CODE OF PRACTICE FOR THE CARE AND HANDLING OF GOATS: REVIEW OF SCIENTIFIC RESEARCH ON PRIORITY ISSUES

August 2020

Goat Code of Practice Scientific Committee

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Excerpt from Scientific 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.

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 Scientific 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 Scientific Committee report is publicly available, the transparency and credibility of the Code is enhanced.

For each Code of Practice being developed or revised, NFACC will identify a Scientific Committee. This committee will consist of a target number of 6 scientists familiar with research on the care and management of the animals under consideration. NFACC will request nominations from 1) Canadian Veterinary Medical Association, 2) Canadian Society of Animal Science, and 3) Canadian Chapter of the International Society for Applied Ethology. At least one representative from each of these professional scientific bodies will be named to the Scientific Committee. Other professional scientific organizations as appropriate may also serve on the Scientific Committee.

Purpose & Goals

The Scientific Committee will develop a report synthesizing the results of research relating to key animal welfare issues, as identified by the Scientific 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 Scientific Committee report will not contain recommendations following from any research results. Its purpose is to present a compilation of the scientific findings without bias.

The full Terms of Reference for the Scientific 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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Introduction: Approaches to Defining and Evaluating Animal Welfare

The scientific evaluation of animal welfare involves the use of empirical methods to obtain information about animals that can be used to inform ethical decision-making regarding their quality of life. One major challenge is that people have diverse views about what constitutes a good quality of life and therefore express a variety of ethical concerns and use different criteria for defining animal welfare. These have been grouped into three general categories: 1) biological functioning; 2) affective states; and 3) natural living and form the bases for different approaches to animal welfare research (Fraser et al., 1997). The biological functioning approach emphasizes basic health and normal function and includes measures concerning health and productivity, stress response, and normal (or absence of abnormal) behaviour (Broom, 1991). Animal welfare defined in terms of affective states is often referred to as the feelings-based approach and concerns the subjective experiences of animals with an emphasis on states of suffering (pain, fear, frustration), states of pleasure (comfort, contentment), and the notion that animals should be housed and handled in ways that minimize suffering and promote positive experiences (Duncan, 1993). Natural living emphasizes the naturalness of the circumstances the animal experiences and the ability of the animal to live according to its nature (Fraser, 2008). While the natural living approach provides another viewpoint for what constitutes a good quality of life for animals, it is more difficult to derive specific measures from it that can be used to evaluate welfare.

The mandate of the Scientific Committee was to address the implications for goat welfare within the topics identified. Few, if any, references are made to economic considerations or human health and welfare concerns as these were beyond the scope of the committee's mandate and were rarely addressed in the papers reviewed. The Code Development Committee, for which this report was prepared, represents considerable expertise in these areas and is tasked with considering such factors in its discussions.

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1 Natural Behaviours

Conclusions

Location preferences and feeding behaviour:

1. **Goats prefer environments with the option to climb.**
2. **Goats are motivated to hide overnight, during adverse weather, when there is a risk of predators, and to escape aggressive behaviour.**
3. **Goats prefer harder flooring surfaces, which may allow for the natural wear of the feet; however, their preference for surface is dependent on the activity being performed.**
4. **Goats are selective foragers, and when given a choice will browse at or above eye level; they are capable of adapting to different feed types and qualities.**

Social behaviour and cognitive capabilities:

5. **The maternal bond takes approximately 4 hours to form, and does rely on a combination of senses to identify their young.**
6. **Horns can play a role in mating behaviour, hierarchical position, and self-grooming.**
7. **Goats prefer small groups, in which they form strong hierarchies; interactions amongst herd members contribute to the formation of social hierarchy and have a large influence on mating success.**
8. **Isolation is a stressful event.**
9. **Goats are driven to partake in cognitive challenges; they are capable of understanding human cues.**
10. **Boredom is a welfare concern, and enrichment is encouraged.**
11. **Enrichment positively influences goat physical and mental states.**

1.1 Introduction

Naturalness is a fundamental component of animal welfare (Fraser et al., 1997). The natural behaviours demonstrated by feral and wild animals, when either present or absent in farm settings, are useful indicators of the same species' welfare (Friend, 1989; Yeates, 2018). Production environments and management practices can impact animals' ability to express natural behaviours (Miranda-de la Lama & Mattiello, 2010). The drive to perform certain natural behaviours can be powerful, and the inability to display these behaviours can cause distress (Friend, 1989). This chapter will reference numerous feral and wild goat observational studies as indicators of natural goat behaviour.

Compared to natural habitats, how animals interact with their environment changes in farming systems; aspects that are altered include space, feed and water availability, shelter options, predation risk, and social interactions (Miranda-de la Lama & Mattiello, 2010). For this review, two categories have been used: location preferences (including feeding) and social and cognitive behaviours. However, behaviours and their underlying drivers should be considered together (Zobel et al., 2019).

1.2 Location Preferences and Feeding Behaviour

Goats show immense flexibility and adaptability in harsh, mountainous, and changing terrain (Zobel et al., 2019). Goats housed in farming systems retain these capabilities, regardless of their housing (Zobel & Nawroth, 2020). Therefore, elevated spaces, hard surfaces, opportunities to hide and be active, and varied feeding repertoires should be provided and promoted to improve goat welfare.

1.2.1 Elevation Preference

Feral goats (*Capra sp.*) have a preference for elevated and sloped terrain (Geist, 1960; McTaggart, 1971; Shi et al., 2003); such environments provide access to unique foraging opportunities and the ability to watch for and escape predators. Commercial facilities rarely provide opportunities for goats to gain such vantage points; however, when given the opportunity, goats will seek elevation, with potential social benefits as outcomes. In indoor housed dairy goats, Andersen and Bøe (2007) found that the availability of 2 levels in goats' lying area significantly decreased aggression when compared to a single-level laying area with identical space allowance.

When Zobel et al. (2017) offered a raised platform to a dozen dairy goats naïve to climbing opportunities, all used the platform, either for climbing or for hiding beneath. Aschwanden et al. (2009a, 2009b) reported that when raised surfaces and dividers were added to the feeding environment, the lower-ranking goats used the platform and aggressive interactions decreased.

1.2.2 Hiding Behaviour

Feral goats prefer to hide in natural hiding spaces such as caves during the night, during unfavourable weather conditions (e.g., rain and wind), and when there is a risk of predators (Shi et al., 2003; Shi et al., 2005; Stachowicz et al., 2019; Zobel et al., 2019). Conversely to what is seen in sheep, Lickliter (1984) observed that shortly after birth, the majority of the kids hid in boxes when they were supplied and continued this behaviour for roughly 5 days. Does have also been observed to distance themselves from the herd when kidding (e.g., Australian bush goats, nearly 50% kidded 60 metres or more from the herd, remaining there for 14 hours on average; Allan et al., 1991). When brush is available, feral goat kids will hide; otherwise they continuously follow the doe (Kilgour & Ross, 1980). This natural behaviour of isolation during kidding and hiding the kid afterwards is rarely possible on farm.

Bøe and Ehrlenbruch (2013) demonstrated that goats preferred to go inside during adverse weather conditions, and overall, they utilized an outdoor space more when it had an overhanging roof as opposed to when it had no cover. Outdoor space has value for goats but will not necessarily meet "ranging needs" (Stachowicz et al., 2018, 2019). Covered areas are not typically considered in indoor facilities; however, as suggested by Zobel et al. (2019), goats seek hiding opportunities even when climate and predation are not concerns. Shelters may serve as refuges from antagonistic interactions. Zobel et al. (2017) found that while some goats climbed a platform when given the opportunity, others, particularly those with more submissive-avoiding personalities, chose to use the space underneath to hide and rest. Hiding may be even more important in systems with large group sizes and minimal space allowance, where aggression can be high.

1.2.3 Surface Preferences

Feral and wild goats are often observed in rocky terrain (Geist, 1960; McTaggart, 1971; Shi et al., 2003). Hard surfaces are thought to be integral to maintaining foot health by allowing for natural wear down of the hoof wall (Cottom & Pinsent, 1988; Williams, 1990). In cattle, cow comfort hinges on the opportunity for cows to lay on soft surfaces; as such, it is not surprising that the majority of indoor goat facilities use straw and wood shavings (Zobel et al., 2019). However, goats have been shown to least prefer straw at any temperature and expanded metal in moderate temperatures, while preferring solid wood or rubber mattresses (e.g., dairy cow mattresses) in low temperatures (Bøe et al., 2007). In a temperate indoor climate, when offered 4 different flooring types, goats preferred to lie on rubber mats and plastic slat flooring compared to metal mesh or wood shavings; wood shavings were used mainly for defecation and urination (Sutherland et al., 2017). This variety in flooring choices demonstrates an innate drive to lay on a hard-dry surface and urinate away from preferred resting substrates.

1.2.4 Ranging Behaviour

Goats occupy home-ranges that change during the mating season and vary with seasonality (O'Brien, 1988). In extensive systems, goats will forage away from a central location, often returning to a central area for another resource. Shrader et al. (2008) found this to be water, while Zobel et al. (2018) suggested the driving resource was shelter and perhaps the routine of daily milking. Depending on the location, terrain, and management system, goats may travel between 3 and 12 km per day (Ouédraogo-Koné et al., 2006; Schlecht et al., 2006; Zobel et al., 2018). Conversely, indoor housed milking goats are typically kept close to the milking parlour and may spend more than 15 hours per day lying down (Zobel et al., 2015).

If given the opportunity to explore a large range, goats can meet their drive to forage different vegetation types; this is in contrast to commercial systems' typically short feeding periods of homogenous feed. In large ranges, goats have the opportunity to seek out various ground surfaces and elevations not afforded in barn environments. Research comparing behavioural impacts of large ranges versus indoor commercial environments is lacking; however, an established consequence of farming goats (either indoor or outdoor) is the need for frequent hoof trimming, with overgrowth being a significant problem. Depending on the system, overgrown hooves have been reported to be between 79% (Anzuino et al., 2010) and 100% of the animals monitored (Hill et al., 1997). It has been suggested that allowing goats to walk further, particularly on varied and hard terrain, could help alleviate these issues (Zobel et al., 2019).

McGregor (2010) also stressed that if Angora goats, raised in Australia, are outdoors, then shelter must also be provided to prevent cold stress and death. Goats with shelter overnight expended less energy due to protection from cold stress (Tovar-Luna et al., 2011).

1.2.5 Feeding Behaviour

Feral goats have been observed to graze and browse various greenery (El Aich et al., 2007; Geist, 1960; McTaggart, 1971), ranging from herbaceous plants to trees and shrubs. The type of greenery consumed is related to season and availability (Ferreira et al., 2013; Sanchez-Rodriguez et al., 1993; Shi et al., 2003). Depending on the season, feral goats spend the majority of their day browsing (El Aich et al., 2007; Leidy et al., 2015; Shi et al., 2003); this is relevant for comparing how natural time budgets deviate from those in commercial systems. Sanchez-Rodriguez et al. (1993) noted a linear relationship between dairy goat selection of grass and its seasonal growth: when grass quality decreased, the consumption of shrubs increased. When offered a choice of feed with different quality levels, goats preferred the highest quality (Shrader et al., 2008). When forage quality decreases or is a limited resource in their natural environment, goats will compete for feed (Shi et al., 2003). During mating season, time dedicated to eating drops due to males disrupting typical feeding routines (Shi & Dunbar, 2006).

Goats have a complex behavioural feeding repertoire: they vary what they eat, how long they eat for, whom they eat with, and in what posture and location. They are sensitive to how feed is presented and can be aggressive if stocking density is high and feed is presented all on the same level (Andersen and Bøe, 2007). They are often seen in a browsing posture (e.g., feeding head-level or above), and at times raised on their hind legs (Pfister et al., 1988; Sanon et al., 2007; Tolu et al., 2012). Neave et al. (2018) demonstrated that 13-month old Saanen goats competed for access to a feeder that promoted a browsing posture, even when a ground-level feeder was available containing an identical feed. Goat anatomical features may be an indicator of their dietary preferences as well. Jamunapari goats, a large dairy breed from India, prefer to browse; this preference is thought to be due to their convex Roman noses and long pendulous ears (Rout et al., 2002). The shorter jaw compared to the nose promotes browsing, and the long ears alert the animal when they are too low; it is hypothesized that the latter adaptation protects the breed from parasitic infection.

Zobel et al. (2019) encourage a rethinking of the current uniform feeding of most commercial farming systems. While not well studied, there are likely negative implications of minimal variability and complexity in the diets typically provided, including abnormal or destructive behaviour arising from too much idle time and lack of stimulation (Zobel & Nawroth, 2020).

1.3 Social and Cognitive Behaviour

1.3.1 Maternal Behaviour

Does rapidly form a bond with their young. Gubernick et al. (1979) reported that if a kid was taken away after only 5 minutes of contact post-partum, an hour later does could not discriminate between their own or a foreign kid, with the majority accepting both. Gubernick (1980) conducted a similar study where does were allowed to interact with their own kid for 5 minutes after birth and were either allowed to smell and lick their kid or were not. Allowing the doe to lick the kid was to test if "labelling" occurs by the transfer of their own rumen microflora. After 1 hour of separation, the majority of does accepted both their own and a foreign kid, irrespective of whether they had been able to lick the kid. When does were permitted to interact with their kid for 4 hours, then isolated from the kid for 15 minutes, all does accepted their own kids and the majority rejected foreign kids (regardless if they had been "labelled" or not; Romeyer et al., 1993).

Other studies have supported that the maternal bond is established in the first 4 hours (Bordi et al., 1994; Poindron et al., 2003). These studies, unfortunately, did not break down the contact time further. As such, it is only possible to say that 5 minutes is not long enough to form a bond, but 4 hours typically is. Other work examining the importance of licking and nursing in forming the maternal bond has been confounded by kid age (e.g., some foreign kids were up to 36 h; Gubernick, 1981).

When kids were separated from their dam immediately after birth, but their dam was allowed to hear and smell them, the majority still accepted their own kids 4 hours later (Romeyer et al., 1993). Briefer et al. (2012) demonstrated that does remember their kids' vocalizations for up to a year post-weaning. Studies have verified that does depend on their kid's smell to identify them (Bordi et al., 1994; Poindron et al., 2003), but this must be done at a close distance (Poindron et al., 2003). Terrazas et al. (2003) showed that the majority of does were able to identify their 48-hour old kids' only by their bleats. Overall, maternal imprinting is complex: it involves a combination of senses and relies on the length of time the dam and kid spend together post-partum. It is clear that does do recognize their young and show aggression to unknown foreign kids that are within 3 metres of their own kid(s) (Allan et al., 1991).

It is important to note that maternal behaviour may be impacted by stress experienced during pregnancy; thus, effort should be made to minimize stressful events (e.g., adversive handling; Baxter et al., 2016).

1.3.2 Buck-Doe Relations

In feral goat herds, males are often observed separated from the group except during breeding season (Kilgour & Ross, 1980; McTaggart, 1971; O'Brien, 1988). There is a complex relationship between sex, age, horns, feed availability, and individual personality when determining hierarchy (Miranda-de la Lama & Mattiello, 2010). The hierarchy within the herd has a significant impact on mating dynamics and success.

Feral mating behaviour has been well documented, and the dominant male is usually seen to monopolize breeding with receptive females (Kilgour & Ross, 1980). The dominant buck will guard the females and threaten other males that approach but may allow younger bucks (≤6 months) in the vicinity (Kilgour & Ross, 1980).

The presence of bucks induces ovulation in does during breeding season, and doe hierarchy has an impact on when they will ovulate. Alvarez et al. (2003) reported that high-ranking does were the first to ovulate after exposure to bucks. This may be due to higher-ranking does spending more time with the bucks than those of a lower rank.

Observation in wild *Oreamnos americanus* herds (referred to as the mountain goat, but not directly related to *Capra* sp.), suggests that dominance is positively associated with age, and mating success is more likely to occur with an older, dominant male (Mainguy et al., 2008). Therefore, in commercial systems, the hierarchy of males should be considered when introducing bucks into groups of does. In small groups, younger/smaller bucks may receive more aggression; in larger groups, these bucks may have more mating success, as social interactions have been reported to decrease as group size increased (Andersen et al., 2011). Improved reproductive performance has been reported in buck to doe ratios between 1:5 to 1:20 and decreased performance when the ratio falls to 1:30 (Zarazaga et al., 2018). Unfortunately, the work only focused on reproduction, and the stress effects of different male to female ratios (including 1:1, sometimes used on high-value animals) were not measured.

1.3.3 Significance of Horns

Depending on the farming system, horns may be left intact (e.g., Angora) or be removed (e.g., dairy). Removal of horns is painful (see *Section 5: Painful Procedures*) and may be detrimental to the goat for other reasons, including reduced grooming capability (Zobel et al., 2019) and delayed establishment of hierarchy (e.g., horned dairy does engaged in less head-butting and chasing compared to hornless goats; Aschwanden et al., 2008a). Successful management of horned goats includes consideration for more space provision, particularly at the feedbunk. Generally, older large animals with horns occupy the highest hierarchy positions in the herd (Barroso et al., 2000; Rout et al., 2002). However, some studies have not found this link (Escós et al., 1993; Stears et al., 2014).

Horns play a role in mating behaviour. Females have been seen to rub their horns on the buck's neck and shoulders during courting (Shank, 1972). In wild and feral populations, large horned males have greater success during mating than younger small-horned males (Kilgour & Ross, 1980; Shank, 1972). Furthermore, horns may influence goat behaviour towards unfamiliar humans (Mersmann et al., 2016).

1.3.4 Grouping Size and Stability

When allowed to do so, goats naturally form small groups and have the capability to distinguish individuals; little is known about how goats experience large groups in confined spaces. Feral goats typically live in loose groups varying in size, ranging from 2 to 100, that may vary depending on several factors, including seasonality, feed availability, and definition of proximity used (Kilgour & Ross, 1980; Leidy et al., 2015; McDougall, 1975; O'Brien, 1988; Shank, 1972; Shi et al., 2005; Stanley & Dunbar, 2013).

Larger group sizes may be more susceptible to dissolution (Calhim et al., 2006). A study that observed social interactions between goats in various group sizes, with consistent space allowance, reported that both positive and negative interactions per goat decreased with increased group size (Andersen et al., 2011). Van et al. (2007) reported increased aggressive behaviour with increasing group size at an individual space allowance of 0.73m^2 in a study of 16-week-old Bachthao and Bachthao crosses. When management includes large groups, flat open pens without the opportunity to segregate into smaller groups (Zobel & Nawroth, 2020), and low space allowance, commercial housing will not promote social cohesion and the development and maintenance of bonds between individuals (Zobel et al., 2019).

In commercial systems, regrouping of animals is common (e.g., for breeding, entering the milking herd). However, regrouping has been reported to cause increased aggression and stress, affecting production (e.g., decreased milk yield; Fernández et al., 2007). Andersen et al. (2011) randomly chose pairs of goats to rotate between groups weekly for 7 weeks. When regrouped, there was an increase in aggressive behaviour that decreased after the first day. A study that assessed the effect of the presence of familiar goats during social confrontation with an unfamiliar group reported that the presence of peers reduced agonistic interactions and lowered cortisol levels of those being confronted (Patt et al., 2013a), suggesting that movement of individual goats should be avoided. Goats that were individually introduced to a group experienced agonistic interactions and displayed signs of stress. Groups should be kept as stable as possible, repetitive regrouping should be avoided, and newly introduced animals should be monitored (Miranda-de la Lama & Mattiello, 2010).

Isolation is a stressful experience. Even short periods (5 min) of isolation promote fear responses in kids (e.g., increased vocalization and rearing; Price & Thos, 1980). Stress due to isolation has also been reported in adult goats (Kaanan et al., 2002; Aschwanden et al., 2008b; Patt et al., 2013b). Miranda-de la Lama and Mattiello (2010) recommended that goats never be isolated, but if necessary, they should have olfactory, auditory, and visual contact with others.

1.3.5 Interaction with Peers

Keil et al. (2012) showed that goats discriminated between familiar and unfamiliar goats, even when their heads were not visible. Pitcher et al. (2017) suggested that goats use both stored information (e.g., memory), and current sensory cues (e.g., seeing another goat) when determining familiarity with an individual.

Observational studies of feral goats reveal normal interactions that goats have with their peers. In social groups, the dominant female often initiates group activity (Escós et al., 1993; Kilgour & Ross, 1980). The physical environment will dictate how animals interact with one another (Kilgour & Ross, 1980). In open areas, the herd will maintain visual contact, but in bushy areas with limited visibility, animals will bleat to maintain contact.

Goats take cues from one another: they will look where other goats are looking (Kaminski et al., 2005). Feral goats have been observed to make an alarm snort to notify the group of a concern (Shank, 1972). Shrader et al. (2007) reported that goats relied on social cues to select feeding areas: when goats were able to watch others eat out of trays, they were able to identify which had the most feed.

Goats with positive bonds are preferred lying partners and have smaller individual distances at feeding (Aschwanden et al., 2008a). The strength of partner preferences varies based on the individual and the size of the group; partner preferences were measured from affiliative approaches between goats and provided strong evidence that goats seek out and remain close to specific goats (Stanley & Dunbar, 2013). This study revealed that a core group of 12 to 13 individuals formed a “clique,” and the authors suggested this was the maximum stable group size.

The hierarchy of the herd is maintained through continuous interactions. When group dynamics are disturbed, these interactions will be physical (e.g., clashing, butting); however, once hierarchy has been established, non-physical interactions will dominate (e.g., approaching with the intention to displace). Animals will approach each other to test one another: subordinate animals will often withdraw from confrontation, and higher-ranked animals will interact (Escós et al., 1993; Shank, 1972).

Play occurs in most species, more so in young animals, and its presence can be used as an indicator of environmental conditions (Oliveira et al., 2010) and the affective (emotional) state of animals. Animals are more likely to play when they are well cared for without stressful conditions. Adult goats are observed playing more when kids are present, and play behaviour includes thrashing horns in shrubs and running and jumping (Kilgour & Ross, 1980). Play behaviour in adult goats has been described as mock fighting for a short period (Patt et al., 2012). It should be noted that play is not isolated to peer-to-peer interactions: solitary play has been reported (Ajuda et al., 2020). While adult goat play has not been reported to take up a large portion of their daily activity, this does not indicate that it is not valued.

The methodology used when observing goat behaviour potentially underrepresents play in adults (Patt et al., 2012a). Although not investigated in goats, there is evidence in multiple species that early life enrichment has an impact on adult behavioural repertoire and its flexibility. For example, mice raised in an enriched environment have been reported to be more flexible behaviourally and have improved neurogenesis (Garthe et al., 2016). Therefore, there is potential that increased play behaviour would occur in adult goats if it were promoted and developed in kids. Zobel and Nawroth (2020) suggest that enrichment should be introduced at a young age in order to promote safe play and interactions during adulthood.

1.3.6 Interaction with Humans

Goats are sensitive to humans, taking cues and reading their body language. Goats will respond to simple gestures such as the way a person is directing their head (Nawroth et al., 2016a) and prefer indicators of positive human emotion (e.g., smiling faces; Nawroth et al., 2018). Nawroth et al. (2016b) demonstrated that goats learned to detour around an obstacle faster when a human demonstrated how to do so. Goats will choose to position themselves where they are more likely to be seen by humans (Nawroth & McElligott, 2017), demonstrating that they recognize the potential benefits of interacting with a person. However, this may be linked to socialization (e.g., Mastellone et al., 2020, reported that social interactions with humans was positively linked to how much previous human exposure they had).

Positive human-animal interactions provide production (e.g., milk production and reproductive performance) and behavioural (e.g., calmer animals) benefits in a number of species (e.g., dairy cattle and pigs; Ebinghaus et al., 2018; Hemsworth & Barnett, 1991; Hemsworth et al., 1989; 2000). In goats, handling quality during pregnancy impacts placental traits, pregnancy success, and maternal behaviours (Baxter et al., 2016). Jackson et al. (2007) reported that gentle handling of goats decreased their stress and had a positive impact on their health (i.e., increased heart girth) and habituated them faster to a human presence. Given the degree to which goats connect with people, positive human-goat handling and interactions in commercial farming systems are important.

1.3.7 Non-Social Cognitive Capabilities

Goats have developed cognitive abilities to thrive. These abilities allow goats to navigate spatially and identify peers (Zobel & Nawroth, 2020), as well as avoid predators and assist in foraging (Zobel et al., 2019). Yet stereotypies (non-functional behaviours associated with boredom) are seen on farms (Anzuino et al. 2010), suggesting that these cognitive capabilities are not being met in such systems.

Cognitive capabilities of goats have been widely demonstrated. Langbein (2012) demonstrated that goats could successfully learn a Y-maze and recall how to complete the maze 3 months later. Watson and Binks (2019) suggested that ungulates that possess elongations of the distal CA1 (hippocampal components related to spatial learning) have an enhanced capacity to integrate complex topographical features into their spatial navigation; goats have these elongations. Goats readily learn how to interact with devices outside of what they would encounter in nature (e.g., manipulate a screen; Briefer et al., 2014). Using such a device, Meyer et al. (2012) demonstrated that Nigerian dwarf goats learned that that when they saw certain symbols and pressed a button, they would get a reward; the goats were able to distinguish novel symbols as well.

Goats are able to use inference to solve problems. When Nawroth et al. (2014) provided goats with a choice between 2 containers (only 1 of which contained feed), goats were able to determine where the feed was located by not only seeing a full container but also by seeing the empty container. Earlier stages of object permanence skills were also observed in kids (Vas et al., 2019).

When goats were trained to operate a device to receive a reward, goats continued to operate the device even when the reward was freely offered (Langbein et al., 2009). This demonstrates that goats are driven to partake in cognitive challenges. Boredom is a welfare concern and providing enrichment in the form of cognitive challenges is encouraged (Meagher, 2019).

1.3.8 Promoting Natural Behaviours

Increasing the complexity of goat housing has behavioural and cognitive benefits. By providing enrichment in both indoor and outdoor management systems, behavioural flexibility will be promoted (Zobel & Nawroth, 2020). Constant, non-demanding environments are known to reduce flexibility (Kihslinger & Nevitt, 2006; Price, 1999), making animals less resilient and less able to cope with challenges and management stressors. Providing early life enrichment appears to be especially important in many species (mice: Garthe et al., 2016; pheasants: Whiteside et al., 2016; salmon: Salvanes et al., 2013). For goats, regardless of age at exposure, physical enrichment has been associated with steeper learning curves in comparison to those raised in barren environments (Oesterwind et al., 2016). Goats that were raised in a feedlot setting with objects to climb and to play with (i.e., suspended pipes and containers) grew faster than those that were not raised with enrichment (Flint & Murray, 2001; however it should be noted that both groups had poor growth rates). Fighting and competitive behaviours have been reported to decrease when enrichment is available (Gomes et al., 2018). Therefore, providing more enrichments that promote natural behaviour in commercial goat farming systems may help create more resilient individuals that can cope better with management (e.g., regrouping, handling).

1.4 Future Research

1. Goats' preference for elevated surfaces presents an opportunity for using multi-level environments; research is needed to determine how these environments should be organized.
2. Research is needed on doe preference to hide at kidding in commercial systems (e.g., self-isolation in partitions or hides).

3. Different combinations of flooring must be explored to determine benefits (behavioural and economical) of goats' preferential bedding/flooring use.
4. Physical and cognitive benefits of providing outdoor space in commercial settings are not yet quantified.
5. Research is needed to explore the impact of buck to doe ratios on behaviour, performance, and welfare.
6. Research is needed to assess the influence of smaller group sizes on behavioural and production measures, as well as practical options for implementing choice for goats to segregate into smaller group sizes.
7. Goat enrichment needs to be explored, including the impact of early life exposure. Preference testing is needed to determine what enrichment goats prefer and which options best utilize and promote their cognitive capabilities.

1.5 References

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2 Lameness Due to Poor Hoof Care and Nutritional Diseases

Conclusions

1. **Goats' hooves are worn by routine movement in conjunction with grazing, browsing, and other natural behaviours and depending on the terrain. This wear may be sufficient to mitigate the need for trimming; if not trimmed, adult hooves will grow approximately 4–5 mm a month. The required frequency of hoof trimming to maintain a healthy foot is determined by many environmental and nutritional factors that affect hoof growth.**
2. **Good foot health is positively associated with improved animal performance and reduced morbidity and mortality.**
3. **The housing environment and equipment used in foot trimming can transmit pathogens associated with foot disease between animals.**
4. **Optimal hoof health cannot be maintained without proper hoof care, including keeping the foot properly trimmed and balanced. Failure to do so, or improper or aggressive trimming, will increase the risk of foot disease.**
5. **Lameness may also be due to disease or injury of the limbs and spine of the goat; disease may be infectious or nutritional.**
6. **Poor feeding management of high energy diets increases the risk of lameness due to acute and chronic laminitis.**

2.1 Introduction

Lameness is painful. It is often characterized by an altered stance or gait (Cottom & Pinsent, 1988). The ability animals to exhibit natural behaviour is compromised with increasing lameness severity (Whay & Shearer, 2017). Goats that are lame have lower milk production (Christodoulopoulos, 2009; Warnick et al., 2001), decreased daily activity levels (O'Callaghan et al., 2003), and increased risk of culling (Booth et al., 2004). When severe, animals that are lame reduce feeding time and increase lying time; thus, there may be a loss of body condition (Hodgkinson, 2010). Low body condition score (BCS), regardless of the cause, has been associated in many studies with poorer productivity, including lower kid survival. Sharma et al. (2018) reported that higher BCS does exhibited fewer antagonistic behaviours at feeding, had significantly higher milk yield, and had significantly lower disease incidence than lower BCS does. Regardless if a lame animal shows physical or production limitations, lameness is known to cause pain; if left untreated, painful conditions result in suffering, therefore early identification and treatment, including pain mitigation, are important (Whay & Shearer, 2017).

The degree to which an animal is lame is typically assessed using a locomotion scoring system. In goats, there have been various systems developed (see *Table 2.1*): each has advantages and disadvantages (e.g., 2- or 3-point scoring systems are easier to use, but exclude mild lameness, while 4- and 5-point systems require more training but better identify gait abnormalities). Pressure-sensing walkway systems have been used to assess the gait, stride, ambulatory forces, and weight-bearing abnormalities in goats (Rifkin et al., 2019). However, such technologies are not realistic for on-farm use. On-animal devices (e.g., accelerometers) have demonstrated that overgrown hooves limit doe activity around kidding (Zobel et al., 2016); however, no devices are commercially available.

Gait scoring of the herd is an essential first step to identify lame animals, followed by examining the animal, including the limb and foot, for the cause of the lameness (Deeming et al., 2018; Hill et al., 1997). Causes of lameness can be classified as: 1) physical (e.g., injuries), 2) environment (e.g., wet or heavily contaminated bedding), 3) nutritional diseases (e.g., mineral or vitamin imbalances), 4) infectious diseases, or 5) overgrown (e.g., deformed hooves or damaged from improper trimming) (Anzuino et al., 2010; Caroprese et al., 2009; Christodoulopoulos, 2009; Kaler et al., 2010; Nonga et al., 2009; Smith & Sherman, 2009). Lameness may worsen when goats are housed with high stocking densities (Kaler & Green, 2009). Foot trimming practices and nutritional causes of lameness are discussed in this review.

Table 2.1 Description of locomotion scoring systems available for goats.

	Locomotion scoring system			**Assessment criteria**			
Category	**2-point**	**4-point**	**5-point**	**Willing to move forward**	**Weight-bearing**	**Head nodding**	**Description**
Normal gait	0	1	1	Yes	Yes	No	Even gait, walking unhalted.
Uneven gait	0	N/A	2	Yes	Yes	No	Short stride, stiff gait, or swinging of hoof.
Mild lameness	0	2	3	Yes	Yes	Maybe	Mild limp. Affected limb not readily identifiable.
Moderate lameness	0	3	4	Reluctant	Reluctant	Yes	Moderate limp. Affected limb(s) identifiable.
Severe lameness	1	4	5	Unwilling	Unable	Yes (severe)	Severe limp. May walk on knees or walking with limbs stretched and not bending joints (i.e., goose-stepping).

Modified from Deeming et al. (2018) and derived from Anzuino et al. (2010), Battini et al. (2015), and Deeming et al. (2018).

2.2 Hoof Health

2.2.1 Normal Hoof Growth and Consequences of Overgrown Feet

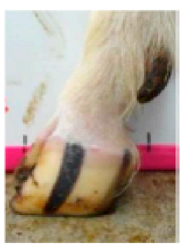
In a healthy hoof, the horn grows distally from the coronary band. The claw of the goat has a weight-bearing hoof wall that surrounds the distal phalanx and protects the concave sole that connects with the heel bulb (Kaneps, 1996). Normal wearing on hard surfaces will keep excess growth to a minimum.

When the horn is not worn down and excess growth accumulates, the hoof wall will curl under the foot, trapping material against the sole (Cottom & Pinsent, 1988). This growth creates a cavity between the claw and the sole that can fill with dirt, fecal material, and contaminated bedding, and produces a moist environment for infection to develop. Similarly, overgrowth of the inner walls may allow entrapment of dirt and fecal material in the interdigital cleft. The toe will elongate, forcing the weight of the goat back onto the heel, resulting in bruising of the sole and abnormal strain on the ligaments and tendons of the foot (Smith & Sherman, 2009). Chronic malformation of the foot will result in inflammation and permanent damage to distal limb structures. If the overgrown horn breaks or cracks, there is an increased risk of dirt and feces gaining access to the sensitive part of the foot and creating foot abscesses (Smith & Sherman, 2009; Williams, 1990).

2.2.2 Effect of Trimming on Foot Health

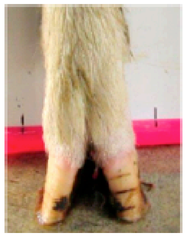
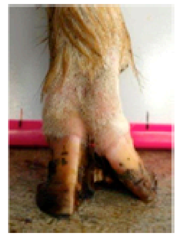
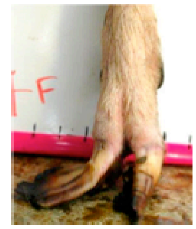
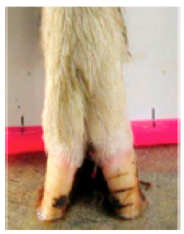
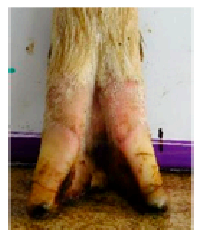
While foot trimming is viewed to be beneficial on reducing lameness, some researchers reported that increased frequency of foot trimming in small ruminants was associated with higher levels of lameness (goats: Hill et al., 1997; sheep: Kaler & Green, 2009). This may be because lame animals may be more frequently trimmed, or it may be that trimming, in the face of lameness, is not always beneficial. This is true when sheep with footrot are aggressively trimmed (Wassink et al., 2010).

Claw length is positively correlated with claw deformation, and the length and proportion of the animal's claws that are deformed is positively correlated with lameness in that animal (Ajuda et al., 2019). It should be noted that this study had limitations (e.g., small sample size, weak statistical methodology); nonetheless, it is currently the only peer-reviewed study noting this correlation. While developing a scoring system for evaluating claw deformation, Deeming et al. (2019a) demonstrated that a large proportion of hooves in commercial dairy systems have some level of conformation abnormality, including overgrown hooves, dipped heels, splayed claws, misshapen claws, and dipped fetlocks (see *Figure 2.1* and *Figure 2.2*). However, these authors did not report trimming frequency of these goats, so hoof care cannot be linked to these conformation issues. Furthermore, Ajuda et al. (2014) used thermography to measure inflammation in overgrown and deformed goat claws before and after trimming. There was a significant decrease in inflammation detected 15 days after trimming, indicating that trimming overgrown claws decreased inflammation. Trimming is a tool to diagnose the cause of lameness, remove loose horn, correct overgrown feet, and maintain normal conformation as long as it is done without damaging underlying structures or trimming to blood (Smith & Sherman, 2009; Winter, 2011).

Hoof Aspect	Ordinal Score		
	0	**1**	**2**
Toe length	 **Toe is not overgrown** Length of the toe is less than half of the length of rest of the hoof	 **Toe is moderately overgrown** Length of the toe is greater than half, but less than the full length of the rest of the hoof	 **Toe is severely overgrown** Length of the toe is greater than the full length of the rest of the hoof
Heel shape	 **Heel is upright** Not walking on heel, coronet band parallel to ground	 **Heel is moderately dipped** Not walking on heel, but coronet band is angled towards the ground	 **Heel is severely dipped** Walking on heel, coronet band angled sharply towards the ground
Fetlock shape *	 **Fetlock is upright and straight**	 **Fetlock is dipped towards the ground** Bony lump on pastern may be apparent	

* Fetlock scored as binary 0 or 1.

Figure 2.1 Assessment of goat hoof conformation with the use of an ordinal scoring system. Deeming et al. (2019a) The development of a hoof conformation assessment for use in dairy goats.

Hoof Aspect	Ordinal Score		
	0	1	2
Claw shape	 **Both claws are straight**	 **One claw is bent/twisted** either away or towards the midline of the hoof	 **Both claws are bent/twisted** either away or towards the midline of the hoof
Claw splay *	 **Claws are not splayed** the distance between the axial edge of the distal tip of both claws are approximately <2 horizontal marks on the whiteboard	 **Claws are moderately splayed** the distance between the axial edge of the distal tip of both claws are approximately >2 and <3 marks on the whiteboard	 **Claws are severely splayed** the distance between the axial edge of the distal tip of both claws are >3 marks on the whiteboard

* Claw splay only scored if claw shape scored as 0.

Figure 2.2 Assessment of goat claw shape with the use of an ordinal scoring system. Deeming et al. (2019a) The development of a hoof conformation assessment for use in dairy goats.

2.2.3 Frequency of Trimming

Feral goats and those raised in extensive systems are thought to wear down their feet on rough surfaces (Williams, 1990). Natural wearing occurs due to the surface on which they spend time, as well as activity; in an alpine environment, milking goats that travelled approximately 3 km in a 24-hour period had convex, solid yet spongy hoof soles and toes that were similar in length to a recently trimmed hoof, despite the hooves not being trimmed for at least 5 months (Zobel et al., 2019). However, goats raised in intensive systems are usually kept on soft surfaces, such as straw or wood shavings, that do not allow for natural wear; thus, routine hoof trimming is required to prevent hoof overgrowth (Cottom & Pinsent, 1988; Groenevelt, 2017; Nonga et al., 2009; Smith & Sherman, 2009; Williams, 1990). While research has focused on goat preference for different flooring (e.g., hard surfaces over straw and shavings: Bøe et al., 2007; Sutherland et al., 2017), the best flooring and bedding for foot health in intensive goat operations has not been examined.

Healthy feet can improve an animal's health and productivity, which increases profit for the producer and reduces the cost for treatment (Koluman-Darcan, 2016). Ibrahim et al. (2018)

compared the effect of trimming in sheep to a control non-trimmed group. The trimmed group had a significant increase in walking, feeding, drinking, and rumination time, and a significant decrease in gait score and serum cortisol levels when compared to the control group. This is supporting evidence that, in sheep, maintaining proper hoof shape and length is critical to prevent lameness due to foot disease; no such work has been conducted for goats.

Suggested trimming frequency ranges from every 6 to 8 weeks (Cottom & Pinsent, 1988) for show goats, to twice a year (Koluman-Darcan, 2016; Smith & Sherman, 2009). However, Groenevelt (2017) stressed that regular trimming is vital to prevent overgrowth and maintain claw shape, and that the frequency of trimming is dependent on several factors such as housing, nutrition, and footing. While Winter (2008) does not recommend routine trimming of healthy feet of sheep other than to remove the severely overgrown horn, these recommendations were in reference to animals raised in the United Kingdom, where most of their time was on pasture, allowing for natural wear. Although sheep foot health literature is often referenced, goats have a different natural habitat, feeding preferences, and foot anatomy than sheep. Therefore, recommendations made for sheep may not translate effectively to goat management (Groenevelt, 2017). Indeed, recently Deeming et al (2019b) found that trimming 3 times a year was not sufficient to prevent overgrowth and changes in internal hoof angles.

2.2.4 Trimming Methods

Trimming may need to be adjusted for different breeds, as hoof variables can vary between breeds (Azarpajouh et al., 2018). Koluman-Darcan (2016) measured hoof differences between dairy and meat goat breeds and reported that there was a significant positive correlation between the length of the hoof (measured from the area between the skin and cornet band to the distal end of the dorsal wall) and body weight. Heavier meat breeds had greater hoof height, measured from the coronet to the vertical point of the sole, than lighter dairy breeds.

In severe lameness cases, pain mitigation treatment is needed, along with corrective trimming (Winter, 2011). Pain mitigation should be used under the advice of the herd veterinarian, and meat and milk withdrawal times must be followed. When trimming, proper equipment should be used, such as small secateurs and a hoof knife, and kept sharp (Cottom & Pinsent, 1988). Equipment disinfection is essential between animals to avoid disease transmission (Christodoulopoulos, 2009; Groenevelt, 2017; Winter, 2011).

To avoid transmission of foot pathogens between animals, a well maintained dry area should be used to gather animals for trimming (Groenevelt, 2017; Winter, 2011). Goats may be held in a standing position to have their feet trimmed. A flip cradle or tilt table may also be used as long as the animal is held securely with minimal discomfort (Cottom & Pinsent, 1988; Williams, 1990). The aversiveness of these tables has not been assessed.

It is recommended to shape the sole from heel to toe, allowing for proper alignment of the third phalanx (Cottom & Pinsent, 1988). To start, all overgrown hoof wall is trimmed to the level of the sole and the heel, and the angle of the weight-bearing surface of the wall is parallel to the coronary band when the animal is standing squarely (Smith & Sherman, 2009). To allow for even wear, both heel bulbs must be the same height (Cottom & Pinsent, 1988).

Excessive trimming of the toes to blood causes severe damage (Smith & Sherman, 2009); it can also damage the sensitive laminae which fail to properly heal, potentially leading to the formation of toe or sole granulomas (Groenevelt, 2017; Hodgkinson, 2010; Winter, 2008, 2011). However, it should be noted that cause of these extremely painful lesions is not well understood. While trimming, care should be taken to inspect the sole as well as wall, heel bulb and between the toes: This will ensure identification of bruising, areas of necrosis, and/or infection. Individual animal records are instrumental for appropriate follow-up and monitoring.

2.3 Nutritional Causes of Lameness

Nutrition and feeding management have a significant impact on animal health, including hoof, skeletal, and joint conditions. Adequate proportions of minerals and vitamins in the feed are essential to meet the animal's nutritional needs. For example, goat diets are recommended to have a calcium (Ca) to phosphorus (P) ratio from 1.5:1 to 2:1 (Smith & Sherman, 2009). Mineral excess, deficiencies, and disproportioned ratios can have a significant adverse impact.

2.3.1 Laminitis

Laminitis is the inflammation of the sensitive laminae of the hoof, the tissues responsible for forming new hoof tissue and maintaining the integrity of the hoof and underlying structures (Smith & Sherman, 2009). Numerous endotoxemic and septicemic conditions have been connected to laminitis, such as mastitis or metritis (uterine infection; Cottom & Pinsent, 1988; Kaneps, 1996; Smith & Sherman, 2009). Often laminitis is a consequence of poorly regulated intake of a high energy diet causing a temporary drop in ruminal pH to acidic levels, known as subacute ruminal acidosis (SARA; Cottom & Pinsent, 1988; Groenevelt, 2017; Groenevelt et al., 2018; Kaneps, 1996; Zhang et al., 2018).

In cases where animals are fed a high energy diet, are exhibiting signs of lameness, and may be at risk of bouts of SARA, laminitis should be considered (Groenevelt et al., 2015). The risk of SARA must be minimized when feeding high energy diets; this requires feeding the diet frequently throughout the day and assuring adequate intake of forage as a fibre source at the same time. This can be done feeding a well-formulated total mixed ration or feeding small volumes of grain 4 to 5 times a day along with ad libitum access to high-quality forage. This reduces the risk of digestive upsets and overgrowth of bacteria that produce lactic acid. All feed changes should be done slowly to allow rumen microflora to adapt (Smith & Sherman, 2009).

In SARA, the levels of lipopolysaccharides, volatile fatty acids, and lactic acid will increase (Zhang et al., 2018). An increased level of lipopolysaccharides prompts an inflammatory response. The blood vessels in the hoof laminae will spasm, causing anoxic damage to those tissues they feed (Cottom & Pinsent, 1988; Smith & Sherman, 2009; Zhang et al., 2018). This damage to the laminar tissue leads to abnormal hoof growth and poor hoof quality. This acute inflammation and the subsequent damage of the hoof is an important cause of lameness (Groenevelt, 2017; Groenevelt et al., 2018; Smith & Sherman, 2009).

Acute laminitis in an individual is often not easily noticed (Cottom & Pinsent, 1988), which demonstrates the need for routine and diligent gait scoring. Signs of acute laminitis are more noticeable if goats are allowed to walk normally and not rushed; goats will demonstrate an unwillingness to walk and a preference for recumbency, and there will be physical evidence such as swelling and heat over the coronary band (Cottom & Pinsent, 1988; Smith & Sherman, 2009; Zhang et al., 2018).

In chronic laminitis, a result of repeated bouts of SARA or other inflammatory causes, the damage to the sensitive laminae causes a loss of integrity between the hoof wall and laminae. Without that integrity, the flexor tendons attached to the back of the distal phalanx rotate the bone, so it is angled downward. Chronic laminitis may be identified by an increased rate of hoof growth that is abnormal, resulting in long toes and heels, with the wall often deformed with growth rings (Cottom & Pinsent, 1988; Kaneps, 1996; Smith & Sherman, 2009). The quality of the hoof keratin is poor and flakey, leading to gaps in the white line and cracks in the wall, which both allow entry of dirt and gravel, resulting in foot abscesses. The animal may walk on their knees or place their hind feet forward under the body (Smith & Sherman, 2009) and walk with a "goose-step" (where the front legs are forced stiffly in front of the goat as she walks). Heat is usually not felt on the affected feet. Repeated and frequent trimming is used to correct abnormal foot conformation; however, trimming will not correct the misalignment of the distal phalanx (Groenevelt et al., 2018; Smith & Sherman, 2009).

2.3.2 Osteomalacia of Kids (Rickets)

Rickets is characterized by inadequate calcification of the bones and epiphyses (i.e., growth plates) in growing animals resulting in deformed joints, particularly of the carpi (i.e., knees), enlargement of the costochondral joints (i.e., ribs), curvature and lordosis of the spine, and abnormally angled long bones (Smith & Sherman, 2009; Yousif et al., 1986). Subclinical rickets often does not have any clinical signs aside from anorexia and diminished growth.

Rickets is often seen in fast-growing kids when the diet is deficient in Ca and/or P, and when there is also a deficiency in vitamin D (Cottom & Pinsent, 1988; Smith & Sherman, 2009; Yousif et al., 1986). It is more likely to be seen in housed kids or kids reared at pasture where the climate is frequently cloudy or foggy, and there is little to no supplementation of vitamin D in the diet.

2.3.3 Osteomalacia of Adults

Osteomalacia, due to poor mineralization of mature bones, is a rare condition that occurs in older goats that are fed a diet low in P in relation to Ca (Cottom & Pinsent, 1988) and that have vitamin D deficiency. Goats often have stiff, painful joints in their limbs and may have bending of the long bones, usually the forelimbs.

2.3.4 Osteodystrophia Fibrosa

Osteodystrophia fibrosa is mostly seen in growing animals fed a diet low in Ca and high in P, such as a diet of grain and bran (Andrews et al., 1983; Cottom & Pinsent, 1988; Smith & Sherman, 2009). Corn silage and cereal-based hays are also low in Ca. Hyperphosphatemia suppresses Ca, causing hypocalcemia that stimulates parathyroid hormone (PTH) release. Increased PTH levels intensify renal resorption of Ca and P and encourage Ca resorption from the bone (Aslani et al., 2001; Smith & Sherman, 2009).

The bones become soft and rubbery, often affecting the facial bones, possibly affecting the animal's ability to eat. The vertebrae and lower limbs can also be affected, causing joint swelling, bending of the long bones, and a stiff gait (Andrews et al., 1983; Aslani et al., 2001; Cottom & Pinsent, 1988; Smith & Sherman, 2009). If diagnosed early, damage can be reversed by correcting the Ca-to-P ratio in the diet.

2.3.5 Nutritional Osteopetrosis

Nutritional osteopetrosis occurs when the diet is high in Ca relative to P (Cottom & Pinsent, 1988; Smith & Sherman, 2009). Osteopetrosis is usually seen in bucks fed a diet intended for lactating does for an extended period. This results in the over-calcification of the animal's skeleton resulting in enlarged joints, restricted joint movement, and a stiff gait.

2.3.6 Enzootic Ataxia (Swayback)

Enzootic ataxia occurs in young kids from birth up to 4 months of age but is a result of the dam being fed a copper-deficient diet while pregnant. The risk may extend into the early neonatal period depending on the post-kidding diet of the dam (Cottom & Pinsent, 1988). The copper deficiency may be primary (i.e., insufficient in the diet) or secondary (i.e., diet has high levels of competing minerals). The age of onset of clinical signs in kids is related to the length and severity of the deficiency during gestation and the early post-partum period. In severe cases, kids are born affected: They are weak, may be unable to rise unassisted, and have muscle tremors with uncontrolled head shaking (Cottom & Pinsent, 1988; Smith & Sherman, 2009). In the delayed form, kids are born without clinical signs but develop paresis most commonly between 1 week and 28 days of age; however, they may develop the disease up to 4 months of age. Initial signs include weakness, tremors, difficulty rising, and incoordination. Long bones may be deformed as well. Paresis is always symmetrical and initially affects the hind limbs. Weakness may progress to all limbs and kids will be reluctant or unable to stand. The diagnosis is confirmed on postmortem where sections of the white matter of the spinal cord and sometimes cerebellum are demyelinated. Serum copper levels of gestating does and newly affected kids (not correctively supplemented) can aid the diagnosis. There is no effective treatment of affected kids. Prevention must be done by assuring proper mineral supplementation of does during pregnancy and early lactation.

2.3.7 Selenium Toxicity

Selenium (Se) toxicity is usually seen in kids (up to 3 months of age) born to dams fed a diet excessive in Se (>5 mg/kg), or in kids injected with too much Se (≥0.40 mg/kg; Cottom & Pinsent, 1988; Smith & Sherman, 2009; Żarczyńska et al., 2013). Signs may be sudden death (usually occurs when injected with too much Se) or more chronic. Affected kids lose their coordination, develop a stiff gait, have swelling of the coronary band, and may slough their hoof (Cottom & Pinsent, 1988; Kaneps, 1996). Older goats exposed to toxic levels of Se may develop cracking and peeling of the hoof wall (Kaneps, 1996). In Canada, levels of Se in the feed are regulated. There are a few locations in Canada where soil Se levels may be high, however (CCME, 2009). Selenium deficiency can also have an impact on goat health.

2.3.8 Nutritional Muscular Dystrophy (White Muscle Disease)

Nutritional muscular dystrophy is usually seen in 3 to 6-week-old kids due to a dietary deficiency of Se and/or vitamin E (Cottom & Pinsent, 1988; Smith & Sherman, 2009). Selenium deficiency is associated with deficient soils in the area, which impacts the Se content of local feeds (Smith & Sherman, 2009). Vitamin E (alpha-tocopherol) levels are high in green forages, but levels decline rapidly once those forages are harvested and stored. Animals fed on stored feeds must be supplemented with vitamin E.

Deficiency in Se and vitamin E reduces the animal's ability to clear the damaging effects of free radicals from normal oxidative reactions in the body. These compounds accumulate, resulting in muscle necrosis of the most active muscles (Smith & Sherman, 2009). Muscles affected usually appear white or gray at postmortem.

In its acute form, kids suddenly die during or after exercise (Cottom & Pinsent, 1988). In its subacute form, kids display respiratory distress, stiffness, limb trembling, and weakness, and are unable to stand (Cottom & Pinsent, 1988; Smith & Sherman, 2009; Żarczyńska et al., 2013). In the subclinical form, kids fail to thrive or grow properly (Smith & Sherman, 2009).

Deficient areas should anticipate Se or vitamin E deficiencies and supplement in feed or give doses prophylactically (Smith & Sherman, 2009). While parenteral administration of Se is frequently done, the levels drop quickly and may be subtherapeutic in as little as 2 weeks. Vitamin E injections are not considered adequate after 3 to 5 days. It is much preferred to supplement the ration with adequate levels of Se and vitamin E daily to the gestating and lactating does. Selenium will cross the placenta to the developing fetuses. Vitamin E will pass into the colostrum and milk, properly supplementing the nursing kid. Kid rations may also be formulated to deliver the correct amount of Se and vitamin E on a daily basis.

2.4 Future Research

1. The effect of flooring and bedding on foot health and trimming frequency must be established.
2. There is little research on the relationship between trimming frequency and foot health in a controlled setting.
3. Endpoints are needed for determining when a lame goat should be euthanized.
4. Research on causes of lameness (including the multfactoral causes of granulomas lesions, SARA, and specific pathogens) is needed.

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3 Space Allowance

Conclusions

1. **Goats prefer to lie apart without body contact with other animals.**
2. **Goats prefer to lie against a wall as opposed to an open area.**
3. **As the number of waterers per animal decreases, drinking time, competition, and aggression increase.**
4. **As the number of animals per feeding space increases, the time spent feeding decreases, the time spent waiting for feed increases, and aggressive behaviours may increase. These effects are most pronounced in restricted feeding systems and may be less pronounced when goats are fed ad libitum.**
5. **The adverse effects of reduced feeding space (such as decreased feeding time) are more pronounced in socially low-ranking goats compared to high-ranking goats.**
6. **Goats will form small groups if given the opportunity.**
7. **Goats are flexible space users; it is part of their natural behaviour to climb, go outside, and seek shelter if given the opportunity.**
8. **Vertical space allowance in housing layout positively influences goat behaviour.**

3.1 Introduction

The amount and type of space provided affect goat health and behaviour. Space allowance refers to the amount of space/animal, while stocking density refers to the number of animals/unit area. Assessing goat behaviour in their natural environment and at different space allowances has allowed identification of some goat preferences. High stocking densities affect the quality of the environment (e.g., high ammonia levels, higher pathogen loads), which can negatively impact goat health (Muri et al., 2013; Toussaint, 1997).

Proper feed bunk and waterer space allowances are essential to meet goats' physiological demands and support optimal performance. There are many factors that must be considered when determining space allowance, such as animal size, feeding management, social behaviour, barn design, and layout. This review concentrates on goat-centered studies, as goats utilize their space differently from other livestock.

3.2 Housing Space Allowance

A number of studies and extension services have made recommendations for housing space allowance (see *Table 3.1*). Only one extension service document stated peer-reviewed sources. Recommendations from peer-reviewed studies are based on the space allowances explored, and it is unknown how other space allowances might affect goat health and behaviour.

A survey of Ontario dairy goat producers in 2015 reported housing space allowances ranging from 1.20 m^2 to 4.21 m^2/animal for doelings (<1 year old) to adult bucks, respectively

(Oudshoorn et al., 2016). However, these values may not represent actual farm practices as they were self-reported and only 37/216 eligible Ontario producers participated.

The focus on specific breeds, age groups, production stage or the use of dehorned goats in these studies makes generalizations challenging. Therefore, where available, the breed, age, weight, production stage, and horned/dehorned status of goats studied will be specified.

3.2.1 Housing Space Allowance and Social Behaviour

Space allowance and stocking density affect social interactions and lying behaviour. When overcrowded, animals exhibited greater aggressive behaviours and less positive interactions (Toussaint, 1997; Vas et al., 2013). Specifically, the most frequent antagonistic behaviours were recorded at 1.0 m^2/goat and the lowest at 3.0 m^2/goat, but antagonistic behaviours were still displayed at 2.0 m^2/goat (pregnant, dehorned Norwegian dairy goats, 2–5 years; 36.4 to 68.5 kg; Vas et al., 2013).

In contrast, aggressive behaviour was not significantly affected in either horned or hornless goats when the space allowance was decreased from 2.0 m^2 to 1.0 m^2/goats in a study with various dairy breeds (2–4 years old, in late gestation; Loretz et al., 2004).

Although Toussaint (1997) is often referenced for a minimum housing space allowance of 1.5 m^2/animal, science-based evidence to support this is not provided.

3.2.2 Housing Space Allowance and Lying Behaviour

Lower stocking density (i.e., greater housing space allowance) may enable goats to utilize more space and maintain space preferences between animals. Vas and Andersen (2015) demonstrated that pregnant, dehorned Norwegian dairy goats (2–5 years; 36–69 kg) maintained greater inter-animal distances when given 2.0 m^2 or 3.0 m^2 compared to 1.0 m^2/goat, although distance remained unchanged at allowances of 2.0 m^2 and 3.0 m^2/goat, suggesting a threshold density between these two values, possibly because of social cohesion or antipredator strategy. In contrast, distance between lying animals was not affected by pen size (ranging from 1.0 m^2 to 2.0 m^2) or presence of horns in various dairy breeds (2–4 years old, late gestation) but at 1.0 m^2 hierarchically lower ranking goats spent significantly less time lying than higher-ranked goats (Loretz et al., 2004). Similarly, adult Norwegian goats spent more time resting when housing space allowance was 0.75 m^2 or 1.0 m^2/goat compared to 0.5 m^2/goat (Andersen & Bøe, 2007).

Vas and Andersen (2015) recommended higher space allowances for late gestation does based on observations that dehorned Norwegian goats rested significantly further from each other with increasing stage of pregnancy when given a space allowance of 3.0 m^2/goat. There was no difference in inter-animal distance based on the stage of pregnancy when goats were allocated 1.0 m^2/goat, however, late-pregnant goats moved significantly further from each other at 2.0 m^2/goat compared to early and mid-pregnant goats. These findings align with the natural distancing behaviour seen in extensively managed goats (Allan et al., 1991).

Andersen and Bøe (2007) observed that adult (1–4 years old), pregnant, dehorned Norwegian goats preferred resting against a wall (as opposed to an open area) and lying in contact with another was rare. However, at 0.5 m^2/goat, goats spent significantly less time resting against the wall as opposed to in an open area (Andersen & Bøe, 2007). In contrast, Loretz et al. (2004) found no significant difference in the frequency of in-contact resting (goats with or without horns, various dairy breeds, 2–4 years old, late gestation) at different space allowances (ranging from 1.0 to 2.0 m^2/goat). Aschwanden et al. (2008) determined that the extent of resting in contact with other goats depended on the strength of social bonds.

3.2.3 Housing Space Allowance Over Multiple Levels

Andersen and Bøe (2007) also investigated the effect of different space allowances at multiple levels in adult (1–4 years old), pregnant, dehorned Norwegian goats on lying space organization and resting behaviours. 2 levels/heights provided more opportunity to avoid body contact and reduced antagonistic behaviours between goats than did a single level with the same space allowance. Also, the duration of resting was more dependent on overall space allowance than on the presence of multiple levels. For more details on multi-level space used see *Section 1: Natural Behaviours*.

3.2.4 Housing Space Allowance and Outdoor Access

Housed goats will spend time outside if given the option (Freeman, 2018). Therefore, providing outdoor access can increase space allowance (Bøe et al., 2012). Stocking rate on pasture was positively associated with time spent grazing and negatively associated with time spent being idle, possibly because increased stocking rates limited available pasture, so goats had to travel further to eat enough forage (Animut et al., 2005).

3.2.5 Housing Space Allowance and Group Size

Most stocking density literature focuses on typical commercial herd sizes. When allowed to do so, goats naturally form small groups (Stanley & Dunbar, 2013). For more information on goat group size preferences, see *Section 1: Natural Behaviours*.

Table 3.1 A summary of space allowance recommendations in studies or extension publications.

Reference	**Document type**	**Age/Production stage**	**Space allowances recommended (m^2/animal)**
Cull (1988), *Goat Veterinary Society Journal*	Peer-reviewed	Adult does	Individual pens = 1.80–3.00 Loose housing = 1.60 Tied stalls = 1.00
		Young stock	Individual pens = 1.2–2.00 Loose housing = 1.0
		Bucks	Individual pens = min 4.00
Toussaint (1997), *Livestock Production Science*	Peer-reviewed	≤30 d	0.20
		≥7 mo	Open housing with yard = 1.50 Stall housing = 0.50
Vas et al. (2013), *Applied Animal Behaviour Science*	Peer-reviewed	Adult does	>1.50
Vas and Andersen (2015), *PLoS ONE*	Peer-reviewed	Adult does	At least 1.00–2.00
CARC (Canadian Agri-Food Research Council) (2003)	Guideline	Adult does	1.10–1.70
		Adult bucks	2.80–3.70
		Kids >30 kg	0.70–0.90
		Kids <30 kg	0.30–0.50
Tarr, ShurGain Nutrifax	Extension	Artificially milk-fed kids	0.30–0.50
		Feeders	0.60
		Nursing does with 1–3 kids	1.20–2.50
		Dry does	1.00
		Pregnant does	1.50
		Bucks	2.50–4.0
University of Massachusetts Extension	Extension	Does	Loose housing = 0.90–1.40 Additional exercise space = 2.30 Group housing = 1.40 Individual pens = 0.50

Reference	**Document type**	**Age/Production stage**	**Space allowances recommended (m^2/animal)**
		Kidding area	1.20 m x 1.50 m
Schoeninan (1999), University of Maryland Cooperative Extension	Extension	Kidding area	1.20 m x 1.50 m
		Adult	Group housing = 1.80 Additional exercise space = 2.80 Open housing = 0.90–1.40
University of New Hampshire Extension (2017)	Extension	(Dairy) does	Group housing = 1.80–2.30 Additional exercise space = 4.60
Irish Dept. of Agriculture, Fisheries and Food (grant application guidelines)	Guideline	Doe	1.80
		Kidding pen	2.00
		Kid rearing pen	2.00 for 12 kids (<4 weeks old) 4.00 for 12 kids (>4 weeks old)
		Buck	2.50
New Zealand Government (2018)	Guideline	Adult	Minimum 2.00 Recommends 3.00

3.3 Feeder and Waterer Space Allowances

Many studies have made recommendations on feeder space allowance (see *Table 3.2*); however, science-based evidence within them is lacking. Caution must be taken when comparing these studies to one another, as there are many options for feeder and waterer access. Tsukahara et al. (2014) suggested that the number of goats per feeder did not influence performance or behaviour when the feed was offered ad libitum, but conceded that their study was flawed, due to conflicting results with a previous work and low sample size. Cull (1988) stressed that the amount of feed space required is dependent on the type of feed and the feeding methods. Indeed, robust research is lacking comparing the various feeding options (e.g., round bale feeder, a hay rack, bunks).

A 2015 study surveying Ontario dairy goat producers reported that feeder space ranged from 0.30 ± 0.09 m for doelings to 0.93 ± 0.93 m for adult bucks, respectively (Oudshoorn et al., 2016). However, as cautioned above, this was producer reported and included responses from just 17% of eligible producers.

The presence of horned animals is an important variable when considering feed space allowance. Loretz et al. (2004) investigated the effects of gradually reducing the number of feeding places allotted to separately housed horned and hornless does. All animals were fed restrictedly with hay twice daily. As feeding places diminished, space between the animals decreased; lower-ranking animals were forced to share feeding space, and higher-ranking animals took up multiple spaces. The horned goat group was more affected by reduced feeding space than the hornless goat group. Similarly, as feeding space allocation per animal decreased, the time spent feeding decreased, the frequency of feeding bouts decreased, animals spent more time waiting for feed, and aggressive behaviours increased (Jørgensen et al., 2007). This again affected lower-ranking goats more. Multiple peer-reviewed studies recommend ≥1 feeder space (0.33–0.40 cm) per animal (Loretz et al., 2004; Jørgensen et al., 2007; Muri et al., 2013), but many stated that feeding spaces may be reduced if the feed is accessible ad libitum.

Feed bunk design affects goat feeding behaviour. Aschwanden et al. (2009) reported that the use of partitions between feeding spaces decreased aggressive behaviours and goats spent more time feeding. In hornless goats, Nordmann et al. (2011) reported that the use of metal palisades caused less stress and displacements from feeders, whereas neck rails were associated with agonistic behaviours leading to displacement. However, feed barriers had no significant impact. Furthermore, goats have been observed to prefer feeding elevated up on platforms, or from feeders where the feed is presented at or above head-level (Aschwanden et al., 2009; Keil et al., 2017; Neave et al., 2018). Goat feeding behaviour is covered in more detail in *Section 1: Natural Behaviours*.

Water may be offered in a raised tank automatic water bowl that is triggered by consumption or by pushing a lever or a water nipple triggered by the animal pushing to obtain a water stream. For these systems, 1 animal may drink at a time. The Canadian Agri-Food Research Council (CARC) initially recommended 40 to 50 does, 10 bucks, and 50 to 75 kids (>30 kg) per nipple drinker (CARC, 2003). Muri et al. (2013) recommended approximately 10 dairy goats per drinker. However, a study that assessed competition for water at different densities of dairy goats per nipple drinker concluded that more than 7.5 goats per nipple was associated with decreased drinking frequency and increased drinking speed (Ehrlenbruch et al., 2010). Furthermore, competition for water increased when there were more than 15 goats per nipple. It was recommended that the water system must be able to provide 9 litres per head per day, regardless of the source (New Zealand Government, 2018).

Table 3.2 A summary of feeder space recommendations.

Reference	Document type	Age/Production stage	Horn status	Feeder space and/or number of feeder spaces/animal recommended
Cull (1988), *Goat Veterinary Society Journal*	Peer-reviewed	Does	N/A	0.40 m/goat
		Youngstock		0.30 m/goat
		Bucks		0.60 m/goat
Toussaint (1997), *Livestock Production Science*	Peer-reviewed	Adult	N/A	0.40 m/goat
		≥7 mo		0.33 m/goat
Loretz et al. (2004), *Applied Animal Behaviour Science*	Peer-reviewed	Does	Horned	1.5–2 feeder spaces*/goat
		Does	Hornless	1.5 to 2 feeder spaces**/goat
Jørgensen et al. (2007), *Applied Animal Behaviour Science*	Peer-reviewed	Does	Hornless	≥ 1 feeder space/goat
Muri et al. (2013), *Animal Welfare*	Peer-reviewed	Adult	N/A	≥ 1 feeder space/goat
CARC (Canadian Agri-Food Research Council) (2003)	Guideline	Does	N/A	Limit fed = 0.41–0.50 m/goat Ad libitum = 0.10–0.15 m/goat
		Bucks		Limit fed = 0.30 m/goat Ad libitum = 0.15 m/goat
		Kids >30 kg		Limit fed = 0.23–0.30 m/goat Ad libitum = 0.10 m/goat
		Kids <30 kg		Ad libitum = 0.03–0.05 m/goat
Tarr, ShurGain Nutrifax	Extension	Does	N/A	0.40m/goat
		Replacements/feeders		0.30m/goat
		Bucks		0.40m/goat
Schoeninan (1999), University of Maryland Cooperative Extension	Extension	All	N/A	Enough space for all animals to eat at once
		Does		0.41 m/goat 0.20–0.30 m/goat, if hay ad libitum

Reference	Document type	Age/Production stage	Horn status	Feeder space and/or number of feeder spaces/animal recommended
		Youngstock		0.30 m/goat 0.05–0.10 m/goat, if hay ad libitum
Irish Deptartment of Agriculture Fisheries and Food (2010)	Guideline	Does	N/A	0.35–0.45 m/goat (depending on body size)
		Young stock		0.25 m/goat
		Bucks		0.50 m/goat

* Feeder space was 0.50 m
** Feeder space was >0.50 m

3.4 Future Research

1. Research is needed on feeder, waterer, and space allowance for different breeds and different production stages, and comparing horned and hornless goats is required with a specific focus on welfare impacts.
2. Research is needed on water demand and preference in different commercial settings (i.e., dairy, meat, and fibre operations). Water flow rates at drinking stations should be considered when aiming to determine the most appropriate number of waterers per animal.
3. Most research focuses on minimum space allowance; more research is needed on production and welfare effects of higher space allowances.
4. Research on space allowance has focused mainly on one-level barns. Goats naturally use elevated space when given the opportunity; research is needed to establish appropriate space allowance for multi-level systems.
5. Space allowance needs to be evaluated in the context of group size.

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4 End-of-Life Management

Conclusions

1. **Method of on-farm euthanasia or slaughter should be as free of pain and distress as possible.**
2. **Barbiturates require a veterinary prescription, proper restraint, and veterinary administration via intravenous injection. Animals euthanized with barbiturates may be unsuitable for some methods of deadstock disposal.**
3. **Insensibility can be confirmed through the presence of the following signs: collapse immediately after method application, muscle rigidity followed by involuntary muscular movements, lack of rhythmic breathing, and lack of corneal reflex.**
4. **Following insensibility, an adjunctive method may be needed to ensure the death of the animal depending on the primary method used.**
5. **Death must be confirmed by identifying at least 3 of the following signs: lack of heartbeat, absence of respiration, absent corneal reflex, no response to a firm toe pinch, graying of the mucous membranes, and maximum dilation of the pupil(s).**
6. **All devices available for use by producers or veterinarians require frequent and regular maintenance in order to be effective.**

4.1 Introduction

There are inevitable circumstances in a livestock operation that will require an animal to be euthanized. On-farm slaughter may also be an occurrence on some operations. Regardless of the purpose for the death, it should be brought about in a method that minimizes pain and distress (Shearer & Ramirez, 2013; AVMA, 2016, 2020; Humane Slaughter Association, 2018).

Methods of euthanasia should utilize techniques that cause immediate insensibility (i.e., unconsciousness), followed by subsequent death, which may be brought on by the primary method used or by the addition of an adjunctive method (Blackmore, 1979; Daly & Whittington, 1989; Shearer & Ramirez, 2013; OIE, 2019a; AVMA, 2020).

Indications of insensibility include collapse of the animal immediately after method application, failure of the animal to right itself after application, muscle rigidity after application followed by involuntary muscular movements, lack of rhythmic breathing, and lack of corneal reflex (Shearer & Ramirez, 2013; AVMA, 2016, 2020). After insensibility is confirmed but not death, an adjunctive method must be used to ensure death (Shearer & Ramirez, 2013; AVMA, 2016, 2020). Death must then be confirmed.

4.2 Methods

Primary methods listed below include those approved for on-farm euthanasia or slaughter. Not all methods can be performed by producers. Barbiturate euthanasia can only be performed by a licensed veterinarian, while the remaining methods can be performed by producers when and if they have the appropriate training and/or equipment and feel comfortable with performing the procedure.

4.2.1 Barbiturates

An overdose of barbiturates (e.g., pentobarbital) depresses the central nervous system, renders the animal unconscious, and subsequently leads to death (AVMA, 2020). However, barbiturates require veterinary prescription and must be administered by a licensed veterinarian to ensure they are administered for their intended purpose and using appropriate restraint to administer the intravenous injection (Humane Slaughter Association, 2018; AVMA, 2020). Adjunctive methods are not needed to ensure death when using this method (AVMA, 2020).

Animals that are euthanized by barbiturate overdose cannot be consumed or rendered due to residues in the tissues; carcasses cannot go into the food chain, either human or animal, including scavengers. Therefore, carcasses require immediate appropriate disposal on-farm using a method that will prevent scavenging (AVMA, 2020).

4.2.2 Electrocution

Electrical stunning uses specialized equipment to pass an electrical current through the brain, causing substantial stimulation, which exhausts the central nervous system causing insensibility and must be followed with an adjunctive method (Blackmore, 1979). Two different methods of electrocution have been studied in sheep: the head-only method and the head-to-back method (Blackmore & Newhook, 1982). Head-only stunning in sheep is reversible (i.e., the animal regains consciousness) in 30 to 58 seconds (Blackmore & Newhook, 1982), whereas head-to-back stunning causes immediate and irreversible insensibility (Blackmore & Newhook, 1982; Anil & McKinstry, 1991). A recent opinion of the European Food Safety Authority reserves judgement on the suitability of this method in sheep and goat kids (EFSA Panel on Animal Health and Welfare, 2015). Due to the equipment needed for this method, it is not commonly used on the farm and will not be reviewed in detail.

4.2.3 Carbon Dioxide

Carbon dioxide (CO_2) is used to cause a reversible state of unconsciousness through respiratory acidosis (AVMA, 2020). Carbon dioxide has the potential to cause pain and stress, but less so when delivered gradually. In a study that examined the use of CO_2 to euthanize kids, there were no avoidance behaviours observed when kids were exposed to 10 to 30% CO_2 concentrations, and the authors supported its use to euthanize kids (Withrock, 2015). Due to the specialized equipment needed for this method, it will not be review in detail.

4.2.4 Gunshot

When euthanizing animals by gunshot, appropriate firearms must be used to ensure death or rapid unconsciousness. For small ruminants, the following firearms are recommended: .22 LR rifle, .38 Special, .357 Magnum, 9mm or equivalent handguns, and shotguns (AHA, 2016; Humane Slaughter Association, 2018; AVMA, 2020). Hollow-point bullets are not advised because they may fragment and not yield the desired penetration and brain destruction that can be achieved with solid-point bullets (AVMA, 2020). All regulations regarding the legal discharge of firearms must be followed.

The firearm should not be pressed flush with the skull but held between 10 to 30.5 cm (4 to 12 inches) away (Humane Slaughter Association, 2018; AVMA, 2020). The firearm should be directed slightly behind the poll at the site of the occipital protuberance and aimed towards the lower chin (see *Figure 4.1*; Shearer & Ramirez, 2013; AHA, 2016; Humane Slaughter Association, 2018; AVMA, 2020). For large-horned goats, the firearm can be aimed high on the forehead (at the intersection of two lines drawn from the lateral canthus of each eye to the middle base of the opposite ear) toward and in line with the spinal column of the cervical vertebra (Humane Slaughter Association, 2018; AVMA, 2016, 2020).

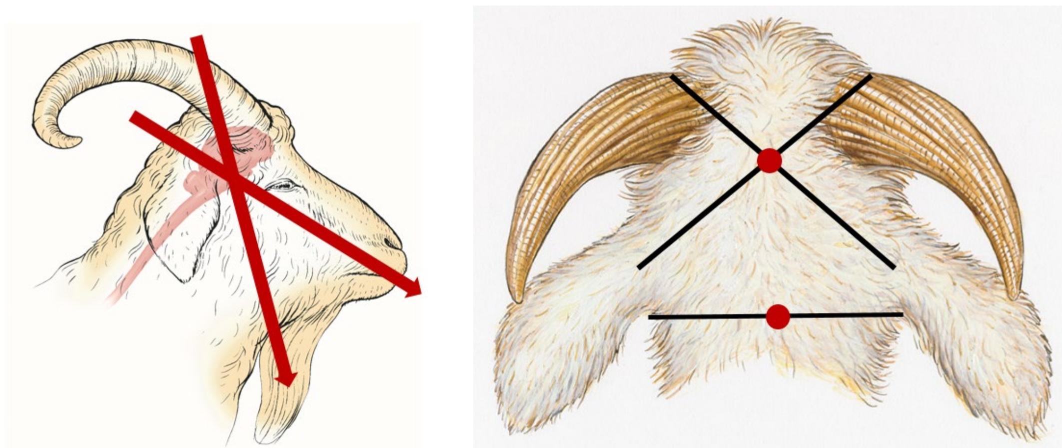

Figure 4.1 Lateral and dorsal views of anatomic sites for euthanasia of adult goats. JK Shearer, Iowa State University; adapted from the AVMA Guidelines for the Euthanasia of Animals: 2020 Edition.

Once the animal has been rendered unconscious and death is not immediate, an adjunctive method must be used to ensure death. If not successful on the first shot, the shooter must be prepared to deliver a second shot immediately, and if necessary, a third shot (AVMA, 2020). Firearms must be well maintained to humanely euthanize livestock (AHA, 2016; AVMA, 2016, 2020, 2019; OIE, 2019b).

4.2.5 Penetrating Captive Bolt

Penetrating captive bolts (PCB), when used appropriately, cause immediate insensibility (Blackmore & Newhook, 1982; AHA, 2016; AVMA, 2020). The PCB induces insensibility through the force applied to the skull which causes damage to the brain (Daly & Whittington, 1989). Immediately following insensibility, an adjunctive method must be performed to ensure death as soon as possible (Shearer & Ramirez, 2013; Humane Slaughter Association, 2018; AVMA, 2020). Daly and Whittington (1986) reported that all sheep stunned with PCB applied to the poll lost visual evoked responses, but 5 out of 8 recovered within 50 seconds, indicating that adjunctive methods must be used immediately following application.

Landmarks used when euthanizing an animal with a PCB are usually the same as those used for gunshot, but the bolt should be placed firmly flush against the skull (Shearer & Ramirez, 2013; Humane Slaughter Association, 2018; AVMA, 2020). A recent study proposed aiming at the intersection of two lines drawn from the lateral canthus of an eye to the middle base of the opposite ear (Plummer et al., 2018).

4.2.6 Non-Penetrating Captive Bolt

Non-penetrating captive bolts (NPCB), when used appropriately, cause immediate insensibility through mechanical force trauma that must be followed by an adjunctive method (Blackmore & Newhook, 1982). A NPCB applies high impact force to the head and brain. Loss of consciousness is induced by high-velocity waves that alter the brain's physical tissue by the rapid change in intracranial pressure and through the brain impacting with the skull (Blackmore, 1979). Together, these forces disrupt cerebral cortex activity, and the animal loses consciousness.

Non-penetrating captive bolts are sometimes not recommended for euthanizing adult goats due to their thick skull (AHA, 2016). However, Collins et al. (2017) compared tissue damage between adult female goats that were euthanized using either a PCB or NPCB applied to the poll and aimed towards the lower jaw and reported that both methods yielded immediate unconsciousness and sufficient damage to the brain. In a study to investigate the effectiveness of NPCB to euthanize neonatal kids (i.e., ≤8 days old), Grist et al. (2018) proposed adjusting the landmarks by aiming the NPCB between the ears on the midline while tucking the kid's chin into the neck for a more successful stun. Similarly, Sutherland et al. (2016) compared different anatomical sites for NPCB for euthanizing kids less than 48 hours old. All kids that received NPCB applied behind the poll, between the ears, while the chin was bent, were rendered immediately insensible (see *Figure 4.2*). However, when the study was repeated with kids up to 30 days of age, two shots at the same location were needed to render the older kids immediately insensible (Sutherland et al., 2017).

As with firearms, both penetrating and non-penetrating captive bolts must be well maintained to humanely euthanize livestock (AHA, 2016; AVMA, 2016, 2019, 2020; OIE, 2019b).

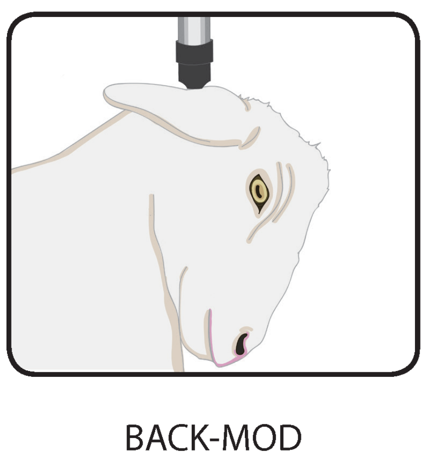

Figure 4.2 Evaluation of the efficacy of a non-penetrating captive bolt to euthanase neonatal goats up to 48 hours of age.
Adaptation from Sutherland et al. (2016).

4.2.7 Manual Blunt Force Trauma

The routine use of manual blunt force trauma is cautioned against due to the inability of a person to both properly restrain the animal and consistently apply enough force to immediately induce unconsciousness (Shearer & Ramirez, 2013; AVMA, 2020). When no other euthanasia method is available, the Humane Slaughter Association (2018) permits blunt force trauma that is followed by exsanguination to euthanize kids. It is acknowledged that manual blunt force trauma is difficult to do consistently and in a standardized manner. Furthermore, human mental health and social acceptance of this technique should be considered.

Animal Health Australia (AHA, 2016) states that blunt force trauma to the centre of the forehead is an acceptable method to euthanize kids less than a day old. Conversely, the Humane Slaughter Association (2018) indicates that a blunt, hard instrument should be used to apply a firm blow to the back of the head while the kid is restrained. As the front of the skull is considered too thick for a NPCB (AHA, 2016), blunt force to the back of the head may be the preferred method.

The Humane Slaughter Association (2018) recommended the individual dealing the blow use more force than anticipated rather than too little. If the first blow does not render the animal unconscious, a second blow with more force is used.

4.2.8 Exsanguination with and without Stunning

Commonly for religious reasons, animals may be slaughtered using a cut, with a very sharp knife, to the conscious animal's neck that transects the animal's skin, neck muscles, trachea, esophagus, carotid arteries, jugular veins, smaller vessels, nerves, and connective tissue (Mellor & Littin, 2004). These tissues are innervated and cutting them sends a noxious stimulus to the brain, as demonstrated through electroencephalographic responses (Mellor & Littin, 2004; Gibson et al., 2009; Sabow et al., 2016, 2017). However, the animal may experience psychological shock from the cut and the extent to which they perceive the noxious stimulus is not known (Mellor & Littin, 2004). Pre-cut stunning is often advised, and pre-slaughter reversible stunning, such as electrical stunning, has been adopted by many communities to improve animal welfare and respect religious requirements (Mellor & Littin, 2004; Farouk et al., 2016).

The American Veterinary Medical Association (2016) states that the animal must be humanely restrained before the cut, the cut should be performed within 10 seconds of restraining the head, and there should be reduced pressure on the cut to allow for rapid bleed out.

Mellor and Littin (2004) reported that consciousness in goats after a neck cut may range from 2 to 7 seconds, during which the animal may feel pain. However, another study undertaken by Blackmore (1984) observed that lambs and ewes slaughtered by exsanguination displayed positive corneal and palpebral reflexes for up to 200 seconds after the cut. This study was based on a small sample size (2 lambs and 3 ewes), and the exsanguination method only severed the arteries and veins, omitting nerves and other tissues, which may explain the discrepancy in time to insensibility. The experience level of the person making the cut is important, as a failure to cut the carotid arteries or inadvertent occlusion of the vessels post-cut may delay bleed out and cause additional pain (OIE, 2019a)

4.2.9 Inappropriate Methods

Methods that are deemed inappropriate for euthanasia or slaughter include injection of any substance not labelled for euthanasia, injection of potassium chloride and/or magnesium sulphate into a conscious animal, drowning, intravenous injection of air, blunt force trauma (the allowance of this technique in kids varies), and electrocution with a 120 or 220-volt electrical cord (Shearer & Ramirez, 2013; AVMA, 2020).

4.3 Adjunctive Methods

Veterinary intrathecal lidocaine administration has been used in horses under sedation as an adjuctive method. One study investigated the use of this technique in 4 goats and reported that it was successful (Zolhavarieh et al., 2011). However, such a small study is not reliable enough to assure that this method is appropriate for goats.

4.3.1 Potassium Chloride or Magnesium Sulfate

Rapid intravenous injection of a bolus of saturated solution of potassium chloride (KCl) may be used to cause rapid death after an animal has been rendered insensible using gunshot, PCB, or NPCB (AVMA, 2020). Injection of potassium chloride without stunning is unacceptable, as the infusion is exceedingly painful (AVMA, 2019, 2020). Potassium chloride works by causing cardiac arrest. Magnesium sulfate may also be used, but death will not occur as rapidly as with potassium chloride (AVMA, 2020).

4.3.2 Exsanguination

Following the loss of consciousness, a very sharp knife can be used to exsanguinate the animal after it has been rendered insensible using gunshot, PCB, or NPCB. The knife should be at least 15cm long to assure that all tissues are severed with a single cut, be inserted at the joint of the jaw, and drawn forward to cut the jugular veins, carotid arteries, trachea, and esophagus (Shearer & Ramirez, 2013). Alternatively, the brachial vasculature may be cut in the axilla.

4.3.3 Second Shot

In cases where an animal is rendered unconscious with a gunshot, a second shot is an adjunctive method that can be used to cause fatal injury to the brain (AVMA, 2020). The same landmarks as the first shot, stated above, should be used to deliver the second shot and ultimately cause sufficient damage to the brainstem.

4.3.4 Pithing

Pithing is an adjunctive method that can be used following a PCB or gunshot to cause death through the destruction of the brain and spinal cord (AVMA, 2020). A pithing rod, long enough to reach the brain and spinal column, is inserted into the entry site of the bullet or PCB and manipulated to destroy brain tissue.

4.4 Confirmation of Death

Death is confirmed by identifying 3 or more of the following signs: the sustained absence of heartbeat, sustained absence of respiration, lack of corneal reflex, lack of response to a firm toe pinch, the occurrence of graying mucous membrane, maximum dilation of the pupil, or the presence of rigor mortis (Shearer & Ramirez, 2013; AHA, 2016; AVMA, 2020). A combination (at least 3) of these criteria must be identified, as none of the criteria above solely confirm death, except rigor mortis (AVMA, 2016, 2020).

4.5 Future Research

1. Research is lacking on the use of exsanguination without stunning in goats.
2. Research is needed to explore how to make NPCB devices more accessible to producers.

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5 Painful Procedures

Conclusions

1. **Disbudding, dehorning, and castration are painful procedures, and different strategies may be utilized to mitigate pain.**
2. **The use of local anesthesia and/or a non-steroidal anti-inflammatory drug reduces pain associated with castration.**
3. **Non-steroidal anti-inflammatory drugs reduce pain associated with disbudding/dehorning.**
4. **While it is recommended that painful procedures be performed at a "young age," the science-based literature is inconsistent in what this refers to; many recommendations stem from veterinary guidelines that may or may not be based on the most up-to-date science-based evidence.**
5. **The combination of local anesthetic and non-steroidal anti-inflammatory drugs yields longer post-operative pain control in animals undergoing castration than using a single pain mitigation method.**
6. **There is a risk of damage to a kid's skull and brain when hot cautery disbudding is performed improperly.**
7. **Dehorning adult goats results in large openings to the sinuses that can take a prolonged time to heal with the risk of sinusitis.**
8. **Sedation using a chemical agent under the supervision of a veterinarian is advised for all disbudding and dehorning methods.**
9. **Tetanus prophylaxis is needed before a procedure that results in an open wound when routine herd vaccination is not present or colostrum of unvaccinated animals is used.**
10. **Lidocaine toxicity can occur if the dosage exceeds specific levels; the signs are convulsions and respiratory and cardiac arrest.**

5.1 Introduction

Several routine procedures occur on the farm that are known to cause pain, including castration, disbudding, dehorning, and horn tipping, when tipped proximal to the blood supply. These procedures will be reviewed, including preventative measures and pain mitigation strategies. We caution that goat specific peer-reviewed research is often minimal for these procedures. Therefore, there has been a significant reliance on a veterinary reference book (Smith & Sherman, 2009), as well as other literature related to other species such as lambs and calves.

Assessing pain experienced by an animal is done in several ways; when making a decision regarding the severity of pain, all methods of assessment should be considered. Mellor and Stafford (2000) summarized this assessment in the following way: Behavioural responses may be from fear, pain, or both; a variety of behaviours are assessed (e.g., vocalization, tail wagging, suckling, scratching, withdrawal, and flinching). Physiological responses may be acute and be measured through levels of adrenaline, noradrenaline, and heart rate.

5.2 Castration

Castration refers to either the removal of the testes and epididymes or damaging the blood supply of the testes; the latter results in either atrophy and the testes becoming non-functional (clamp method) or necrosis and sloughing of the tissues (elastic rings; Smith & Sherman, 2009). This review does not include vasectomy nor performing shortening of the scrotum so that the testes are forced into the inguinal area against the body wall.

Producers may choose to castrate males to decrease odour and aggressive behaviours and to avoid unwanted pregnancies (Smith & Sherman, 2009; Williams, 1990). However, producers may choose not to castrate or to delay castration. In some cases, this could be for animal health reasons. For instance, Kibria et al. (2016) investigated the effect that castration at different ages would have on penile and urethral development. Penile urethral perimeter was highest in kids not castrated or those castrated between 8 and 10 weeks of age. However, the reported results should be taken with caution, as the study did not perform analyses to determine if there was a significant difference between different ages at castration and had a small sample size. Another reason for not castrating is to access specific markets that prefer intact young males (Ulker et al., 2009).

All methods of castration have been proven to be painful, as demonstrated by blood parameters (e.g., elevated cortisol level) and pain-related behaviours (Mellor & Molony, 1991; Paull et al., 2012). Commonly, it is advised that kids are castrated as young as possible; however, at birth, it may distract the kid from consuming colostrum (Williams, 1990). Interestingly, a study that compared the response of lambs castrated using a surgical, rubber ring, or clamp method at 5, 21, and 42 days of age determined pain-related responses did not differ (Molony et al., 1993). However, Kent et al. (1999) reported that lambs castrated at 42 days by rubber ring had larger lesions than lambs castrated at 2 and 28 days of age, which may indicate that rubber ring castration in older lambs results in longer-lasting pain. In calves, Marti et al. (2017) noted that calves older than 2 months that were surgically or clamp castrated demonstrated signs of chronic pain. Furthermore, older bucks (i.e., several months old) had a higher risk of exsanguination with surgical castration due to larger vessels (Smith & Sherman, 2009).

Castration in ruminant species is considered a risk factor for tetanus, where bacterial spores may enter the open wound (Smith & Sherman, 2009). For that reason, the farm must ensure that does are appropriately vaccinated with a clostridial vaccine that includes tetanus toxoid. If kids are fed colostrum from unvaccinated does or from a commercial bovine colostrum replacer product, then tetanus antitoxin must be administered at the time of surgery.

Although alternative methods (e.g., anti-GnRH vaccine) are being explored and appear promising (Godfrey et al., 1996; Lents et al., 2018; Ulker et al., 2009), they are not commercially available and will not be reviewed. Little research has focused on castration in goats; therefore, this review relies heavily on sheep literature. It is important to note that most of this literature paired castration with tail docking, which may have influenced the behavioural and physiological responses measured.

5.2.1 Rubber Ring Castration

Rubber ring castration is a common method in young kids; veterinary textbooks suggest it should be done in kids less than 3 weeks of age (Smith & Sherman, 2009). Elastrator rings are placed around the neck of the scrotum, thus damaging all blood vessels to the testes and scrotum; this eventually results in the distal tissues becoming ischemic and falling off.

In a study that investigated behavioural and cortisol response to rubber ring castration, lambs did not lie down during 30 minutes post-procedure; there was a significant increase in cortisol, which peaked at 30 minutes and did not return to baseline levels until 180 minutes (Mellor & Molony, 1991). While not pain-specific, changes in lying behaviour and increases in serum cortisol are frequently suggested to be useful indirect indicators of a pain response. Ahmed and Ahmed (2011) concluded that rubber ring castration was more painful than surgical clamp castration, based on increased pain behaviour and reduced feeding.

5.2.2 Clamp Castration

A clamp emasculatome is used to crush the tissues of the spermatic cords, including the spermatic artery, vein and nerve, as well as the vas deferens that transports sperm. This method has the advantage of not creating an open wound and has a decreased risk of tetanus (Smith & Sherman, 2009). However, there is a higher risk of failed castration and tissue necrosis due to improper clamping.

To appropriately castrate using the clamp method, the spermatic cords must be crushed individually above the testes with the clamp not crossing the median raphe: Obliteration of these structures will cause atrophy of the testes and epididymes but will not harm the scrotum (Smith & Sherman, 2009). The kids must be examined 1 month later to ensure that both testes have atrophied.

Clamp castration is often suggested to be less painful than other methods in calves. Many studies have reported that clamp castrated calves exhibited significantly less pain-associated behaviours and less severe and shorter plasma cortisol spikes than surgically (Robertson et al., 1994) or band castrated calves (Molony et al., 1995; Thüer et al., 2007). Ahmed and Ahmed (2011) also recommended clamp castration compared to rubber ring castration in kids.

Kent et al. (2001) investigated the effect of applying a clamp after a rubber ring was applied when castrating one-week-old lambs. When the scrotal neck was clamped proximal to the ring, lambs displayed less pain-associated behaviours than when it was placed distal to the ring. These results indicate that a combination of rubber ring and clamp castration methods may result in less pain. The clamp destroys the nerves in the scrotum and testes by crushing the tissue and it is cautioned to avoid crushing the urethra.

5.2.3 Surgical Castration

A key advantage of surgical castration is that there is a guarantee of success, given that the entire testes are removed (Williams, 1990). While veterinary reference books (e.g., Smith & Sherman, 2009) suggest that there is an age discrepancy as to if kids should or should not be provided with pain mitigation during/following castration (e.g., young kids castrated without anesthesia, while older kids receive anesthesia), it is important to note that these are statements made based on field experience; there is currently no scientific literature examining pain response in kids surgically castrated at different ages with different pain mitigation strategies employed.

Surgical castration of kids only a few weeks old is usually done by performing a closed castration and then gently pulling each spermatic cord until it ruptures while keeping pressure on the inguinal ring to prevent evisceration. When the spermatic artery and vein are pulled, the vessel walls spasm and good hemostasis is achieved. Surgical castration of older kids where the blood vessels are much larger is done with an emasculatome which cuts and crushes the spermatic cord at the same time. However, if done in a similar way as in a young kid, there is an increased risk of blood loss, and vessels should be ligated (Smith & Sherman, 2009). As with any open wound, there is a risk of tetanus, and it is advised to administer tetanus antitoxin before castration (Buttle et al., 1986; Smith & Sherman, 2009).

5.2.4 Castration Pain Mitigation Strategies

Broadly, pain mitigation can be broken down into three key categories: 1) anesthetics, 2) analgesics, and 3) sedatives. Each works differently, and increasing evidence suggests that best practice pain mitigation should aim for a combination of these. Anesthetics alleviate the immediate acute pain, which results in a painful response to the procedure itself (e.g., lidocaine; Smith & Sherman, 2009). Analgesics, such as non-steroidal anti-inflammatory drugs (NSAIDs) are longer acting and useful for post-procedure pain, but will not alleviate acute pain during the procedure (e.g., meloxicam). Sedatives reduce or eliminate awareness during the procedure, but do not in themselves provide pain mitigation (e.g., xylazine) and therefore, will not be reviewed.

Local anesthesia can be administered by diluting lidocaine (0.5–1.0%) to avoid toxicity (toxic dose of 5 mg/kg body weight; Buttle et al., 1986; Smith & Sherman, 2009). It should be noted, however, that dilution of lidocaine must be done immediately before its use, and any leftover product must be discarded and not stored. It is advised that kids be weighed to ensure that the toxic dose of lidocaine is not exceeded (Gascoigne, 2015). A study evaluated the toxicity of a higher dosage of lidocaine; however, the sample size was small and they concluded that more research is needed to determine if a higher dose is safe (Venkatachalam et al., 2018).

For surgical castration or prior to clamping or applying rings, lidocaine can be deposited high in each spermatic cord as well as the scrotal neck, and in the distal end of the testes (Smith & Sherman, 2009). Alternatively, lidocaine can be injected into the testes and subcutaneously in the distal aspect of the scrotum. Lidocaine injection should be done 15–20 minutes before the castration is performed to allow for the anesthetic to diffuse through the tissues (Mellor & Stafford, 2000).

Local anesthetic can be used with the rubber ring methods by infusing lidocaine into the neck of the scrotum and the spermatic cords before rubber ring application to manage pain during and immediately post-operatively (Smith & Sherman, 2009). This was found to be much less painful (as measured by cortisol) than applying a ring with or without clamping in lambs 4–6 weeks of age (Mellor & Stafford, 2000). Ajadi et al. (2012) explored the effect of epidural injection of tramadol and lidocaine on preventing pain in rubber ring castrated kids. Epidural infusion of tramadol did not provide adequate analgesia, but lidocaine resulted in a significant decrease in pain-associated behaviours for up to 1.5 hours after the procedure.

As analgesic treatment, subcutaneous injection of flunixin or meloxicam around the circumference of the scrotum has been reported to alleviate pain-related behaviours in ring castrated lambs compared to those castrated without analgesia (Paull et al., 2012). However, this method has not been compared to other methods, such as local anesthetics, to determine if a local NSAID infusion is a preferred method. Subcutaneous injection of a combination of local anesthetic and NSAID has not been explored.

In a study that compared the effectiveness of different pain mitigation methods, lambs were either not castrated (control); surgically castrated without pain mitigation, with only local anesthesia (lidocaine); only analgesia (flunixin); or with a combination of local anesthetic and systemic analgesia (Straticò et al., 2018). Thirty minutes post-castration all castrated groups had a significant increase in cortisol, highlighting that castration is a painful procedure. Those that were castrated without pain mitigation had the highest cortisol levels at each time point measured up to 9 hours after castration, except at 6 hours, when levels were similar to the lidocaine-only group. Those that received both pain control mitigation strategies had the same level of cortisol to those that were not castrated, indicating that the combination was more effective at mitigating pain.

A similar study assessed the same pain mitigation strategies in adult sheep that were castrated with a clamp. Pain-associated behaviours were observed for up to 32 hours post-castration (Durand et al., 2019). Those sheep that received both local anesthesia and flunixin exhibited lower pain from 2 hours to 32 hours post-procedure than sheep receiving no pain mitigation or lidocaine block only. Notably, the local anesthetic used alone was effective for its time of action (2 hours).

A review of castration and tail-docking in lambs concluded the following with regards to the age at castration and pain mitigation techniques (Mellor & Stafford, 2000): the largest pain response was associated with surgical castration at 4–5 weeks, followed by clamp castration at 4–8 weeks with a lower pain response at 3 weeks. Ring castration elicits a high pain response between 1–8 weeks of age and clamping prior to ring application at 3 weeks did not change this. Injecting lidocaine and waiting less than 2 minutes did not lower pain response but waiting 15 to 20 minutes did lower pain response. This time was necessary to allow diffusion of the anesthetic into the testes and spermatic cords. If a needleless injection device was used instead, the time to effectiveness was lower at 15–30 seconds.

5.3 Disbudding/Dehorning

Disbudding is the procedure that removes the horn bud before it attaches to the skull, while dehorning is the process of removing horn tissue after the horn bud attaches to the skull (Baker, 1981; Buttle et al., 1986). These procedures are done to mitigate the risk of injuries to people and other animals, decrease space requirements (see *Section 3: Space Allowance*), decrease aggression between horned and hornless animals, and prevent damage to housing (Gascoigne, 2015; Hull, 1995; Smith & Sherman, 2009; Wright et al., 1983).

When considering whether to disbud, several factors can be considered, including third-party horn requirements (e.g., show requirements), the target market, the animal's environment, and the social hierarchy in the herd (Smith & Sherman, 2009). With attention to these factors, housed systems can be managed and equipment used (e.g., feeder and milking parlour design) to allow for horns in cows (Menke et al., 2004) and goats (Loretz et al., 2004). For information on measures that may reduce aggressive interactions in housed systems, see *Section 1: Natural Behaviours*.

It is worth noting that the significance of disbudding as a welfare compromising procedure is growing around the world. Disbudding or dehorning a goat is seen by some as adapting or altering the animals to live in an "industrial animal farming" environment; we should always be considering if it is the animal that should change or its environment (Nordquist et al., 2017). In some regions, it may only be performed by veterinarians and under sedation (Gesellschaft Schweizer Tierärztinnen und Tierärzte, 2018). In the Netherlands, anesthetic is required and must be administered by a veterinarian (Van den Brom et al., 2020).

In Canada, the majority of dairy goats are disbudded, likely due to large herd sizes and high stocking densities, as well as the need to avoid entrapment in housing and milking facilities that have been designed for disbudded goats. However, many meat and fibre goats are not disbudded for several reasons, including necessity (e.g., registered Angora goats must have horns), management differences, and market demand (Alvarez et al., 2015; Ulker et al., 2009). Many dairy kids destined for meat production are also not disbudded.

Elastrator bands have been reported as a method to dehorn goats, but there is a concern that the band may slip and cause only the tip to be removed (Smith & Sherman, 2009), and this method will not be covered in this section. Additionally, no research has assessed pain felt by goats dehorned through the use of elastrator bands.

5.3.1 Hot Cautery Disbudding

Hot iron cautery is the most common method used for disbudding kids (Wright et al., 1983). Ideally, kids should be disbudded between 7 to 14 days of age (Hempstead et al., 2018a; Van den Brom et al., 2020; Wright et al., 1983). The horn bud will start to fuse with the skull by 3 weeks of age and will have a higher risk of horn regrowth (Baker, 1981; Smith & Sherman, 2009). There is a breed difference, however, with northern dairy breeds fusing earlier than other breeds such as the Nubian or Boer. Regardless, kids should be disbudded at less than 3 weeks of age.

It has been suggested to clip the hair around the horn bud before cautery disbudding to optimize iron contact with horn bud tissue (Van den Brom et al., 2020). A hot iron, heated to approximately 600°C, is placed on the horn bud for 5 to 10 seconds, depending on the iron wattage, ambient temperature, and type of iron (gas or electric), to heat cauterize the horn bud tissue (Baker, 1981; Hempstead et al., 2018a; Hempstead et al., 2018b; Smith & Sherman, 2009). Hot cautery disbudding that removes the horn bud has been reported to improve disbudding success compared to hot cautery that leaves the horn bud in place (Hempstead et al., 2018c).

The temperature of the cautery and the time held against the horn bud are essential for successful disbudding (Williams, 1990). Low temperatures or holding the iron against the skull for insufficient time is likely to result in scur development.

Alvarez and Gutierrez (2010) compared cortisol and behavioural responses of kids that were hot cautery disbudded to kids that were sham disbudded (i.e., simulated handling using a cold iron). Disbudded kids peaked cortisol concentrations within 10 minutes post-disbudding and cortisol remained elevated for 2 to 3 hours. Disbudded kids exhibited significantly higher vocalizations and kicking than those that went through sham disbudding. This study served to illustrate further that hot cautery disbudding is a painful procedure.

Alvarez et al. (2019) observed wound healing and sensitivity in dairy kids disbudded using hot cautery. Wounds took 7 weeks to heal completely and remained painful throughout the process. Wound sensitivity was directly related to wound size and was more sensitive when damaged tissue was present. However, as reported in humans, it is normal for injured tissue to remain more sensitive to pain (Stubhaug et al., 2007) and the Alvarez et al. (2019) study could not differentiate chronic pain from increased sensitivity to touch. Unfortunately, long-term pain mitigation has not been investigated in goats.

Hempstead et al. (2017) compared the behavioural responses of kids disbudded using hot cautery to those that were sham disbudded. Kids that were disbudded displayed greater head-focused behaviours, such as head shaking, scratching, and rubbing, than sham disbudded kids. Kids that were not disbudded displayed more body shaking than those that were; this may be because the disbudded kids were more focused on their heads.

When compared with other disbudding methods, kids that were disbudded using hot cautery displayed less head-scratching 1 hour post-procedure than those that received cryosurgery or caustic paste disbudding and were seen to shake their bodies more during the hour following disbudding (Hempstead et al., 2018a). This may indicate that hot cautery is less painful than these other disbudding methods. Similarly, kids that were disbudded using hot cautery had the lowest cortisol response in the first 15 minutes, and cortisol response in the first 24 hours was not different from those disbudded using clove oil (Hempstead et al., 2018d).

A study assessed pain sensitivity around the disbudding site up to 14 days post-disbudding in kids that were disbudded using hot cautery, a sodium hydroxide-based caustic paste, or cryosurgery (Hempstead et al., 2018e). Kids that were disbudded using hot cautery had lower pain sensitivity than those that were disbudded using caustic paste or cryosurgery (Hempstead et al., 2018d).

5.3.1.1 Deaths Associated with Hot Cautery Disbudding

Death immediately following cautery disbudding may be due to hypothermia or organ damage from anesthesia-induced cardiopulmonary depression (Van den Brom et al., 2020). Thermal damage to the skull or brain is another risk to kids following hot cautery disbudding. Kids have thin skulls and are highly susceptible to improper disbudding procedures. In a study monitoring kids on 16 commercial farms, Todd et al. (2019) found that of the 107 kids submitted for postmortem in early life, 16% died of disbudding related injuries, which included damage to the brain as well as secondary infections such as meningitis. High temperatures, holding the iron against the head too long, or holding the iron against the skull with too much pressure will result in damage to the skull and brain (Baker, 1981; Buttle et al., 1986; Gascoigne, 2015; Smith & Sherman, 2009; Thompson et al., 2005; Van den Brom et al., 2020; Williams, 1990; Wright et al., 1983). For example, 5 kids that were disbudded using hot cautery between 2 to 3 weeks of age developed incoordination, paraplegia, convulsions, or fell into a coma between 1 to 10 days after disbudding (Sanford, 1989).

5.3.2 Caustic Paste Disbudding

Disbudding using caustic paste is often discouraged because of the risk of the paste getting in the kid's eyes or being rubbed onto another animal (Baker, 1981; Smith & Sherman, 2009). However, a petroleum jelly product can be applied as a ring around the area where the caustic paste is applied to avoid spreading (Smith & Sherman, 2009). Currently, there is no information on how long caustic paste remains active on the kid to determine how long to isolate kids after application to avoid paste transfer. It should be noted that the caustic pastes come in different formulations (e.g., calcium hydroxide combined with sodium hydroxide), and not all have been tested for goat kids.

When behavioural responses to a sodium hydroxide-based caustic paste, hot cautery, cryosurgery, and clove oil disbudding were compared, kids that received caustic paste displayed greater head shaking and scratching and groomed and fed less than those that received hot cautery (Hempstead et al., 2018a). Kids that were disbudded using caustic paste had higher cortisol levels than hot cautery and similar levels to those that were cyrosurgically disbudded (Hempstead et al., 2018d). Kids that were disbudded using caustic paste (the same paste that was used in Hempstead et al., 2018a) had higher pain sensitivity than those that were disbudded using hot cautery (Hempstead et al., 2018e).

5.3.3 Clove Oil Disbudding

The use of clove oil has been recently explored as a method to disbud kids. Clove oil has been shown to stop horn growth when injected into the horn bud (Molaei et al., 2015). It causes inflammation at the injection site and necrosis of the horn bud within 1 week (Hempstead et al., 2018a). Based on pain-associated behaviours (e.g., head shaking and scratching), clove oil disbudding may be as painful as hot cautery. Similarly, when the methods were compared on the physiological response of kids, cortisol response in kids disbudded using clove oil and hot cautery did not differ (Hempstead et al., 2018d). However, there was an increase in haptoglobin at 15 minutes and 24 hours post-disbudding, at which haptoglobin concentrations were greater than kids that were disbudded using other methods. Interestingly, clove oil disbudding was suggested to be less painful (at least in the first 24 hours) in calves (Sutherland et al., 2018).

However, clove oil is not as successful as hot cautery. In a study that compared clove oil and hot cautery disbudding, kids that received clove oil were more likely to have scur formation or total failure to eliminate the horn bud resulting in normal horn growth (Hempstead et al., 2018c).

In one study, 4 of 11 kids that were disbudded using clove oil died with evidence of suppurative meningitis or other lesions (Still Brooks et al., 2017). Another report by a practitioner stated that of 20 Nigerian Dwarf kids disbudded by using clove oil (injecting 0.2 mL injected under the horn bud), 2 died, and there was evidence of bone necrosis (Balch, 2018). In the USA, Food Animal Residue Avoidance Databank (FARAD) recommends against its use and states any animal treated with clove oil would not be able to enter the food chain for life (*Wool & Wattles*, 2016).

5.3.4 Cryosurgical Disbudding

Cryosurgical disbudding uses a specialized tool to apply liquid nitrogen onto each horn bud for 10 seconds (Hempstead et al., 2018e). Kids that were disbudded using the cryosurgical method have been observed to head scratch more than those that were disbudded using hot cautery and similar to those disbudded using caustic paste (Hempstead et al., 2018a).

Over 24 hours, kids that were disbudded using cryosurgery had similar cortisol levels to those disbudded using hot cautery (Hempstead et al., 2018d). These findings may indicate that cryosurgery disbudding is more painful than hot cautery and as painful as caustic paste disbudding.

5.3.5 Surgical Dehorning

Adult goats may be dehorned using a surgical method by a veterinarian, but this procedure is considered invasive because of the severity of the wound post-operatively. The skin 1 centimetre around the base of the horn must be incised to the skull, and then obstetric wire or a saw is used to remove the horn (Baker, 1981; Bowen, 1977; Buttle et al., 1986; Hull, 1995). Gouges, Barnes dehorners, and Keystone dehorners are not recommended as the bone separating the frontal sinuses from the brain is very thin and prone to damage, including fracture (Baker, 1981; Bowen, 1977; Hull, 1995).

It is advised to not use overhead feeders after surgical dehorning to avoid debris entering the sinus (Smith & Sherman, 2009). Surgical dehorning typically takes 4 to 6 weeks to heal, but may take several months, depending on horn size (Baker, 1981; Bowen, 1977; Buttle et al., 1986; Hull, 1995).

5.4 Disbudding/Dehorning Pain Mitigation Strategies

It is recommended that goats should be sedated for disbudding and dehorning (Baker, 1981; Bowen, 1977; Buttle et al., 1986; Van den Brom et al., 2020). Nfor et al. (2016) explored the use of dexmedetomidine hydrochloride before hot cautery disbudding as a sedative and analgesic. Kids that were sedated with dexmedetomidine hydrochloride also received intramuscular meloxicam and a lidocaine ring block and displayed significantly less pain-associated behaviours and maintained low cortisol levels; those that did not receive sedation but received meloxicam and lidocaine displayed significantly greater pain-associated behaviours and cortisol levels. Therefore, dexmedetomidine hydrochloride is a promising sedative to alleviate pain associated with disbudding.

Anesthesia can be performed by veterinarians with a variety of drugs. A combination of xylazine and butorphanol will provide mild to moderate sedation (Seddighi & Doherty, 2016). However, this protocol was deemed insufficient in 35.8% of cases, with the kids exhibiting responses during the disbudding procedure performed by the farmer (Wagmann et al., 2018). The researchers found that if the kids were manipulated during the induction phase, they were more likely to react to disbudding. It should be noted that it is illegal to dispense ketamine in Canada and it must only be administered by a licensed veterinarian. Propofol, which cannot be dispensed to the public, may also be used at 4 mg/kg to provide temporary general anesthesia to kids, and is best used in combination with an analgesic (Ferreira et al., 2016).

A local anesthetic may be administered to each horn by blocking the cornual branch of the lacrimal nerve and the cornual branch of the infratrochlear nerve on each side (Bowen, 1977; Buttle et al., 1986; Hull, 1995). The cornual branch of the lacrimal nerve can be blocked by injecting lidocaine between the lateral canthus and the posterior aspect of the horn (Bowen, 1977; Smith & Sherman, 2009). The cornual branch of the infratrochlear nerve can be blocked by injecting lidocaine at the dorsomedial rim of the orbit. The branches of these nerves can make performing an effective nerve block difficult (Hempstead et al., 2018b). The efficacy of local anesthetics for use during disbudding in kids is problematic, and the literature is not conclusive. For example, Ajuda et al. (2020) compared hot cautery disbudded kids using a local anesthetic alone or in combination with an analgesic (flunixin meglumine) to those that were disbudded without pain mitigation. It was reported that there was no significant differences between treatment groups. Alvarez et al. (2015) reported that when they compared pain responses in kids that were hot cautery disbudded after both nerve blocks were applied to those that did not receive nerve blocks, there was no difference in cortisol and behavioural responses up to 4 hours post-disbudding. This suggests that either pain was still perceived or that the stress and pain of receiving 4 nerve blocks was similar to the stress and pain associated with disbudding.

A ring block around the horn base has been recommended (Baker, 1981). Alvarez et al. (2009) evaluated a ring block around the horn 20 minutes before hot cautery disbudding in comparison to kids that received no anesthesia before disbudding. There was a significant increase in serum cortisol and pain-associated behaviours in both treatment groups, demonstrating that hot cautery disbudding was a painful procedure and that a ring block did not supply sufficient pain mitigation.

It should be noted that the maximum dose of lidocaine to be administrated to a goat is calculated as 5 mg/kg body weight (Buttle et al., 1986; Smith & Sherman, 2009). Each mL of lidocaine solution contains 20 mg of lidocaine. This means that a 4 kg kid can receive 20 mg, or 1 mL, of lidocaine. Many veterinarians will dilute the lidocaine to 1%; further dilution may decrease its efficacy. These small volumes make accurate blocking of the appropriate nerves more difficult (Smith & Sherman, 2009). It is recommended that local anesthetic be performed 20 minutes before disbudding (Van den Brom et al., 2020). Lidocaine toxicity causes convulsions and respiratory and cardiac arrest resulting in death.

Meloxicam, an NSAID, has been evaluated to relieve pain associated with disbudding. In a study that assessed intramuscular meloxicam injection administered at 0.5 mg/kg immediately after hot cautery disbudding under general anesthesia, meloxicam treated kids displayed a lower level of pain-associated behaviours in the first 24 hours than those that received a placebo (Ingvast-Larsson et al., 2011). Oral meloxicam has been shown to be equally effective as an intramuscular injection. However, while kids that received meloxicam subcutaneously or orally immediately prior to castration were both observed to display behaviours similar to those that were sham disbudded, they had cortisol levels similar to those that were disbudded with hot cautery without pain mitigation (Hempstead et al., 2018b). This suggests that more research is needed to determine the true efficacy of NSAIDs and the optimal time to administer to reduce disbudding pain post-operatively.

5.5 Horn Tipping

Producers sometimes choose to remove the tip of their goats' horns instead of dehorning them to avoid pain and a long healing period (Smith & Sherman, 2009). Tipping is often done when scurs that occur as a result of improper disbudding or dehorning threaten to grow into the body of the goat. Many countries require that pain mitigation always be used in older animals with the assumption that it is painful despite choosing this method (Alvarez et al., 2009; Thompson et al., 2005). Unfortunately, there is no literature to date that examines the effect of horn tipping on goat welfare; however, the producer should weigh the risk of a scur growing into the body of the goat with the pain associated with removing the tip of the horn. Horn tipping in cattle has been associated with less pain when tipped distal to the blood supply (Neely et al., 2014; Winks et al., 1977). Additionally, cattle that were tipped to the point of hemorrhage had lower weight gains than those cattle that were not tipped or dehorned (Winks et al., 1977).

5.6 Disbudding/Dehorning Alternatives

Unlike with some cattle breeds, breeding for polled goats is not an advisable strategy to reduce the need for dehorning. In goats, the polled trait is dominant (P) and horned recessive (p). However, homozygous polled females (PP) have masculinized genitalia (i.e., hermaphrodites or pseudohermaphrodites), and so are infertile (Smith & Sherman, 2009; Soller et al., 1963). This is termed the Polled Intersex Syndrome. Early literature suggested that breeding of a polled heterozygous doe (Pp) to a polled heterozygous buck (Pp) would produce mostly polled offspring (Soller et al., 1963). Research is underway to seek ways to prevent the sex-reversal associated with the polled gene, and so be able to produce animals that can breed polled offspring without sex-reversal (Boulanger et al., 2008).

5.7 Future Research

1. More research is needed on acute and long-term pain mitigation protocols for disbudding and castrating kids, including the efficacy of NSAIDs.
2. Castration research in goats is limited, and research is needed to compare which methods result in the least amount of pain, both acute and chronic.
3. Research on the effect of age at the time of castration is needed.
4. Research into alternatives to disbudding (e.g., best practice for managing horned goats) is needed.
5. Research exploring the use of genes or gene markers to assist in the breeding of polled animals without reproductive issues should be explored.
6. Research on horn tipping in goats is required to evaluate the procedure and determine its impact on goat welfare.

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6 Perinatal Management to Optimize Kid Health

Conclusions

1. **Colostrum management is the main perinatal management practice influencing overall kid health and survival.**
2. **Successful passive transfer of immunity from the ingestion of colostrum is linked to timing, volume, and colostrum quality.**
3. **Colostrum quality should be established using on-farm measures that are available.**
4. **Freezing colostrum is an acceptable storage method, but repeated thawing and freezing can impact colostrum quality. Refrigeration of colostrum for a short period is possible, but bacterial growth can still occur and may reduce IgG absorption.**
5. **Thawing colostrum using a microwave can lead to uneven heating and destruction of immunoglobulins and therefore should be avoided.**
6. **Fresh, frozen, or lyophilized bovine colostrum and heat-treated goat colostrum are acceptable alternatives to fresh or frozen goat colostrum.**
7. **Disease agents can be transmitted to kids through the ingestion of infected colostrum and milk.**
8. **Heat treatment of colostrum can reduce the survival of these pathogens and so may reduce disease transmission but may result in a loss of immunoglobulins if not done correctly.**
9. **Doe nutrition and management during late gestation significantly impact colostrum quality.**
10. **Several factors, such as birth weight, neonate health, and serum immunoglobulin levels, influence neonatal growth.**
11. **Extensive system studies report that kid survival improves with each parity up to the third or fourth kidding, after which survival diminishes.**
12. **Extensive system studies indicated that as litter sizes increase there may be a decrease in the amount or quality of nutrients available to kids, which may reduce kid survival.**
13. **Very small and very large birth weights are associated with increased kid mortality.**

6.1 Introduction

Kid illness and mortality are welfare concerns and affect farm profitability (Dwyer et al., 2016). Kid survival and health are impacted by numerous factors, from the womb to weaning. Many of these factors are the result of management practices. Management of the perinantal period, including colostrum administration, is a crucial practice for the prevention of kid mortality and assuring optimal health. For this report, the impact of colostrum management factors on kid survival will be addressed as well as other factors that may affect kid health just prior to birth and within the first 7 days of life. However, this is not an exhaustive review of all applicable ruminant literature. When possible, goat literature was the focus of this review.

It is important to note that goat kid-specific morbidity and mortality research is minimal, and therefore, this review relies significantly on other ruminant literature. Often when it is available, kid health research is of limited quality, or it is sourced from a veterinary reference manual (i.e., Smith & Sherman, 2009), and therefore may be based on field observation and lacks scientific peer review.

6.2 Colostrum

Colostrum management is the main management practice that influences early calf health/survival (Godden et al., 2009). As with all ruminants, antibodies from the doe cannot be transferred to the fetus since they cannot cross the type of placenta they develop during pregnancy. Newborn kids are, therefore, born without circulating antibodies (Nagyová et al., 2017) and are dependent on ingesting antibody-rich colostrum to provide passive immunity. Without this passive transfer of immunity, the animals are at an increased risk of infection until they start producing their own antibodies at a level that will provide protection (O'Brien & Sherman, 1993; Smith & Sherman, 2009), which can take many weeks. Adequate passive transfer is dependent on the timely ingestion of a sufficient volume of good quality colostrum. Immunoglobulin G (IgG) is the main antibody found in colostrum (85–90%) with IgM (7%) and IgA (5%) present to a lesser degree. Aside from its importance in transferring immunity to newborn kids, colostrum has essential nutrients, hormones, minerals, components that contribute to intestinal tract development, and other non-immunological substances that aid in kid development (Fernández et al., 2007; Lima et al., 2013; Moretti et al., 2012a; Smith & Sherman, 2009). Inadequate transfer of antibodies is called failure of transfer of passive immunity (FTPI).

Research has not specifically addressed any limitations of feeding IgG from different species to goat kids, nor has there been a systematic assessment of effects of feeding colostrum from animals not exposed to the same pathogens that the kids are likely to encounter in their environment.

6.2.1 Definition of Failure of Transfer of Passive Immunity

Scientific evidence about the appropriate volume of colostrum to be administered to kids, when to administer, and what constitutes high-quality goat colostrum is scarce. Failure of transfer of passive immunity in dairy kids has been defined as a serum IgG concentration at 24 hours of <12 mg/mL (O'Brien & Sherman, 1993). Mellado et al. (1998) suggested that 8 mg/mL was sufficient for reducing mortality. However, both studies suffered from either a problematic description of methodology or limitations with sample size. Therefore, conclusions should not be made about the impact of serum IgG on mortality from this work.

Failure of transfer of passive immunity has been related to increased risk of a health problem in neonates (Cuttance et al., 2018). Kids with FTPI may be at higher risk for infection with opportunistic pathogens such as *Klebsiella pneumoniae*, which can cause joint ill and septicemia (Bernabé et al., 1998).

6.2.1.1 Timing of Feeding

The intestinal tract of a newborn kid is capable of absorbing macromolecules such as immunoglobulins (Ig) from colostrum. However, as the fetal enterocytes are replaced by 96 hours of age with adult enterocytes in the small intestine, that ability diminishes rapidly (Moretti et al., 2012a, 2012b; Nordi et al., 2012). Adult enterocytes are impermeable to macromolecules, such as Ig (Nordi et al., 2012). Therefore, the timing of colostrum delivery is very important.

Although there is a risk of exposure to infectious disease pathogens when kids are allowed to nurse from the doe, many operations still utilize this method; it is a relevant method when endemic infectious diseases, such as caprine arthritis encephalitis virus (CAEV), are not a concern. In one study, natural suckling over multiple days resulted in higher serum IgG levels compared to restricted (100 mL/kg birth weight of first-milking colostrum pooled from multiparous goats) twice-daily bottle-feeding for 2 days; mortality in the first 3.5 days of life (study duration) was highest in the restricted colostrum fed kids (Argüello et al., 2004a).

Castro et al. (2009) assessed the duration of colostrum feeding on passive immunity transfer by allowing dairy goat kids to nurse their dam for 1, 2, or 5 days. There was no significant difference in serum IgG concentration between kids with different colostrum feeding durations, and the authors concluded that 24 hours was enough time to successfully transfer immunity from doe to kid. This finding is supported by other studies that demonstrate that IgG absorption in kids is highest in the first 24 hours (Argüello et al., 2004b; Castro et al., 2005). Although these studies suggest that colostrum can be administered in the first 24 hours of life, there is strong evidence from cattle studies that administration within the first 2 to 4 hours after birth is best (Beam et al., 2009; Chigerwe et al., 2008). Comparable studies in goats are lacking.

6.2.1.2 Amount of Colostrum Administration

The amount of colostrum to be administered to avoid FTPI depends primarily on its IgG concentration. For example, in calves receiving colostrum by oroesophageal intubation in the first 2 h after birth, it has been recommended to administer 3 to 4 litres of good quality colostrum (i.e., colostrum containing 50,000 mg IgG/mL) to supply a total of 150,000–200,000 mg of IgG (Chigerwe et al., 2008; Godden et al., 2009). When administering good quality colostrum by bottle, smaller volumes were sufficient to achieve adequate transfer of passive immunity in calves (Godden et al., 2009).

Unfortunately, similar specific information is lacking in goats. Some literature suggests that goat kids should receive 10–20% of a kid's birth weight in litres or a colostrum volume >3000 mg IgG/kg birth weight, administered in 4–6 feedings over the first 24 hours (Castro et al., 2005; Constant et al., 1994). However, these recommendations are based on studies with a small sample size (e.g., Constant et al., 1994) or on the finding that kids receiving 3,400 mg of IgG/kg BW had a significantly higher average serum IgG concentration compared to kids that received only 1,600 or 800 mg of IgG/kg BW (e.g., Castro et al., 2005). However, even kids receiving 3,400 mg of IgG/kg had FTPI if a serum IgG concentration of 1,200 mg of IgG/mL (O'Brien & Sherman, 1993) is considered indicative of successful transfer. This value was concluded using a small sample size. Therefore, more research is needed to determine the appropriate amount of colostrum that must be administered to kids.

6.2.1.3 Measuring Colostrum Quality

The quality of colostrum is usually determined by the amount of IgG it contains. The concentration of IgG can either be measured in the laboratory or estimated using specific gravity (e.g., hydrometer) or total solid (e.g., refractometry) measurements. With regards to measuring goat colostrum quality, Castro et al. (2018) determined that a clinical refractometer value of 10 mg/mL estimated a colostral IgG concentration of >20 mg of IgG per mL with 100% sensitivity and 95.2% specificity. In other words, based on that study, a reading of 10mg/mL on the clinical refractometer will identify colostrum with >20 mg of IgG/mL in 100% of tested colostrum samples but will only identify 95.2% of those colostrum samples that do not have at least 20 mg of IgG/mL; this means that bad quality colostrum (i.e., having less than 20 mg of IgG/mL) will be falsely identified as good quality colostrum in 4.8% of tested samples. However, no explanation was given about the reasoning behind choosing a cut-off of >20 mg of IgG/mL and an IgG ELISA test was used as the reference method to determine colostral IgG as opposed to the gold standard radial immunodiffusion test. For these reasons, values determined should be considered with caution. In cattle, a colostrum IgG concentration of 50 mg/mL is usually considered good quality colostrum (Chigerwe et al., 2008; Fleenor & Stott, 1980). Whether a similar IgG concentration in goats should be considered is currently unknown (Zobel et al., 2020).

The application of a hydrometer devised for cattle correlated well with direct density measurement of goat colostrum and could be used as a stall-side test; however, ambient temperature is important when using a hydrometer as temperatures below 37°C may result in an overestimation of the IgG concentration (Rudovsky et al., 2008). The mean IgG concentration in colostrum samples obtained from healthy goats tended to be about 50 mg/mL (Rudovsky et al., 2008). Zobel et al. (2020) reported that a hydrometer had the highest accuracy to measure colostrum quality but recommended the use of a Brix refractometer (both digital and optical) for on-farm colostrum quality assessment due to its ease of use; the authors recommended a minimum cut off of 19%.

6.2.1.4 Measuring Successful Transfer of Passive Immunity

Transfer of passive immunity can be evaluated directly by measuring serum IgG (reported as mg of IgG/mL) or indirectly as serum total protein (reported as g/dL), Brix percentage on a refractometer, or glutaraldehyde coagulation time (reported as minutes to coagulation; Lima et al., 2013; Yalcin et al., 2010; Zobel et al., 2020). These indirect indicators have been validated to be good indicators of serum IgG.

Kid health and survival is associated with the successful transfer of antibodies from colostrum. Kids with higher levels of serum IgG are more likely to survive than those with low serum levels (Arguello et al., 2004a; O'Brien & Sherman, 1993). For example, kids that survived to 84 hours had a significantly higher serum IgG (above 14 mg/mL for the duration of the 84-hour study-period) than kids that died during the first 84 hours (consistently below 9 mg/mL for the study period; Argüello et al., 2004a). In a small study using 39 kids, O'Brien and Sherman (1993) stated that a serum IgG concentration of 12 mg/mL at 24 to 48 hours of age is necessary to provide adequate immunity. This recommendation was based on the findings that kids that remained healthy (n=24) had a serum IgG of 14.4 mg/mL while those that fell ill (n=4) or died (n=11) had a serum IgG of less than 8 mg/mL. Despite the small sample size, a serum IgG concentration of 12 mg/mL is often used as the threshold for FTPI in kids based on this study alone and validation from other studies is lacking.

Although the exact amount of IgG necessary for adequate transfer of passive immunity has not been definitively determined in goats, greater than 3 g IgG/kg body weight (BW) has been recommended (Castro et al., 2005). Despite this recommendation, however, kids that received greater than 3 g/kg BW still all had serum IgG levels of less than 12 mg/mL, which would constitute FTPI based on the limited sample size study by O'Brien and Sherman (1993).

In healthy calves, multiple tests have been evaluated to determine successful transfer of passive immunity, but measuring serum total protein concentrations as a proxy of serum IgG concentrations is one of the most practical measurements for FTPI (Hogan et al., 2015; Weaver et al., 2000). In that species, a serum total protein concentration of 5.2 g/dl measured by manual refractometry was associated with a serum IgG concentration of 10 mg/mL, which is generally considered indicative of successful transfer of passive immunity. Similarly, a Brix refractometer approximates the total solid percentage in serum and, when used on calf serum, provides a strong estimate of the serum IgG concentration (Deelen et al., 2014).

There is little information on measuring serum total protein concentrations in goats following colostrum ingestion. Although Batmaz et al. (2019) evaluated serum refractometry (Brix), glutaraldehyde coagulation time, gamma-glutamylstransferase activity and total protein concentration in comparison to serum IgG concentrations after colostrum administration, there are serious concerns about the validity of these results as a serum IgG ELISA test was used as the reference test as opposed to the radial immunodiffusion which is considered the gold standard. For this reason, results must be interpreted with caution and require validation by more rigorous studies.

Oman et al. (2018) evaluated a digital Brix refractometer to assess FTPI in 30 goat kids and determined that a serum refractometer reading of 8.4% corresponded with a serum total protein concentration of 5.4 g/dL. While the authors concluded that this indicated successful transfer of passive immunity, they neither provided a serum total protein cut-off value for that statement nor correlated their findings to serum IgG concentrations. Further studies are necessary to validate these findings.

6.2.2 Serum IgG and Growth

Studies that focus on the relationship between serum IgG and growth must be considered with caution. Each study has different methodologies. Some use multiple ELISAs, but there is little validation of these tests with the gold standard that is radial immunodiffusion (RID). Nonetheless, ELISAs are often used to validate other indirect measures of IgG, such as Brix refractometer and gamma-glutamyl transferase activity. While serum IgG is an important factor in keeping neonates healthy in their early lives, many other factors contribute to growth that must be investigated in a large controlled study. To date, no such study has been completed in small ruminants.

Gökce et al. (2013) reported that lambs that had a serum IgG concentration of less than 10 mg/mL at 24 hours of age had significantly lower growth performance than those lambs that had a serum IgG concentration of greater than 10 mg/ml. Lambs were allowed to naturally nurse from the dam for the first week of life, followed by bottle feedings. However, ELISA testing was used to measure serum IgG concentrations without additional testing. Other factors, such as dam age, birth weight, litter size, and lamb health, significantly influenced body weight at 28 days of age. Massimini et al. (2007) suggested that when allowed to suckle their dam for 9 hours per day until weaning, kids with increased serum IgG had improved daily weight gain and weaned heavier at 30 days of age; however, this work used a limited number of kids (n=20), did not include any kids with FTPI, and the analysis was unduly influenced by 4 outliers.

Cuttance et al. (2018) investigated the effect of FTPI (defined in the study as serum total protein ≤52 g/L) on morbidity, mortality, and body weight in pasture-raised dairy calves. The study included 2,855 calves from 82 dairy farms in the weaning weight analysis. Calves that were classified as FTPI had lower weaning weights (0.83 kg) than those calves that had successful transfer of passive immunity. For each 10 g/L increase in total serum protein, there was an increase in weaning weight by 0.4 kg.

Similarly, Robison et al. (1988) assessed the effect of passive immunity on weight gain and performance of Holstein dairy heifers up to 180 days of age. Calves were permitted to naturally suckle from the dam for the first 24 hours of life and were then intensively raised. Serum total protein was measured using RID from samples collected between 24 and 48 hours and at 35 days of age. Season of birth and serum IgG levels were all reported to have a significant impact on average daily gain up to 180 days of age. The age of the dam was also significant, but only up to 35 days of age. Elsohaby et al. (2019) performed a similar study with Holstein calves but reported that serum IgG only had a significant relationship with average daily gain between birth and 21 days of age.

6.2.3 Pathogens of Concern in Colostrum

The transmission of small ruminant lentiviruses (SRLVs), such as CAEV, is a concern when feeding infected colostrum and milk to kids, although both in utero and horizontal transmission of the virus are important routes of transmission as well (Blacklaws et al., 2004; Peterhans et al., 2004; Pisoni et al., 2007). Small ruminant lentiviruses are mostly contained within infected cells but may be present freely in colostrum (Pisoni et al., 2007). Infection with CAEV causes life-long infection and chronic inflammation and degeneration of the joints and mammary gland, and may cause chronic progressive pneumonia and, rarely, leucoencephalitis (Smith & Sherman, 2009; Stonos et al., 2013). It is an important financial threat to an operation and can cause a 10% decrease in milk production in seropositive does (Blacklaws et al., 2004; Stonos et al., 2013). In a retrospective study of 22 goat herds in Spain, does that were seropositive for CAEV had shorter lactations, lower milk yield, reduced milk quality, and higher somatic cell counts in comparison to seronegative does (Martínez-Navalón et al., 2013). The estimated prevalence of SRLVs in Ontario goat herds is 80.4% in dairy herds and 17.0% in meat herds (Stonos et al., 2013). In addition to CAEV, colostrum may contain *Mycobacterium avium paratuberculosis* (MAP), the causative agent of Johne's disease (Smith & Sherman, 2009; Sweeney et al., 2012). In Ontario, the prevalence of MAP in dairy goat herds has been estimated to be as high as 83%, while the average within herd prevalence was estimated at 35% (Bauman et al., 2016).

To reduce the risk of pathogen transmission, the colostrum may be heat-treated at 60°C for 60 minutes (Godden et al., 2012). Lower risk sources of IgG, such as fresh or frozen bovine colostrum from a MAP-negative herd, or the use of bovine-sourced lyophilized colostrum replacement products, may also be used (Smith & Sherman, 2009). Heat-treatment of colostrum (following appropriate methodology), feeding lyophilized colostrum replacement products, or using bovine colostrum can reduce the transmission of SRLVs and other disease-causing organisms such as *Mycobacterium avium paratuberculosis* (Sweeney et al., 2012). Therefore, producers must consider their options when choosing to reduce infectious disease incidence in their herds and achieve successful passive transfer to their kids. Antibodies in the dam's colostrum target those pathogens that are either common in the dam's (and hence the kid's) environment or against which the dam has been vaccinated (Awa et al., 2002; Balamurugan et al., 2012; de la Rosa et al., 1997; Vihan, 1993). An alternative product will likely have a different antibody composition and producers must consider this when sourcing colostrum off-site.

6.2.4 Types of Colostrum

Although research is sparse for goats, there are different colostrum options for producers, such as allowing the kids to nurse naturally or manually feeding heat-treated, fresh, refrigerated, or frozen goat or cow colostrum, as well as lyophilized bovine colostrum replacer products.

6.2.4.1 Colostrum from Other Ruminants

Lyophilized bovine colostrum is a commonly used source of IgG for kids. Moretti et al. (2012c) compared lyophilized bovine colostrum to frozen pooled goat colostrum. They reported that kids that received bovine colostrum (31,400 ± 1,400 mg IgG total) had adequate IgG absorption and circulating antibodies at 24 and 48 hours of age (14.1 and 14.6 mg/mL, respectively) but that this declined to below the threshold for adequate passive transfer at 72 and 96 hours, the time when serum IgG levels are typically tested. Further work is needed to address why this occurred and if it is a repeatable finding. Multiple studies have reported that kid small intestines are capable of absorbing bovine IgG (Lima et al., 2013; Moretti et al., 2012a, 2012b; Nordi et al., 2012); however, no research has determined any limitations of cross-species IgG sources.

6.2.4.2 Heat-Treated Colostrum

It is commonly recommended to heat-treat colostrum before feeding to prevent the transfer of infectious organisms. Godden et al. (2006) reported that heating bovine colostrum to 60°C for 120 minutes, did not significantly affect IgG concentration. Heat-treatment of bovine colostrum also increased IgG absorption efficiency and reduced morbidity in calves when compared to those fed fresh bovine colostrum (Godden et al., 2012).

Information regarding the heat-treatment of goat colostrum is scarce. Heat-treatment (at 56°C for 30 minutes or at 57°C for 10 minutes followed by one-hour storage in a thermos that was preheated using boiling water) has been reported to significantly reduce goat colostrum IgG levels by approximately one-third (from 33.6 mg of IgG/mL to 21.2 and 20.9 mg of IgG/mL, respectively; Argüello et al., 2003). Loste et al. (2008) reported that heat-treating sheep colostrum (56°C for 30 minutes) resulted in a decrease in IgG levels (from 64.2 mg of IgG/ml to 42.1 mg of IgG/ml), and lambs that received the heat-treated colostrum had significantly lower serum IgG concentrations than lambs that were fed untreated colostrum. However, the health and performance of the lambs was not affected by heat-treating the colostrum. Pasteurization of colostrum (68.3 to 70.8°C) has been reported to destroy MAP bacteria in bovine colostrum successfully but resulted in a 25% decrease in IgG concentration (Stabel et al., 2004). In contrast, Trujillo et al. (2007) did not find a difference between heat-treated (56° for 60 minutes or 63° for 30 minutes at very high pressure) and raw goat colostrum. However, the IgG concentration was slightly reduced in the heat-treated colostrum.

6.2.4.3 Lyophilized Colostrum

Castro et al. (2005) noted that lyophilized goat colostrum fed as a paste was a superior and viable alternative. Kids that received the lyophilized colostrum paste (3,368 mg of IgG/kg BW) had significantly higher IgG concentrations than those that received frozen goat colostrum. Lyophilized goat colostrum is not commercially available in Canada; however, bovine lyophilized colostrum is. Rodríguez et al. (2009) reported that kids fed the same total amount of Ig absorbed more Ig when atomized colostrum was used to create an 80mg/ml paste (kids were fed 25mL of paste/kg BW) compared to pastes with lower Ig concentrations and fed with higher volumes. A number of goat studies have demonstrated that lyophilized bovine colostrum replacer is an acceptable alternative to goat colostrum (Lima et al., 2013; Moretti et al., 2012a, 2012b, 2012c; Nordi et al., 2012). This is supported by similar findings in lambs (Berge et al., 2018; Tsiligianni et al., 2012). To date, there is no evidence that lyophilized bovine colostrum has a negative influence on small ruminant health.

6.2.5 Colostrum Storage

Producers may choose to save colostrum from other goats to feed in circumstances where the dam's colostrum is unavailable or of poor quality. Argüello et al. (2003) investigated the refrigeration of colostrum for up to 3 months. IgG concentration decreased by 25% in that time, and the authors recommended to refrigerate colostrum for a maximum of 1 month. However, although no specific literature is available for goat colostrum, bacterial growth in refrigerated bovine colostrum is a real concern, and unacceptably high levels of bacterial counts may be reached even during refrigeration as short as 48 hours (Godden et al., 2019; Kryzer et al., 2015). Freezing may, therefore, be a preferred storage option, but it must be thawed appropriately to maintain its quality (Argüello et al., 2003).

Colostrum can be thawed and refrozen; however, each cycle of thawing and refreezing goat colostrum results in a loss of IgG (Balthazar et al., 2015; Argüello et al., 2003). While Argüello et al. (2003) found no difference in IgG reduction between different thawing methods of goat colostrum (hot water bath, fridge, room temperature, microwave), the colostrum used was of poor quality. Balthazar et al. (2015) and Wiking and Pedersen (2009) suggested that if IgG concentration is sufficiently high to compensate for the loss during microwave thawing, then this method may be used. Nonetheless, it is not advised. Microwave heating may be uneven, and if areas are overheated, then degradation of IgG will occur, compromising colostrum quality. Instead, options include thawing in the refrigerator for 2 days before use or thawing in warm water baths (double boiler also known as a bain-marie). Balthazar et al. (2015) compared IgG levels in bovine colostrum thawed using either a microwave or a bain-marie and found a decreasing IgG concentration as well as coagulation in colostrum thawed by microwaves and in a bain-marie heated to 60°C. Using a bain-marie set to 40°C to thaw colostrum resulted in the least amount of IgG loss (8%) but did take the longest to complete.

6.3 Additional Factors that Affect Kid Mortality

6.3.1 Dam Factors

Doe health during gestation can have a significant impact on kid survivability. Maternal ketoacidosis, resulting from pregnancy toxemia, has been associated with metabolic acidosis in the newborn kids, resulting in an increased mortality rate (Andrade et al., 2019).

Colostrum yield is related to dam nutrition fed in the last 3 weeks of gestation (Dwyer et al., 2016). It is secreted until 36 hours post-partum; however, both total protein and IgG concentrations decrease in that time (Romero et al., 2013).

The time between dry off and kidding has a significant impact on colostrum quality and kid mortality. Caja et al. (2006) compared colostrum quality of 17 dairy does that were dried off 8 weeks before kidding to those that were milked until kidding. Does that were milked throughout late pregnancy (n=3) had significantly smaller kids (~0.5 kg lower in weight) and produced colostrum with a lower concentration of IgG (5.6 mg/mL) than those that had a dry period (32.9-52.4 mg/mL). 5 goats in the study dried off spontaneously 27 days before kidding thereby reducing the number of does in the no-dry-off period to 3, which is a very small sample size to base these results on and this finding needs to be re-evaluated in a larger study. There was no difference in colostrum quality between the goats with a 27-day dry period compared to those with the 56-day dry period.

In extensive systems, where kids are reared by the dam, poor bonding between the dam and the young can cause starvation, hypothermia, and death in kids (Dwyer et al., 2016). Refer to *Section 1: Natural Behaviours* for a review of the doe-kid bond.

Parity has a significant impact on preweaning kid mortality. A study that examined an extensive herd's records to determine factors that affect preweaning kid survival reported that survival rate increased up to and including the fourth parity, but decreased after that (Hailu et al., 2006). Further, Mazumdar et al. (1980) reported that kid survivability improved in subsequent parities (up to the third parity) when they analyzed herd records. The effect of parity on kid survival may be due to mismothering, or insufficient milk let down or production during a dam's first kidding (Singh et al., 2008).

6.3.2 Litter Size

The size of the litter has an impact on kid survival. Pisarska et al. (2002) assessed colostral passive immunity in a small goat herd by collecting blood from kids immediately after birth and up to 28 days of age. The kids were left with the does to allow for natural rearing. Single born kids reached higher IgG concentrations at 48 hours of age than twin kids and maintained higher concentrations for up to 4 weeks of age. Kids born to low hierarchy does did not receive sufficient immunity due to antagonistic behaviours from dominant does. However, Castro et al. (2009) reported that singles and twin dairy kids had similar serum IgG concentrations, but kids from litters of 3 had significantly lower levels. In this study, the time allowed for kids to stay with their dam ranged from 3 days, after which they were artificially reared. There was no significant difference in serum IgG between kids with different durations of natural suckling.

Hailu et al. (2006) reported that litter size influenced the preweaning survival rate of Borana and Arsi-Bale goats in an extensive system. Triplets had a lower survival rate than twins and singles. It was theorized that larger litter sizes cause fewer nutrients to be delivered to each kid in utero and in colostrum and milk after birth. Argüello et al. (2006) reported that does with a single offspring had higher colostrum fat and lactose content than those with multiple offspring; however, parity did not have an effect on Ig content.

6.3.3 Birth Weight

The effect of litter size is correlated to birth weight, as single kids are often heavier than kids born to twin or triplet litters. In a study that evaluated the effect of newborn characteristics on passive immunity transfer, kids that weighed ≥2.8 kg had significantly higher IgG concentrations than lighter kids (Castro et al., 2009). Hailu et al. (2006) stated that kids born in an extensive system that weighed more than 3 kg had the highest survival rate (74%) compared to 72% for kids that weighed between 1.1 to 3.0 kg and 68% for kids that weighed less than 1 kg.

Some studies have stated that kid sex has an impact on kid mortality (Hailu et al., 2006; Iji et al., 1996), while others reported no difference (Castro et al., 2009; O'Brien & Sherman, 1993). Iji et al. (1996) associated higher male kid survival to heavier male kids. This is supported by previously mentioned studies that support higher survivability in heavier kids. However, Hailu et al. (2006) reported that male kids had higher mortality rates. Unfortunately, no explanation behind this difference was supplied.

6.3.4 Environment

Mortality can be affected by the environment the kids are born and raised in. For instance, disease is more of a concern in housed kidding systems and less so in outdoor systems (Dwyer et al., 2016). Environmental hygiene practices, such as cleaning procedures in intensive systems, may have an impact on kid mortality (Todd et al., 2019). However, outdoor systems have an increased risk of predation, starvation, and hypothermia (Dwyer et al., 2016).

In extensive systems, preweaning mortality has been related to seasonality and rainfall. This relation may be due to feed availability during seasons with heavier rainfall (Hailu et al., 2006). Newborn kids are susceptible to cold temperatures, and the risk of hypothermia increases when small, wet kids are exposed to cold, windy, or wet environments (Smith & Sherman, 2009). Secondary hypothermia is a result of kids not receiving enough colostrum and milk to maintain their internal body temperature. It is recommended that the kidding area be kept clean, warm, and dry to improve kid survivability.

6.3.5 Milk Quality for the Pre-Weaning Feeding Period

Milk replacer and acidified milk replacer are options available to feed kids after adequate colostrum administration, especially those in a dairy system where doe milk is marketed or if there is a concern of SRLV transmission. De Palo et al. (2015) compared goat milk, warm goat milk replacer, and acidified goat milk replacer on Saanen kid growth and carcass quality. There was no significant effect of kid diet on growth or carcass performance.

Similarly, Vacca et al. (2014) reported that kids bottle-fed acidified bovine milk replacer initially had a lower growth rate than kids allowed to feed off their dams, most likely due to difficulties in bottle training. By 6 weeks of age, there was no significant weight difference. Nonetheless, this study was confounded in the sense that there was no evaluation of dam milk fed from a bottle. The growth of Criollo kids did not differ when allowed to nurse off the dam or when fed milk replacer (Paez Lama et al., 2013). These studies indicate that milk replacer and acidified milk replacer are acceptable alternatives to natural milk. However, there are limited studies available on kid milk requirements and on acceptable milk hygiene.

6.4 Future Research

Goat kid health and mortality research is limited in amount, scope and quality. A large number of the studies encountered in this review were found to make recommendations based on either poorly described or poorly designed studies. Suggested research areas include:

1. Determining the total amount of colostrum to be fed to kids to ensure the successful passive transfer of immunity and to satisfy kids' nutritional requirements.
2. Determining what constitutes "good quality" colostrum (i.e., the IgG concentration in colostrum that provides adequate passive transfer).
3. Determining if antibodies from non-caprine species circulate as long as antibodies from a caprine source.
4. Determine the effectiveness of different colostrum administration methods (e.g., voluntary suckling versus tube feeding).
5. Heat-treatment methods of colostrum and their effect on colostrum quality and pathogen load.
6. Use of other colostrum sources for kids with regards to the prevalence of FTPI, change in immune status over time, growth, and incidence of diseases.
7. Investigating milk replacer product components needed for kids.
8. Determining the impact of milk/milk replacer hygiene and milk requirements (i.e., amount, frequency, and delivery method) on kid health.

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