lying was more common in the first 90 minutes than in controls. High proportion of lateral lying during first 30-90 minutes post-treatment.	Cortisol increased in response to treatment, peaking at approximately 60 minutes and reaching pre-treatment levels at 210 minutes post-treatment.	Lester et al., 1996
	5-8 days	REQ[2] scores were higher than controls. Lambs spent less time than controls lying normally and more time in abnormal postures. Higher incidence of abnormal postures than controls.	All methods of castration caused a peak cortisol response greater than controls. Cortisol concentrations peaked between 30 and 60 minutes post treatment, falling to pre-treatment levels at approximately 120 minutes post treatment.	Kent et al., 1998
	Average 47 days (30-64)	CR lambs spent less time lying in normal ventral position than controls, but more than CK. CR lambs spent higher proportion of time lying laterally and in abnormal ventral lying. CR lambs spent lower proportion of time standing normally and higher proportion statue standing and standing abnormally than controls. CR spent lower proportion of time abnormal standing, standing normally and statue standing than CK. Proportion of time spent walking normally was lower than controls and similar to CK. Total abnormal behaviours were lower in CR than CK, which were both greater than controls.	Cortisol response peaked at approximately 30 minutes post-treatment, reaching higher concentrations than controls but lower than CK. Cortisol response was similar to controls at 6 hours before rising again to levels similar to CK at 12 hours. Rectal temperature was similar to controls and lower than CK at 6 and 12 hours post-treatment.	Colditz et al., 2012
	Average 43 days (28-64)	Restlessness[1] was highest in CR and SS lambs, and was significantly greater than clamp castrated lambs. CR lambs performed less normal standing and walking than control lambs. Abnormal and ventro-lateral recumbency was distinct in CR lambs. CR had more abnormal recumbent behaviours than CB lambs. Lateral recumbency occurred most in CR lambs and was not observed in controls or CB lambs.	The average cortisol response of CR peaked at 60 and 90 minutes post-treatment, remaining elevated above pre-treatment levels for 150 minutes post-treatment. CR lambs had cortisol concentrations higher than SS lambs from 45-60 minutes (peak cortisol).	Dinniss et al., 1997 (physiological response) and Dinniss et al., 1999 (behavioural response)

Procedure*	**Age**	**Behavioural Response**	**Physiological Response**	**Reference**
**Using a rubber ring (CR); surgically (CK); using a rubber ring and a clamp (CRB); using a clamp only (CB), and short scrotum with rubber rings (SS)]*				
Castrated surgically (CK)	28-37 days		Cortisol response significantly higher than control and greater than ring	Lester et al., 1991
	28-37 days	Restlessness scores[1] were similar to controls and lower than CR. Standing/walking and lying behaviours were similar to controls.	Cortisol increased in response to treatment, peaking at approximately 30 minutes and remaining above pre-treatment levels throughout the observation period.	Lester et al., 1996
	Average 47 days (30-64)	CK lambs spent lower proportion of time lying in normal ventral position than controls and CR, whereas abnormal ventral lying and lateral lying did not differ from controls but was less than CR. CK lambs spent lower proportion of time standing normally than controls and higher proportion statue standing and abnormal standing than controls. CK spent higher proportion of time statue standing, abnormal standing, and normal standing than CR. Proportion of time spent walking normally was lower than controls and similar to CR. Total abnormal behaviours were higher in CK than CR, which were both greater than controls.	Cortisol response peaked at approximately 30 minutes post-treatment and was higher than controls and CR at 30 minutes at 6 hours. Cortisol remained elevated above controls until at least 12 hours post-treatment. Rectal temperature rose following the procedure and was higher than CR and controls at 6 and 12 hours post-treatment.	Colditz et al., 2012
Castrated with rubber ring followed by clamp (CRB)	5-8 days	REQs[2] were not different than controls and lower than lambs castrated with rubber ring only. Lower incidence total abnormal postures than CR, similar to controls, but more than CRB plus LA.	Peak cortisol response was greater than controls and lower than CR. Cortisol levels peaked at approximately 20 minutes post-treatment and fell to below pre-treatment levels by 60 minutes post-treatment.	Kent et al., 1998
Castrated with rubber ring followed by clamp for 1 second (CRB1)	Average 43 days (28-64)	CRB lambs showed slightly more normal standing/walking than CR lambs. Abnormal and ventro-lateral recumbency was distinct in CRB lambs. Lateral recumbency was observed in CRB lambs, but less so than in CR lambs.	Cortisol response peaked by 30 minutes post-treatment, earlier than CR, but followed a similar pattern otherwise.	Dinniss et al., 1997 (physiological response) and Dinniss et al., 1999 (behavioural response)
Castrated with rubber ring followed by clamp for 5 seconds (CRB5)	Average 43 days (28-64)		Cortisol response peaked by 30 minutes post-treatment, but followed a similar pattern otherwise.	Dinniss et al., 1997 (physiological response) and Dinniss et al., 1999 (behavioural response)

Procedure*	Age	Behavioural Response	Physiological Response	Reference
*Using a rubber ring (CR); surgically (CK); using a rubber ring and a clamp (CRB); using a clamp only (CB), and short scrotum with rubber rings (SS)]				
Castrated with rubber ring followed by clamp for 10 seconds (CRB10)	Average 43 days (28-64)		Cortisol response peaked by 30 minutes post-treatment, but followed a similar pattern otherwise.	Dinniss et al., 1997 (physiological response) and Dinniss et al., 1999 (behavioural response)
Castrated with clamp applied for 1s (CB1)	Average 43 days (28-64)	Lambs which were castrated with the clamp only had lower restlessness[1] scores than CRB lambs. CB lambs were observed standing and walking normally more than CR lambs. CB1 lambs stood/walked normally more than CRB lambs. CB lambs showed less abnormal recumbency than CRB lambs.	Cortisol concentrations were higher than controls from 15-150 minutes post-treatment, peaking at 30 minutes post-treatment. Cortisol responses peaked earlier and lower than CR, and were significantly lower from 60-90 minutes post-treatment.	Dinniss et al., 1997 (physiological response) and Dinniss et al., 1999 (behavioural response)
Castrated with clamp applied for 10 seconds (CB10)	Average 43 days (28-64)	No difference was in normal standing/walking between CB10 and CRB lambs.	Cortisol concentrations were higher than controls from 15-210 minutes post-treatment, peaking at 90 minutes post-treatment. The cortisol response of CB10 was similar to that seen for CR lambs, but peaked slightly later and remained elevated longer.	Dinniss et al., 1997 (physiological response) and Dinniss et al., 1999 (behavioural response)
Short scrotum with rubber ring (SS)	Average 43 days (28-64)	Abnormal walking occurred most notably in SS lambs.	Cortisol response was lower than CR lambs between 45 and 60 minutes post-treatment.	Dinniss et al., 1997 (physiological response) and Dinniss et al., 1999 (behavioural response)
All methods			Cortisol response ranking (greatest to least): Surgical at 4-5 weeks. Clamp (10s/cord) at 4-8 weeks. Ring at 1-8 weeks. Ring and Clamp (1-10s) 3-8 weeks. Clamp (10s/cord) 3 weeks. Clamp (10s/cord) plus LA before 3-8 weeks. Short scrotum ring, 4-8 weeks. Clamp (1s/cord) 4-8 weeks.	Mellor & Stafford, 2000 (review)

Procedure*	Age	Behavioural Response	Physiological Response	Reference
**Using a rubber ring (CR); surgically (CK); using a rubber ring and a clamp (CRB); using a clamp only (CB), and short scrotum with rubber rings (SS)]*				
			Ring, with or without clamp (10s/cord) plus LA, 4-8 weeks. Ring plus LA, 1 week. Clamp (10s/cord) plus NSAID, 3 weeks Control handling, 4-8 weeks. Ring and clamp (10s), 1 week. Ring, with or without clamp (10s/cord) plus LA, 4-8 weeks. Ring, with or without clamp (10s) plus LA, 1 week. Control handling, first week.	

[1]Number of times lamb stood up and laid down in first 60 minutes.
[2]Sum of incidences of restlessness, rolling, stamping, kicking and easing quarters.

Table A.3: Response to various methods of castration and tail docking performed concurrently.

Procedure*	Age	Response	Reference
Using a rubber ring (CR-TR); surgically (CK-TK); using a rubber ring and a clamp (CRB-TRB); castrated with a rubber ring and clamp and docked with a rubber ring (CRB-TR); castrated with rubber ring and docked with a docking iron (CR-TIR); Rubber ring applied to short scrotum and tail (SS-TR)			
Castrated and docked with rubber rings (CR-TR)	28-37 days	Physiological: Cortisol response greater than control, less than CK-TK.	Lester et al., 1991
	Approximately 5, 21 or 42 days of age	Behavioural: Significantly higher restlessness scores[1] than controls, CK-TK and CRB-TRB at each age. Restlessness scores were significantly higher in 21 and 42 day old lambs than 5 day old lambs. More abnormal lying than controls, CRB-TRB and S at all ages. More time spent in abnormal postures than controls, CRB-TRB and CK-TK.	Molony et al., 1993
	28-37 days	Behavioural: More restlessness during first 60 minutes than all other groups. Lambs spent more time lying during first 90 minutes than controls and more time standing from 1.5 to 3 hours after treatment. High proportion of lateral lying during first 30-90 minutes post-treatment. Physiological: Cortisol increased in response to treatment, peaking at approximately 60 minutes and reaching pre-treatment levels at 210 minutes post-treatment.	Lester et al., 1996
	Less than 2 days[3]	Behavioural: Foot stamping, kicking and tail wagging occurred at a greater incidence in CR-TR lambs without LA than those given LA and control lambs. These behaviours peaked at 31 days post-treatment. CR-TR without LA had the highest incidence of abnormal lying, abnormal standing, and lying idling.	Kent et al., 2000
	5, 21 or 42 days old	Physiological: Peak cortisol was higher than control lambs (with or without the baseline values subtracted) at all ages. Peak cortisol response was lower at 21 and 42 days than at 5 days.	Kent et al., 1993
	26-34 days (docked); 1 day or 10 days (castrated).	Behavioural: Decrease in proportion of time spent in normal postures and increase in restlessness in the 30 minutes following tail docking. Lambs castrated at one day showed more unsteady and abnormal standing and rolling after tail docking than those castrated at 10 days. No difference between age of castration on abnormal ventral lying, jumping, stamping feet, kicking, repetitive standing, restlessness and combined active behaviours.	McCracken et al., 2010
	Average 50 days (45-55)	Physiological: Cortisol concentration increased after treatment and peaked at 45 min post-treatment, remaining elevated for 2 hours.	Dinniss et al., 1997

Procedure*	**Age**	**Response**	**Reference**
**Using a rubber ring (CR-TR); surgically (CK-TK); using a rubber ring and a clamp (CRB-TRB); castrated with a rubber ring and clamp and docked with a rubber ring (CRB-TR); castrated with rubber ring and docked with a docking iron (CR-TIR); Rubber ring applied to short scrotum and tail (SS-TR)*			
Castrated and docked with knife (CK-TK)	28-37 days	Physiological: Cortisol response greater than control and CR-TR.	Lester et al., 1991
	Approximately 5, 21 or 42 days of age	Behavioural: More time spent in abnormal postures than controls.	Molony et al., 1993
	28-37 days	Behavioural: Restlessness scores[1] similar to controls and lower than CR-TR, CR-TIR, and SS-TR. Physiological: Cortisol increased in response to treatment, peaking at approximately 30 minutes and remaining above pre-treatment levels throughout the observation period. A secondary peak was also seen at 240 minutes post-treatment.	Lester et al., 1996
	3-5 weeks	Physiological: Plasma cortisol concentrations were higher than controls at 15 min post-treatment. Plasma levels of pro-opiomelanocortin-derived peptides of β-endorphin were higher than controls and lambs which received tail docking only.	Shutt et al., 1987
	5, 21 or 42 days old	Physiological: Peak cortisol was higher than control lambs (with or without the baseline values subtracted) at all ages. Peak cortisol response was lower at 21 and 42 days than at 5 days. The peak cortisol response was reached sooner than CR-TR lambs at 21 days. At 21 days of age, cortisol peaked sooner than CR-TR and at a similar time as CRB-TRB, but maintained a higher level throughout the sampling time (180 min). At 42 days of age, peaks were similar but CK-TK lambs maintained higher cortisol concentrations throughout sampling.	Kent et al., 1993
Castrated and docked with rubber rings followed by clamp (CRB-TRB)	Approximately 5, 21 or 42 days of age	Behavioural: More time spent in abnormal postures than controls.	Molony et al., 1993
	5, 21 or 42 days old	Physiological: Peak cortisol was higher than control lambs (with or without the baseline values subtracted) at all ages. Peak cortisol response was lower at 21 days than at 5 days. The peak cortisol response was reached sooner than CR-TR lambs at 5 and 21 days.	Kent et al., 1993
	Average 50 days (45-55)	Physiological: Cortisol concentration increased after treatment and peaked at 45 min post-treatment, remaining elevated for 2 hours.	Dinniss et al., 1997
Castrated with rubber ring followed by clamp and docked with rubber ring only (CRB-TR)	Average 50 days (45-55)	Physiological: Cortisol concentration increased after treatment and peaked at 30 min post-treatment, remaining elevated for 2 hours. Cortisol concentration at 30 minutes was higher than CR-TR and CRB-TRB.	Dinniss et al., 1997

Procedure*	Age	Response	Reference
**Using a rubber ring (CR-TR); surgically (CK-TK); using a rubber ring and a clamp (CRB-TRB); castrated with a rubber ring and clamp and docked with a rubber ring (CRB-TR); castrated with rubber ring and docked with a docking iron (CR-TIR); Rubber ring applied to short scrotum and tail (SS-TR)*			
Castrated with ring docked with iron (CR-TIR)	28-37 days	Behavioural: Restlessness scores[1] greater than controls and CK-TK and lower than SS-TR and CR-TR. Lambs spent more time lying during first 90 minutes than controls. High proportion of lateral lying during first 30-90 minutes post-treatment. Physiological: Cortisol increased in response to treatment, peaking at approximately 30 minutes and reaching pre-treatment levels at approximately 180 minutes post-treatment.	Lester et al., 1996
	28-37 days	Physiological: Cortisol response greater than control	Lester et al., 1991b
Rubber ring applied to short scrotum, rubber ring applied to tail (SS-TR)	28-37 days	Behavioural: Restlessness scores[1] were greater than controls, CK-TK and CR-TIR and less than CR-TR. Lambs spent more time lying during first 45 minutes than controls and more time standing between 1 and 2 hours after treatment. High proportion of lateral lying during first 30-90 minutes post-treatment. Physiological: Cortisol increased in response to treatment, peaking at approximately 30 minutes and reaching pre-treatment levels at 210 minutes post-treatment.	Lester et al., 1996
All types		Physiological: Cortisol response ranking (greatest to lowest) Docked and castrated surgically at 4-6 weeks Castration and docking by rubber ring at 1-8 weeks & Castration with rubber ring and clamp (6 seconds) and docked with rubber ring, with or without clamp from 3-8 weeks. Castration and docking with a tight rubber ring at 1 week & castration and docking with clamp (6 seconds) at 1 week. Castration and docking with ring and LA (in scrotal neck) at 6 weeks. Control handling at 4-8 weeks. Castration and docking with ring and clamp (10 seconds) at 1 week. Control handling in first week.	Mellor & Stafford, 2000 (review)

[1]Number of times lamb stood up and laid down in first 60 minutes.
[2]Sum of incidences of restlessness, rolling, stamping, kicking and easing quarters.

Table A.4: Effect of local anesthetics* on response to tail docking or castration.

Local Anesthetic (LA)	Procedure	Age of Lambs	Result	Reference
0.5ml bupivacaine hydrochloride[1] (Marcain 0.25%, Astra Pharmaceuticals Ltd.) - Subcutaneous: injected across the full width of the tail from a point dorsally and ventrally, 1-2 minutes before docking; - Epidural local anesthetic: injected into the epidural space 1-2 minutes before docking; Analgesic spray: About 6ml of Ralgex freeze spray[1] (Beecham) containing isopentane 67.77%, methoxymethane 14.41% glycol monosalicylate 10% (all w/w), isopropyl alcohol and menthol was sprayed for 3 seconds across the width of dorsal and ventral surface of tail, 10cm from proximal end, a few seconds before docking	Tail docked with rubber ring, rubber ring followed by clamp or with docking iron	Lambs approximately 21 days	Physiological: All analgesic treatments reduced the mean peak cortisol response with all methods of docking. Behavioural: LA (subcutaneous or epidural) reduced the incidence of active behaviours observed and abnormal lying when docked using rubber ring. Subcutaneous LA reduced time spent in abnormal standing in rubber ring docked and time spent in abnormal postures in lambs docked with rubber ring and clamp or docking iron. Analgesic spray reduced active behaviours with all methods.	Graham et al., 1997
0.2mL of lignocaine hydrochloride[2], 2% with adrenaline (Xylotox, Astra) was administered to half the lambs by either high pressure needleless injection or by conventional injection, into left and right dorso-lateral tissues of the tail immediately after the rubber ring	Tail docked with rubber rings, rubber ring and clamp	5-8 days	Physiological: Cortisol response of lambs given LA and docked with rubber rings was similar to control lambs. LA did not impact cortisol response in lambs docked with rubber ring and clamp. Behavioural: Local anesthetic reduced the mean REQ score[2] and reduced the incidence of abnormal postures from lambs docked with rubber rings without LA.	Kent et al., 1998
0.2mL of lignocaine[2] was administered to half the lambs by either high pressure needleless injection or by conventional injection, into the middle of each testis immediately before application of the ring, by high pressure needleless injection into left and right sides of the neck of the scrotum immediately after the rubber ring, or by conventional injection subcutaneously into each spermatic cord immediately after the application of the ring.	Castrated with a rubber ring; rubber ring followed by clamp	5-8 days	Physiological: All methods of LA reduced the peak cortisol response of rubber ring castrated lambs. Cortisol concentrations of rubber ring castrated lambs were higher than controls and rubber ring plus clamp castrated lambs. LA did not impact cortisol response in lambs castrated with rubber ring and clamp. Behavioural: REQs[2] of castrated lambs with LA were higher than controls but lower than lambs castrated without LA. Lambs castrated with rubber rings with LA spent less time than controls lying normally but more than lambs not given LA. Lambs castrated with LA had a higher incidence of abnormal postures than controls but lower than those with no LA.	Kent et al., 1998

Local Anesthetic (LA)	Procedure	Age of Lambs	Result	Reference
Nopaine (2% lignocaine hydrochloride[2], Ethical Agents, Auckland) was injected 15 minutes before castration into the 3 sites (1ml into anterio-medial surface, 0.5ml into each lateral surface) in the scrotal neck or 0.5ml into each spermatic cord or both or 0.5ml into each testis - LA-SN: local anesthetic, scrotal neck - LA-SC: local anesthetic, spermatic cord - LA-SNSC: local anesthetic, scrotal neck and spermatic cord - LA-T: local anesthetic, testis	Castrated with a rubber ring; rubber ring followed by clamp; castrated with clamp	Average 43 days (28-64)	Physiological: Lambs with LA showed cortisol responses similar to controls, except LA-SC, which had a response higher than other LA groups, but lower than rubber ring castrated lambs without LA. LA reduced the peak cortisol concentrations in lambs castrated with the clamp applied for 10 seconds, but cortisol concentrations were higher than control lambs up to 120 post-treatment. Behavioural: LA reduced restlessness significantly in rubber ring castrated lambs, more so in LA-SNSC than LA-SC. Rubber ring castrated lambs that received LA were observed standing/walking normally more than CR lambs without LA, but this still occurred less often than control lambs. LA-SN and LA-SNSC reduced abnormal recumbency in rubber ring castrated lambs. LA significantly reduced the occurrence of lateral recumbency. Lambs castrated with rubber ring and clamp given LA spent more time standing and walking normally than those without LA and lambs castrated with rubber rings only. LA did not affect the amount of normal standing/walking in clamp castrated lambs.	Dinniss et al., 1997 (physiological response) and Dinniss et al., 1999 (behavioural response)
0.3 ml of 2% lignocaine[2] with adrenaline (Norbrook Laboratories Ltd.) applied by two high pressure needleless injections into the neck of the scrotum, the testes and into the dorso-lateral tail just cranial to where the rubber ring was applied	Castrated and docked with rubber rings	Less than 2 days	Behavioural: Foot stamping, kicking and tail wagging occurred at a similar incidence in rubber ring docked and castrated lambs given LA and control lambs. These behaviours peaked at 21 days post-treatment.	Kent et al., 2000

*Local anesthetics are available only by veterinary prescription in Canada.
[1] Not available for use in animals in Canada.
[2] Licensed for use in sheep in Canada

Table A.5: Effect of non-steroidal anti-inflammatory drugs* (NSAIDs) on response to tail docking or castration.

NSAID	Procedure	Age of Lambs	Result	Reference
1.5mg/kg of diclofenac sodium[1] (Voltarol, Geigy) injected into the neck muscle 20 minutes before docking.	Tail docked with rubber ring or with docking iron	Lambs approximately 21 days	Physiological: Treated lambs docked with rubber rings had lower cortisol levels than untreated docked lambs but no difference was seen in hot iron docked lambs. Behavioural: Treated lambs showed more active behaviours and abnormal lying than untreated and docked with rubber ring or docked but given a local anesthetic.	Graham et al., 1997
5mL of Flunixin[2] (50mg/mL; Norbrook Laboratories, UK) or meloxicam[2] (20mg/mL; Boehringer Ingelheim, Australia) injected subcutaneously around the scrotum immediately prior to castration	Castration with rubber rings	4.8 ± 1.6 weeks	Physiological: Flunixin and meloxicam treated lambs had lower peak cortisol than lambs given no NSAID. At 24 hours post-treatment, NSAID treated lambs had cortisol levels intermediate to castrated controls and sham castrated lambs. Rectal temperature, total leukocyte count, neutrophil: lymphocyte ratio and haptoglobin concentrations did not differ between groups. Behavioural: Flunixin treated lambs showed less elevated limb movement and lower total pain avoidance behaviours than control lambs. Flunixin lambs spent more time lying in normal ventral position, less time in abnormal ventral lying and less time in abnormal postures compared to controls. Meloxicam lambs spent more time lying in normal ventral position and standing normally and reduced abnormal standing and total abnormal postures compared to controls. Restlessness and teat seeking did not differ between groups.	Paull et al., 2012
1.5mg/kg of diclofenac sodium[1] (Voltarol, Geigy) injected into the neck muscle 20 minutes before docking.	Clamp castration	3 weeks	Physiological: Diclonfenac reduced peak cortisol levels by one third of controls for clamp castration. Behavioural: Diclofenac reduced the time spent in abnormal postures, especially abnormal lying, and trembling. Time spent in normal standing postures was similar to control lambs.	Molony et al., 1997
Subcutaneous injection of 0.5mg/kg carprofen[1] (Zenecarp for calves; C-Vet), 30 minutes before procedure	Castrated and tail docked using rubber rings	Newborn	Behavioural: Carprofen did not affect the discomfort behaviours (restlessness, turning head into an abnormal position, easing quarters, tail wagging, rolling, and vocalizing) of lambs	Price & Nolan, 2001
Subcutaneous injection of carprofen[1] at 4mg/kg, 90 minutes before the procedure	Castrated by rubber ring or surgically and tail docked using a hot knife	Average age of 5 weeks	Physiological: Cortisol concentrations were reduced by carprofen at 6 hours post-treatment but were higher at 24 and 48 hours than controls. Neutrophil: lymphocyte ratios and haptoglobin concentrations tended to be decreased with carprofen administration. Behavioural: Restlessness tended to be lower in carprofen treated lambs and total pain-associated behaviours were lower in treated lambs compared to untreated ring castrated lambs.	Paull et al., 2009

*No NSAID is licensed for use in sheep in Canada and are available only by veterinary prescription.
[1] Not available for use in Canada in food animals. [2] Not currently licenced for use in sheep in Canada.

Additional Appendix 2 References (not included in text)

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APPENDIX 3: OTHER RESOURCES FOR SNOW AS A WATER SOURCE

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