Development of methods to evaluate hoof conformation and lameness in New Zealand dairy goats and the effects of trimming regimes on goat hoof health

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Abstract

Lameness is a debilitating and painful condition. It is considered a major welfare and economic issue in the dairy industry, due to its high prevalence and associated production losses, and the serious impact it has on individual animals. One major risk factor for lameness is hoof overgrowth and consequently poor hoof conformation. Dairy goats in New Zealand are largely housed indoors; such environments offer limited opportunity for natural hoof wear, therefore hoof overgrowth is likely to be common. However, there are few data in New Zealand evaluating hoof conformation, lameness, or how we can best maintain a normally structured hoof and minimise lameness in commercially housed dairy goats.

The overarching aim of this thesis was to examine the hoof conformation and gait of New Zealand dairy goats and to evaluate how these factors are impacted by hoof trimming. Specifically, I aimed to develop and validate a hoof conformation assessment for use in dairy goats, and to develop a reliable gait scoring system that would allow detection of an uneven gait as a potential precursor to clinical lameness. Furthermore, I aimed to use these methods to evaluate the immediate impacts of hoof trimming and the longer-term impacts of early life hoof trimming and subsequent trimming frequency on anatomical (e.g., hoof conformation, joint positions, hoof growth) and behavioural (e.g., lying behaviour, gait) variables.

The hoof conformation assessment was determined to be reliable following considerable training of observers; both the objective measures and subjective scores could be used to accurately assess aspects of hoof conformation from photographs. As the subjective scores are less time-consuming and do not require technical equipment, I suggest they should be trialed for on-farm use.

A reliable 5-point gait scoring system was developed in a controlled setting at the AgResearch Goat Research Facility. It included an “uneven gait” category, allowing identification of goats which may be predisposed to developing clinical lameness. However, whether it is feasible to detect an uneven gait from live observations on commercial farms is still to be determined.

In an observational study conducted on 16 farms (n = 1099 goats; mean ± SD: 64 ± 9 goats/farm), goats that had not been trimmed prior to first mating (8.0 ± 0.70 months) had greater odds of poor hind hoof conformation at that time compared with goats on farms that had already trimmed prior to mating. In the longer term, goats on farms that had not trimmed before first kidding (14.8 ± 0.86 months) had greater odds of having dipped heels on the hind hooves at the end of second lactation (34.1 ± 0.90 months). In contrast, in a controlled experimental study

conducted on one farm (n = 80 goats), only minor effects of early life trimming (before first kidding) on hoof conformation were found, and these were not consistent at assessments completed at the end of the first (13 months) and second lactations (25 months). In the experimental study, as poor conformation was observed in both the early and late trimmed treatments, it suggests that the subsequent hoof trimming (3 times per year) was not frequent enough to prevent overgrowth; the early life trimming treatment was not effective at this trimming frequency. In the observational study, trimming frequency following first kidding had no observable effects on hoof conformation. However, differences in the housing environment and management may be strongly impacting hoof conformation across the 16 farms.

In the short term, immediate beneficial effects of hoof trimming were observed in the experimental study, with aspects of hoof conformation and joint positions restored to more anatomically correct shapes and positions. There was also some evidence of a transient effect of trimming on lying behaviour, with lying time increasing the day after hoof trimming at 3 out of 4 assessments over the first two years of life. An increase in lying time may be indicative of a pain response. However, daily lying behaviour was highly variable so should be interpreted with caution.

High proportions of dipped heels, misshaped claws and splayed claws, particularly in the hind hooves, were recorded on 16 farms in the observational study and before trimming in the goats on the experimental study. Interestingly, on the latter farm, the prevalence of clinical lameness (scored from videos) in the same goats was lower than expected over the 2-year study period, though prevalence of an impaired gait (either uneven gait or clinical lameness) peaked after both kidding events. In addition, the rate of hoof growth changed across the goats' first two years of life, slowing when the goats were in kid.

Overall, my findings suggest that the trimming regimes evaluated in these studies were not adequate to prevent poor hoof conformation in goats housed in indoor environments that do not promote hoof wear. In order to achieve good conformation and long-term hoof health, dairy goat hoof management strategies should include consideration of the timing of first hoof trimming and subsequent trimming frequency, as well as providing an environment that promotes hoof wear.

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Publications

Publications related to this thesis

Peer reviewed journal articles

Deeming LE, Beausoleil NJ, Stafford KJ, Webster J, Zobel G. 2019. The development of a hoof conformation assessment for use in dairy goats. Animals 9, 973. **(Chapter 2).**

Deeming LE, Beausoleil N., Stafford KJ, Webster JR, Zobel G. 2018. Technical note: The development of a reliable 5-point gait scoring system for use in dairy goats. Journal of Dairy Science 101, 4491-4497 **(Chapter 3).**

Peer reviewed conference abstracts (appendix 2)

Deeming LE, Beausoleil NJ, Stafford KJ, JR Webster JR, Zobel G. 2018. The importance of hoof trimming in maintaining normal joint angles in the hooves of dairy goats. Universities Federation for Animal Welfare, Hong Kong. 25th–26th November.

Deeming LE, Beausoleil NJ, Stafford KJ, JR Webster JR, Zobel G. 2016. Can a workshop alter dairy goat farmers' views on lameness. Interntational Society for Applied Ethology, Auckland. 27th October.

Confidential client report

Zobel G, **Deeming LE**, Counsell L, Turner A, Bruce B, Wester J. 2018. Hoof care and lameness in New Zealand dairy goats. Dairy Goat Cooperative (DGC) Client Summary.

Other publications completed in parallel with thesis research

Peer reviewed journal articles (appendix 3)

Todd CG, Bruce B, **Deeming LE**, Zobel G. 2019. Short communication: Survival of replacement kids from birth to mating on commercial dairy goat farms in New Zealand. Journal of Dairy Science 10, 9382-9388.

Peer reviewed conference proceedings (appendix 4)

Deeming LE, Beausoleil NJ, Stafford KJ, JR Webster JR, Zobel G. 2016. Variability in growth rates of goat kids on 16 New Zealand dairy goat farms. Proceedings of the New Zealand Society of Animal Production 137–138.

Zobel G, Tan BL, **Deeming LE**. 2016. The success of immediate removal of dairy goat kids from the doe as a colostrum management strategy. Proceedings of the New Zealand Society of Animal Production 169–171.

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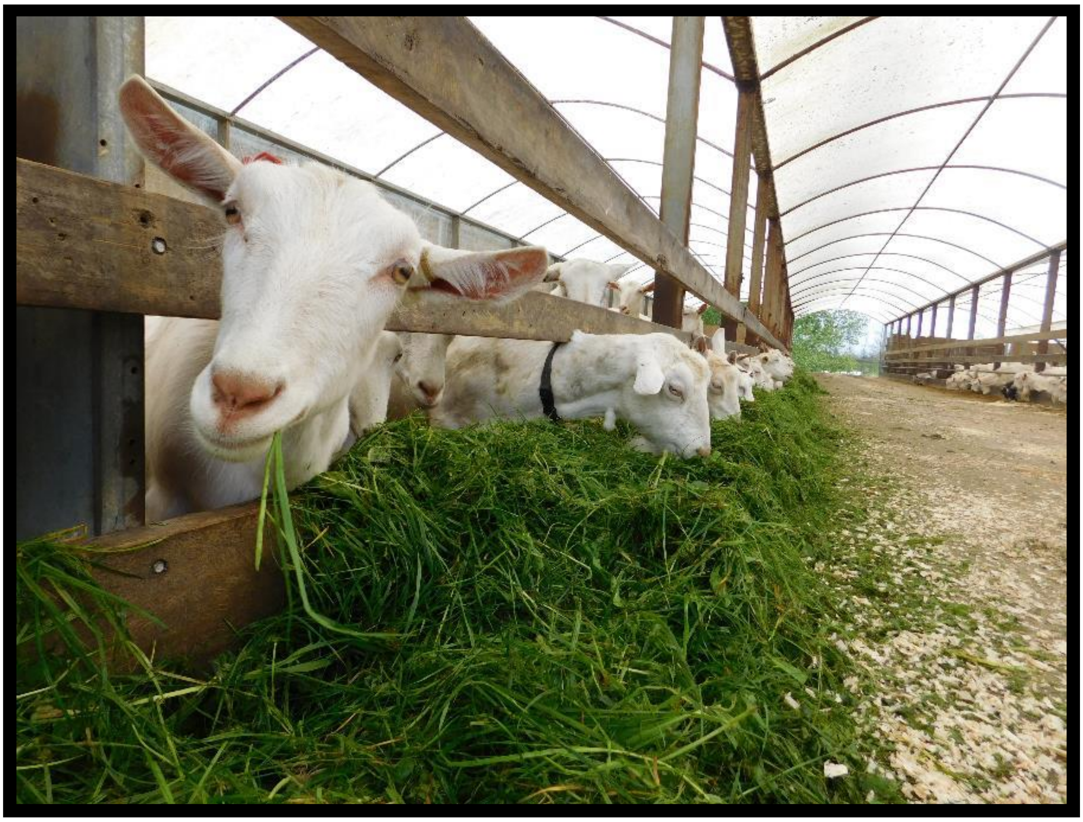
Chapter One

Introduction



Lameness is a serious welfare issue in dairy animals due to its high prevalence (Clarkson et al., 1996), and the serious impacts it has on individual animals (von Keyserlingk et al., 2009). Lameness is associated with hoof overgrowth and consequently poor conformation (Ajuda et al., 2014; Ajuda et al., 2019); thus, it is important that overgrowth is minimised. The housing environment of dairy goats however offers limited opportunity for natural hoof wear, resulting in hoof overgrowth (Anzuino et al., 2010). This necessitates hoof trimming to correct the overgrowth, restore conformation and reduce the risk of lameness.

Methods to accurately and reliably assess hoof conformation and gait are important due to the negative impact poor conformation and lameness may have on animal welfare (Capion et al., 2008), and production (Green et al., 2002). Because of the impact of lameness on animal welfare, the New Zealand government has employed new regulations focusing on preventing the transport of lame animals (MPI, 2018). However, there is a dearth of research specifically investigating lameness or hoof conformation in dairy goats anywhere in the world, and no data specific to New Zealand. My PhD aimed to develop methods of assessing hoof conformation and lameness in dairy goats, and to evaluate how hoof trimming regimes impact on them.

This introductory chapter provides background information that is relevant to the experimental work described in this thesis. It includes a brief overview of the New Zealand dairy goat industry and introduces animal welfare. There is a comprehensive review of relevant literature on lameness, hoof conformation and hoof trimming in dairy goats. Finally, the rationale for the research aims of this thesis and the structure of the thesis is outlined including the main objectives of each chapter.

A caveat to keep in mind when reading this introductory chapter and subsequent chapters is due to the lack of published data available in dairy goats, the literature available is largely from veterinary textbooks or non-peer reviewed conference proceedings, and therefore reflects opinions based on clinical experience rather than the findings of primary research. I therefore acknowledge that a number of references used within this thesis are not evidenced based. Furthermore, because of the scarcity of relevant goat-based literature I have had to extrapolate from other species (mainly dairy cows). Although caution has been taken when making assumptions from data in other species, I acknowledge that dairy goats are not small cows and therefore the referenced literature needs to be considered in a circumspect manner.

1.1. The New Zealand dairy goat industry

Dairy goat farming is a growing industry in New Zealand. Most of the dairy goat farms in New Zealand are part of one cooperative, the Dairy Goat Co-operative (NZ) Ltd. (DGC) and are based in the Waikato region of the North Island. The cooperative comprises 72 farms, with herd size ranging from 210 to 1800 lactating goats (average 650 goats) (Stafford and Prosser, 2016). The DGC is one of the world’s leading manufacturers of goat milk nutritional powders for infants and young children (Stafford and Prosser, 2016).

Dairy goats are commonly indoor housed as this allows for greater milk production due to easy access to feed and shelter and a reduction in parasite infection (Stafford and Prosser, 2016). In New Zealand, dairy goats are typically housed in open-sided barns and bedded on wood shavings (Solis-Ramirez et al., 2011). Most farms typically feed a fresh cut pasture based forage (Solis-Ramirez et al., 2011; Ganche et al., 2015).

The majority of dairy goats (97.5%) in the Waikato region of New Zealand are Saanen or Saanen Toggenburg crosses (Solis-Ramirez et al., 2011). Milking does are typically milked twice a day and on average produce 81kg of milk solids per lactation, with an average (mean ± SD) of 289 ± 26 days in milk (Ganche et al., 2015). Kidding takes place in winter in New Zealand. The kidding start date ranges from 15th June to the 1st August (data from kidding season 2013), with 80% of kidding completed in 36 ± 25 days (Ganche et al., 2015).

1.2. Animal welfare

Animal welfare has been conceptualised into three overlapping areas of focus; 1) basic health and functioning, 2) affective state, and 3) natural living (Fraser et al., 1997). Biological health and function refers to an animal's physical state and is concerned with their health and ability to function, grow and develop (Fraser et al., 1997). Affective state refers to how the animal feels and how it perceives its environment. An animal can experience both positive and negative affective states, with positive states (e.g. excited, playful) experienced as being either rewarding or pleasurable, and negative states (e.g. pain, fear, hunger) experienced as aversive and punishing (Mellor, 2015). There is an acknowledged overlap between the physical and affective state of an animal. Sensory inputs that reflect the animal's internal physical state will influence the animal's affective state (Hemsworth et al., 2015). For example, tissue injury from hoof lesions cause neural impulses to the brain which may then be converted into the experience of pain (Mellor and Beausoleil, 2015). Natural living refers to whether the animal is provided with an environment that enables natural behaviours to be performed (Fraser, 2003). Pain may result in avoidance or withdrawal behaviour (Mellor, 2012) impacting natural behaviours, but also impairing behavioural responsiveness to potentially positive experiences (Mellor and Beausoleil, 2015). Due to the overlap between biological function, affective state and natural living they need to be considered collectively if the major concerns about animal welfare are to be addressed (Fraser et al., 1997; von Keyserlingk et al., 2009).

Commercial animal production systems have traditionally focused on good biological functioning, and using outcomes such as growth, reproduction and health as indicators of good welfare. However, meeting the basic needs of food and water to ensure survival and good biological function is no longer considered enough to ensure that an animal has good welfare. "Indeed, what use is there in satisfying an animal's vital needs if the life the animal then lives is devoid of any enjoyment" (Yeates and Main, 2008). There is general acknowledgement that good welfare involves not only the absence of negative experiences, but also promotes opportunities for positive experience (Mellor and Beausoleil, 2015). In addition, high production does not necessarily equal good welfare, for example, there is strong evidence demonstrating that lameness is a disease associated with high production in dairy cows (Barkema et al., 1994; Alban et al., 1996; Green et al., 2002).

Specifically for dairy goat welfare, the commercial housing systems do not typically promote opportunity for positive experiences or a full range of natural behaviours to be expressed (Zobel et al., 2019). For instance, climbing is in a goat's natural behavioural repertoire, however housing systems are generally devoid of climbing opportunities. This impacts the goat's ability to perform natural behaviours and may therefore impact the animal's affective state. Additionally, the biological function of housed goats may be impacted as there are limited opportunities for hoof wear and therefore hooves become overgrown.

1.3. Lameness

Lameness is a debilitating and painful condition (Whay et al., 1997) that impedes normal walking gait due to the animal attempting to reduce weight on the affected limb (Leach et al., 2009). A pain response represents an awareness by an animal of potential damage to its body; the pain changes the animal's physiology and behaviour to reduce or avoid the damage and to promote recovery (Molony, 1997). In the early stages of lameness a lame animal may present with an uneven gait, such that there is decreased symmetry of limb movement (Winckler and Willen, 2001; Flower and Weary, 2006). In the most severe case of lameness, an animal may be unwilling or unable to bear any weight on an affected limb (Flower and Weary, 2006; Dyer et al., 2007). Lameness therefore has implications for both animal welfare and productivity.

1.3.1. Animal welfare implications of lameness

Lameness is considered to be one of the most serious welfare issues faced by the dairy industry, due to the considerable negative impacts it has on animals (von Keyserlingk et al., 2009). Lameness is therefore one of the most important animal-based welfare indicators (Whay et al., 2003) and is frequently incorporated into animal welfare assessments (cows: Whaytt et al., 2003; sheep: Phythian et al., 2012; goats: AWIN, 2015). When considering lameness, it has the potential to impact all three areas of welfare concern mentioned above.

Lame animals may have reduced biological functioning, which can have serious economic implications. For example, lameness is associated with decreased milk production (cows: Warnick et al., 2001; goats: Christodoulopoulos, 2009), fertility (cows: Melendez et al., 2003) and longevity (cows: Booth et al., 2004). As lameness is generally indicative of a pain response (Whay et al., 1997), a lame animal will be experiencing a negative affective state. Additionally, as lameness limits the mobility of an animal, its ability to express some natural behaviours is reduced. For example, lame cows are reported to lie for longer and graze less than sound cows (Hassall et al.,1993), which may have subsequent effects on welfare status (e.g. hunger, Norring et al., 2014).

1.3.2. Economic implications of lameness

As well as impacting animal welfare, lameness is reported to be one of the costliest health problems affecting dairy cows (Shearer et al., 2005). It may be the second most costly disease after mastitis in the dairy industry (Kossaibati and Esslemont, 1997). It is reported that 87% of the costs associated with lameness are due to reduced milk yield, culling costs and reduced fertility, with the remaining 13% of costs being attributed to labour, treatment and veterinary costs (Willshire and Bell, 2009). In cows, though milk yield decreases following lameness diagnosis (Warnick et al., 2001), clinically lame cows can have a reduction in milk yield for up to four months prior to diagnosis, and up to five months following treatment (Green et al., 2002). This highlights the long-term impacts lameness can have on milk production in dairy cows.

Lameness can reduce the reproductive performance of an animal in several ways. For example, lameness is associated with a longer interval between calving and conception in cows (Hernandez et al., 2001; Chapinal et al., 2013), and with an increased number of services per pregnancy (Sprecher et al., 1997). Moreover a lame dairy cow is 8.4 times more likely to be culled (Sprecher et al., 1997). Culling costs include the loss of the lame animal, and the rearing cost of the replacement heifer (Willshire and Bell, 2009). There are few data investigating the economic implications of lameness in dairy goats, however a reduction in annual milk yield has been reported in lame goats, specifically those with hoof lesions (Christodoulopoulos, 2009; O'Malley, 2019).

1.4. Prevalence of lameness

Lameness is a serious animal welfare and economic concern in part due to the large number of animals it affects worldwide. The average herd lameness prevalence in dairy cows is around 20% (UK: Clarkson et al., 1996; Whay et al., 2002; US: Cook, 2003b; Espejo et al., 2006), but, much higher prevalence levels of 39% (Haskell et al., 2006), 52% (Cook, 2003a) and 55% (von Keyserlingk et al., 2012) have been reported.

The variation in reported lameness prevalence in dairy cow herds may be due to high variability in environmental and management factors between farms (Clarkson et al., 1996; Whitaker et al., 2000). The high variability will also be due in part to whether estimates are based on data from trained researchers, veterinary surgeons or farmers (Clarkson et al., 1996). For example, UK farmers estimated lameness prevalence within their dairy cow herds to be 5%, but the prevalence when assessed by trained researchers was 22% (Whay et al., 2002). Similarly, a study in the U.S found cow herd managers significantly underestimated lameness, with the prevalence of clinical lameness being 3.1 times greater, on average, than the prevalence estimated by the herd managers (Espejo et al., 2006).

The reported lameness prevalence in sheep (8-10%) reared on pasture for meat (Kaler and Green, 2008) is lower than in cows. However, it should be noted that the data were farmer determined, and therefore may be an underestimation. Previous observations on indoor housed dairy goat farms in the UK estimated the prevalence of lameness to be between 9.1% (Hill et al., 1997) and 19.2 % (Anzuino et al., 2010). A lameness prevalence of only 1.7% was reported on Norwegian dairy goat farms (Muri et al., 2013). However, the authors of that study cautioned that crowded pens made observations difficult and therefore some lame animals may have gone unrecognised. Groenevelt et al. (2015b) reported high lameness prevalence (37% and 67%) on two dairy goats farms in the UK, but these researchers intentionally visited farms with high lameness levels.

In the only industry survey of prevalence of lameness on New Zealand dairy goat farms (n = 30 farms), 57% of farms had lameness levels of 2% or less, 40% of farms had 2-5% lameness and 3% of farms had over 5% lameness (Ganche et al., 2015). It is important to note that these data were farmer reported and therefore lameness may be underestimated. Reported prevalence will also depend on the gait scoring system used to assess lameness and how sensitive it is to detect lower levels of lameness. As the New Zealand survey did not provide a standardised definition of lameness, these results must be cautiously interpreted.

1.5. Assessing lameness

Reduction and prevention of lameness is an important step in mitigating negative animal welfare and economic implications in the dairy livestock industries (Mill and Ward, 1994). Therefore, it is important that the lameness status of animals is quickly and reliably identified as the early treatment of lame animals reduces the prevalence of severe lameness and aids faster recovery (sheep: Kaler and Green, 2009; cows: Leach et al., 2012). There are two principal subjective gait scoring methods used to assess the gait of dairy animals and therefore detect lameness.

1.5.1. Gait scoring

Subjective systems are typically used to assess gait in dairy animals. A numerical rating scale (NRS) is the most commonly used subjective approach for ranking an animal's walking ability by evaluating locomotory behaviours and postures indicative of lameness. Generally, the higher the assigned gait score, the more severe the lameness. The other main subjective approach is visual analogue scales (VAS), which involve the observer making a score somewhere on a continuous line with descriptions of extreme states at either end (Flower and Weary, 2009). However, VAS are less commonly used than NRS, possibly due to reduced reliability as they do not have clearly defined categories as with the NRS (Flower and Weary, 2006). This review will focus on the use of NRS systems of gait assessment.

Prey species such as cattle and goats are considered to be stoic animals, meaning that it is unlikely they will show obvious behavioural response to pain until the condition is advanced (Weary et al., 2006). A limp may be considered as an obvious behavioural response, suggesting the lameness is in an advanced stage as the animal has an apparent reluctance to bear weight on the affected limb. As lameness commonly develops over time (de Mol et al., 2013), subtle signs of lameness such as an uneven gait could be a precursor to a limp.

An animal should be considered lame if it fails to move in a sound manner on all four limbs (Sprecher et al., 1997). Therefore, it is important that gait scoring systems enable the more subtle signs of lameness (e.g. "uneven gait") to be detected. The 5-point NRS frequently used in dairy cows includes an "uneven gait" category, which allows the discrimination of a slight variation from a "normal gait" (O Callaghan et al., 2003; Espejo et al., 2006; Flower and Weary, 2006). A detailed (7-point) scale including categories to detect an uneven gait was developed and reliably used in sheep (Kaler et al., 2009). In that study observers were able to identify sheep with an uneven gait; however, this was done entirely from recorded video clips; these authors did not test the scoring system in a live, on-farm setting.

Generally, NRSs with fewer categories are used to assess gait in small ruminants in an on-farm setting. For example, the fast speed with which goats exit the milking parlour has resulted in a simple binary score (lame vs not lame) being used. (Crosby-Durrani et al., 2016). This is due to the difficulties in detecting subtle signs of lameness when the animal does not walk at a steady pace. Using NRS with fewer categories will result in better observer agreement (Schlageter-Tello et al., 2014). However, fewer categories mean that the system is not sensitive enough to detect subtle signs of lameness.

An uneven gait may be recognised as a shortening of stride, the animal not "tracking up" (i.e., the hind hoof not stepping into the placement of the front hoof) when walking, or a swinging of the affected leg inwards or outwards at each stride (Van der Waaij et al., 2005; Haskell et al., 2006). An uneven gait is not necessarily indicative of lameness. For example, conformation, posture, and udder fill of the animal may affect gait (Flower and Weary, 2009). However, using a gait scoring system that includes this category provides an opportunity to investigate the cause of the unevenness. Then if deemed necessary, these animals may be targeted for treatment, rather than waiting until the lameness becomes more severe (Nalon et al., 2014; Thomas et al., 2015).

There are limited data informing the development of an NRS for use in goats. The AWIN (AWIN, 2015) system is commonly used in goat welfare assessments (Battini et al., 2016; Can et al., 2016), and involves binary scoring (not lame vs lame). However, this only recognises the most severe cases of lameness (i.e. not weight bearing, moving on knees). A 4-point NRS has also commonly been used to assess gait in goats (Hill et al., 1997; Anzuino et al., 2010). However, these are not sensitive enough to detect subtle signs of developing lameness (e.g. an uneven gait). Four-point NRS usually require a definite limp to be recognised for an animal to be identified as lame and scores are then assigned based on limp severity. Mazurek et al. (2007) used a 4-point system that did not require a definite limp to be recognised, however the categories are poorly defined, making reproducibility difficult. Additionally, the 4-point NRS described by Mazurek et al. (2007) and Hill et al. (1997) did not offer a description of a "normal gait". If clear definitions of both normal and abnormal gait are not provided accurate and reliable assessments may be difficult (Van Nuffel et al., 2015). Future work should focus on developing a more detailed NRS system in dairy goats. This will enable more subtle signs of developing lameness (i.e. an uneven gait) to be detected and at-risk animals identified.

1.5.2. *Monitoring behaviour to identify lameness*

NRS are the most common method used to assess the gait of individual animals and therefore herd lameness prevalence (Flower and Weary, 2009). However, NRS are time consuming (Thomsen, 2009) and subjective (Channon et al., 2009). The experience (Flower and Weary, 2009) and occupation (Kaler and Green, 2008) of observers impacts the results of NRS. As herd size increases the use of an NRS to individually assess the gait of all animals may not be feasible. Therefore, monitoring behavioural changes other than changes in gait may offer alternative ways of detecting lameness. For example, lame cows have an unequal weight distribution on their limbs when walking and this can be detected by measuring ground reaction forces using a force plate (Rajkondawar et al., 2002).

Changes in animal behaviour are often indicative of poor health (Weary et al., 2009). For instance lame cows feed less (Norring et al., 2014) and ruminate less (Van Hertem et al., 2013). Lying behaviour is a particularly sensitive indicator of poor health and disease. Lame animals can lie up to 2.1 hours a day longer than none lame cows (Blackie et al., 2011), with greater lying times, longer lying bouts and more variability in the duration of lying bouts all associated with lameness (Ito et al. 2010).

Accelerometers are non-invasive devices that are commonly used to monitor lying behaviour (Chapinal et al., 2010c; Ito et al., 2010; Thomsen et al., 2012), feeding behaviour (Mattachini et al., 2016; Pereira et al., 2018) and rumination (Schirmann et al., 2009). Accelerometers are a reliable way of measuring lying behaviour in dairy cows (Ito et al. 2010) and are validated for use in dairy goats (Zobel et al., 2015b). In goats they have been used to identify lying behaviour changes associated with metabolic diseases, such as ketosis (Zobel et al., 2015a) and have been used to show the impact of hoof overgrowth on lying behaviour (Zobel et al., 2016), but they have not been used to identify lameness in dairy goats.

1.6. Causes of lameness

Lameness is often a complex and multifactorial problem (Shearer et al., 2005). Most cases of lameness are associated with claw horn lesions, with lesions in the hind hooves causing 92% of lameness in dairy cows (Murray et al., 1996). Claw horn lesions may affect the sole, wall, heel and white line (van Amstel and Shearer, 2006), and are broadly categorised into infectious (e.g., digital dermatitis) and non-infections (e.g., sole ulcers) lesions. Non-infectious lesions such as sole ulcers and white line disease are some of the most prevalent lesions associated with lameness in dairy cattle. Of 8645 lesions observed by Murray et al. (1996), 28% were sole ulcers, 22% were white line lesions and 13% were associated with digital dermatitis. Similar proportions of lesions were reported by Whay et al. (1998), with sole ulcers, white line disease and digital dermatitis being the most prevalent lesions observed. However, both these studies were completed in dairy cows in the UK and the most common types of lesions will vary between countries depending on whether an extensive or intensive management system is used (Vermunt, 2004). To illustrate, in the Northern American tie and free stall intensive cow housing systems infectious diseases (digital dermatitis) are the most prevalent claw lesions, as the cows would have increased exposure to manure and moisture (Cramer et al., 2008).

The main lesion types differ among ruminant species. In sheep, claw lesions caused by bacterial disease are the most common cause of lameness in sheep (Winter, 2008; Kaler and Green, 2009). Footrot caused by the bacterium *Dichelobacter nodosus* is responsible for approximately 90% of all lameness in sheep (Kaler and Green, 2008). However, other lesions such as contagious ovine digital dermatitis, white line lesions and granulomas lesions have been reported in sheep (Winter, 2004).

Lesion categorisation and aetiology are yet to be extensively described in dairy goats. There are no published data describing claw horn lesions in dairy goats in New Zealand. One study in the UK reported that the common claw lesions in dairy goats were horn separation (30%), white line lesions (13 %) slippering (10%), abscess of the sole (4%), foreign body, and granulomatous lesions (1%) (Hill et al., 1997). However, this was only on four farms and used a claw lesion identification scheme originally described for cattle. A study completed on one dairy goat herd in Greece reported 15% of the goats had claw lesions caused by bacterial disease (digital dermatitis) from wet bedding material (Christodoulopoulos, 2009). More recently, studies have reported infectious claw lesions in dairy goats and the role of treponeme bacteria (Sullivan et al., 2014; Groenevelt et al., 2015a). The aetiology of these lesions was not clear and the authors suggested lesions may have first developed as a white line lesion or sole ulcer, with the treponeme infections being secondary (Groenevelt et al., 2015b).

There are a number of risk factors that are associated with the development of hoof lesions and therefore lameness (Vermunt, 2004). These may be environmental and management risk factors or animal related risk factors, and there are often complex interactions between both (Figure 1).

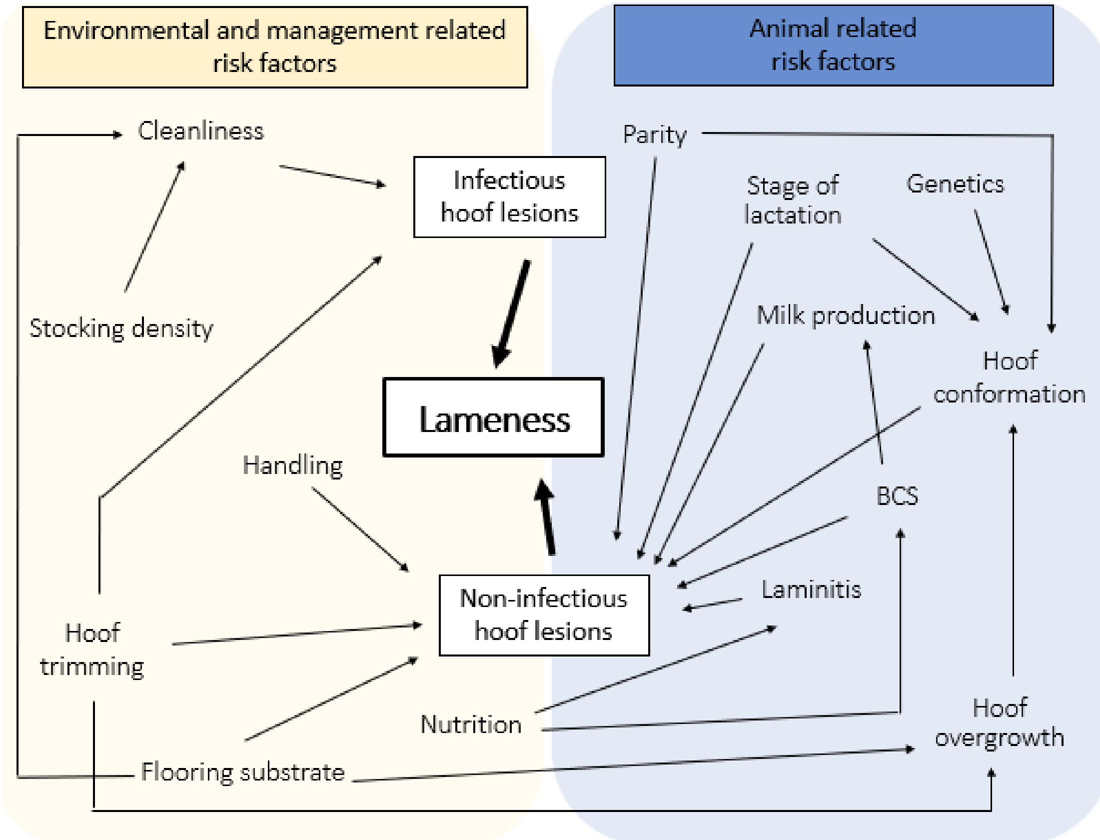


Figure 1. Risk factors associated with the development of hoof lesions and lameness in dairy cows (adapted from: Chesterton et al., 1989; Solano et al., 2015).

1.6.1. Environmental risk factors

The purpose of this section is to discuss some of the risk factors for lameness in dairy cows that are relevant to dairy goats. For a more detailed discussion on environmental risk factors associated with dairy cow management and lameness see Barker et al. (2010) and Cook and Nordlund (2009).

Environmental and management risk factors in dairy cows include flooring surface (Somers et al., 2005), cleanliness (Bergsten and Pettersson, 1992), stocking density

(Leonard et al., 1996), season (Rowlands et al., 1983), animal handling (Ranjbar et al., 2016), and access to pasture (Haskell et al., 2006). Management risk factors can also include diet, as nutrition is associated with lameness due to laminitis (reviewed by: Lean et al., 2013). Additionally, hoof trimming, particularly inadequate trimming is a common risk factor of lameness (Manson and Leaver, 1989; Manske et al., 2002a). Hoof trimming will be discussed in detail later in the review.

In dairy cows one of the main environmental risk factors is flooring substrate (Somers et al., 2003; Dippel et al., 2009; Telezhenko et al., 2009). Substrate plays an important role in the development of injuries such as hock lesions (Mowbray et al., 2003) and in the development of claw horn lesions (Vanegas et al., 2006). Flooring substrate directly influences standing and lying times (Singh et al., 1993), with the risk of lameness increasing with decreased lying comfort (Dippel et al., 2009). Dairy cows prefer soft bedding materials such as straw and wood shavings (Lowe et al., 2001; Tucker et al., 2009). Increased standing time, particularly on concrete is a significant risk factor of lameness (Somers et al., 2003), as compression of the solar corium is directly associated with the amount of time dairy cows spend standing, particularly on concrete (Vermunt, 2004). To illustrate, Haskell et al. (2006) report a lameness prevalence of 15% in dairy cow herds housed in free stall and grazed part of the year, compared with a 39% lameness prevalence in herds housed in free stalls all year round.

There are few published data on the risk factors of lameness in dairy goats. However, as they are typically housed on straw or wood shavings rather than concrete, the prevalent risk factors may be different to dairy cows. For instance, in contrast to dairy cows exposed to concrete, the bedding materials (e.g. straw or wood shavings) used in housed dairy goats do not promote hoof wear, therefore high rates of overgrowth are reported (Anzuino et al., 2010). This results in more frequent hoof trimming being required in dairy goats compared to dairy cows (Smith and Sherman, 2009). Additionally, flooring substrate is not just important in terms of comfort and hoof wear, but also in terms of hygiene and moisture content. Organic bedding material (i.e., straw and wood shavings) result in a higher moisture content and bacteria count than non-organic material (i.e., sand) (Hogan et al., 1989). When cattle stand in a wet environment or in slurry (i.e., faeces plus urine) there is an increased risk of lameness, as the hoof softens and swells as it absorbs moisture and is then more susceptible to bacterial infection (Bergsten and Hultgren, 2002; Gregory, 2004). Therefore, cattle housed in wet, slurry contaminated conditions are more likely to suffer from infectious claw horn lesions (Bergsten and Hultgren, 2002). The bedding of dairy goats frequently becomes wet, especially in the winter months (Christodoulopoulos, 2009). This may explain why infectious diseases are suggested to play a major role in the cause of lameness in goats (Groenevelt, 2017). Treponeme bacterial species have been reported to be involved in lesions causing lameness in dairy goats (Sullivan et al., 2014; Groenevelt et al., 2015a; Groenevelt et al., 2015b), highlighting the importance of clean, hygienic housing conditions.

1.6.2. Animal Related Risk Factors

Animal related risk factors may include parity (cows: Alban, 1995), stage of lactation (cows: Boettcher et al., 1998), body condition score (BCS) (cows: Wells et al., 1993), milk production (cows: Green et al., 2002) and hoof conformation (cows: Distl et al., 1990; cows: Boettcher et al., 1997; sheep: Kaler et al., 2010). BCS is reported to be a risk factor for lameness (Wells et al., 1993; Randall et al., 2015) as cows with lower BCS have reduced thickness of the digital cushion (Green et al., 2014). A thinner digital cushion has less capacity to absorb the pressure from the distal phalanx and therefore increases the risk of claw horn lesions and lameness (cows: Bicalho et al., 2009). However, the loss of body weight might be the result of lameness rather than being a causative factor for lameness. Due to the cross-sectional design of the Bichalho et al (2009) study, it is not possible to conclude a cause and effect relationship.

An animal related risk factor that has received attention in recent years is the association between parturition and lameness. There is evidence in dairy cows that lameness risk significantly increases following calving (Offer et al., 2000; Tarlton et al., 2002; Knott et al., 2007). For example, in a study that evaluated clinical lameness in 24 dairy cow herds, it was determined that lameness was most common during the first 50 days of lactation (Boettcher et al., 1998). It is proposed that metabolic and hormonal changes associated with calving weaken the connective tissue of the hoof suspensory apparatus, leading to an increased risk of lameness due to sole ulcers and white line disease (Tarlton et al., 2002).

There is limited evidence of a similar parturition effect in dairy goats. Groenevelt et al. (2015b) report lameness prevalence in lactating does of 37% and 70% on two UK dairy goat farms, while no lameness was detected in the youngstock (between 2 and 12 months of age) on either farm. The authors of that study suggested that as the housing and feeding were similar between adults and youngstock, the differences in lameness were due to a parturition effect similar to that seen in cows. However, the youngstock were assessed for lameness in the pens, whereas the adult lactating does were assessed for lameness exiting the parlor in a concrete passageway. As goats often do not show lameness until walking on a solid hard flooring substrate (Groenevelt, 2017), lameness in the youngstock may have been missed.

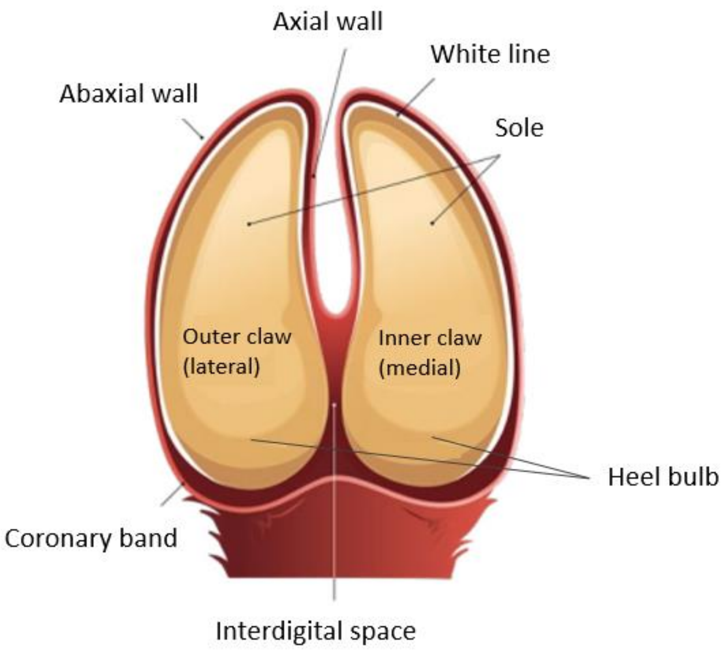
Hoof conformation and hoof overgrowth are considered to be major animal related risk factors that impact lameness (Ajuda et al., 2014; Ajuda et al., 2019). These are also influenced by complex interactions between environmental and management related factors and animal related factors (Figure 1). This will be discussed in detail in the next section of this review.

1.7. Hoof conformation

1.7.1. Anatomy of the hoof

The ruminant hoof comprises two digits, the lateral (outside) claw and the medial (inside) claw. The weight bearing surface of the claws consist of the hoof wall, the sole, the heel bulb and the white line. The junction where the hoof wall meets the sole is called the white line, and is considered a point of weakness (Blowey, 1992a) (Figure 2a) The internal structure within the lower leg and claw horn capsule are the distal part of the proximal phalanx (P1), the middle phalanx (P2), the distal phalanx (P3) and the distal sesamoid bones. The distal phalanx is attached to the hoof wall by laminae and supported by the digital cushion which sits above the sole (Lischer et al., 2002) (Figure 2b).

a)



b)

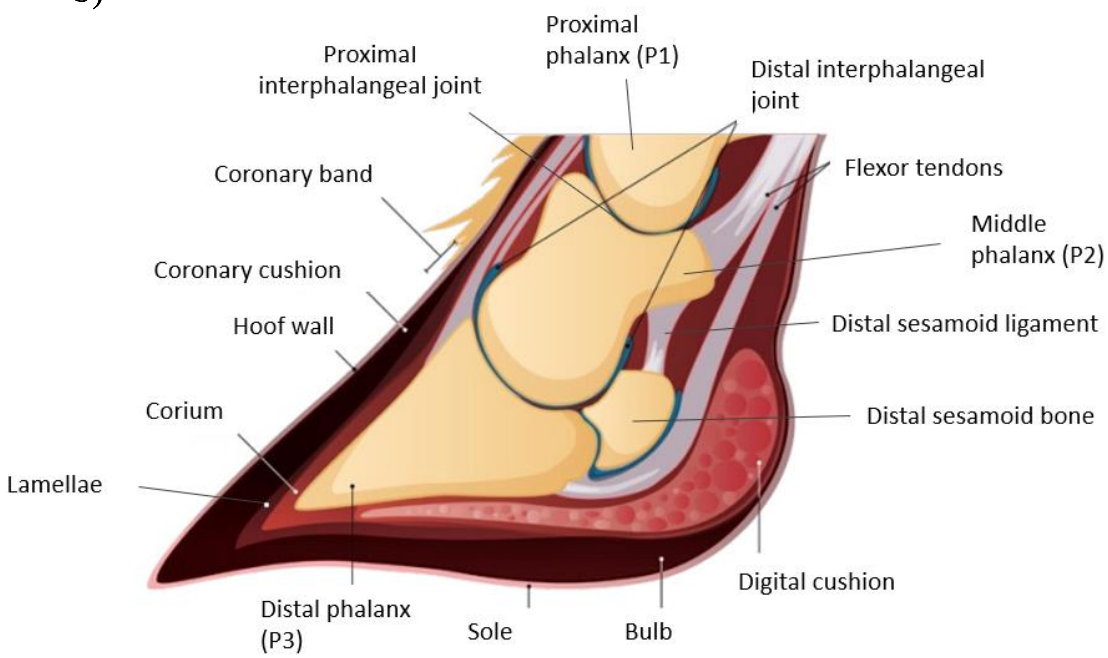


Figure 2. (a) Anatomy of the external underside of the ruminant hoof. (b) Anatomy of the external and internal structures of the ruminant hoof. Adapted from Dairy Australia (2019).

1.7.2. Relationship of hoof conformation to claw horn lesions and lameness

Hoof conformation is important due to its recognised relationship with the biomechanical function of the hoof (O'Grady and Poupard, 2001). Desirable hoof conformational traits include a short toe and steeply angled hoof, a straight fetlock (Häggman and Juga, 2013), an upright heel (van Amstel and Shearer, 2006) and even claws (Boettcher et al., 1997), enabling even weight distribution between the medial and lateral claws (Van der Tol et al., 2002). McDaniel (1994) concluded from three separate comprehensive studies that higher claw angles were positively correlated with increased herd life. Poor hoof conformation is associated with an animal's susceptibility to claw horn lesions and lameness (cows: Distl et al., 1990; cows: Boettcher et al., 1997; sheep: Kaler et al., 2010). For instance, non-infectious lesions such as sole ulcers are caused by changes in pressure, from deviations in hoof conformation in dairy cows (Mahendran and Bell, 2015). Additionally, poor conformation is associated with decreased reproductive performance (cows: Pérez-Cabal et al., 2006), reduced milk production (Warnick et al., 2001) and a greater risk of being culled (cows: Sewalem et al., 2005; sows: de Sevilla et al., 2008).

1.7.3. Factors that impact hoof conformation

There are environmental and animal related factors that impact hoof conformation. Management factors such as flooring substrate (Faull et al., 1996; Telezhenko et al., 2009), bacterial disease due to poor hygiene (Gomez et al., 2015), and trimming frequency (Manske et al., 2002a) have been shown to affect aspects of hoof conformation in dairy cows. Animal related factors such as age (Andersson and

Lundström, 1981), parity and stage of lactation (Offer et al., 2000), can also affect hoof conformation in dairy cows.

Improving hoof conformation in the short term may be achieved by management factors such as hoof trimming (Manske et al., 2002a). However, genetics may need to be considered for long term improvement to be achieved. Claw traits can vary considerably among animals on the same farm, suggesting that genetic variation may have an impact on conformation (Vermunt and Greenough, 1995). For example, breed significantly influences traits such as toe length, hoof width, horn growth and toe angle in Swedish dairy cattle (Ahlstrom et al., 1986). Studies in dairy goats have focused on genetic parameters for milk production (e.g. Bélichon et al. 1999), however to my knowledge there are no published data investigating genetic parameters for hoof conformation. Furthermore, in order to assess genetic influence on, and heritability of, hoof conformation in dairy goats, methods of hoof evaluation need to be developed and standardised.

For a detailed review of risk factors that impact dairy cow conformation see Vermunt and Greenough (1995). As hoof overgrowth is reported to be the main cause of poor conformation and lameness in dairy goats (Ajuda et al., 2014; Ajuda et al., 2019), this will be discussed in detail in the next section .

1.7.3.1. Hoof growth and conformation

Overgrown hooves are those, that due to lack of opportunity for hoof wear and inadequate trimming practices, have excess horn tissue potentially resulting in deformation of the hoof (AWIN, 2015). As hooves become overgrown and toes become long, claw shape becomes abnormal (cows: Manske et al., 2002b), claws become splayed (cows: van Amstel and Shearer, 2006), the fetlocks may become hyperextended (cows: Shearer et al., 2012) and heel depth is reduced (cows: Glicken and Kendrick, 1977; Gitau et al., 1997). Prolonged periods of hoof overgrowth increase the risk of hoof deformation in dairy goats (Ajuda et al., 2014), with chronic overgrowth resulting in a slippered hoof, where the toe curls up and the weight bearing surface transfers to the heel (Hill et al., 1997). In dairy cows, this dipped heel conformation reduces the shock absorbing effect of the digital cushion, resulting in damage to the solar corium and an increased risk of sole ulcers and lameness (Blowey, 1992b). Hoof overgrowth is a main area of concern when assessing the welfare of dairy goats (Can et al., 2016). However, to date there are no data evaluating the impacts of the conformation changes caused by hoof overgrowth on the functionality of dairy goats' hooves.

If the housing environment does not provide opportunity for natural wear then hoof overgrowth can become a health and welfare issue (chamois: Wiesner, 1985; sheep: Bokko et al., 2003; goats: Anzuino et al., 2010). As with lameness, flooring substrate is the main environmental factor affecting hoof wear and conformation characteristics (cows: Vermunt and Greenough, 1996a). Hoof wear increased by 35% in cattle housed on abrasive concrete compared with cows kept on pasture (Hahn et al., 1986). Therefore, abrasive flooring substrates can result in altered hoof conformation with a shorter toe length and steeper toe angle (Telezhenko et al., 2009).

In their natural environment goats populate hilly and rugged environments and often rest directly on rocks in steep terrain (reviewed by Zobel et al., 2019), suggesting a preference for harder surfaces (Zobel et al., 2018). This is supported by research that suggests dairy goats prefer to lie on hard surfaces (Bøe et al., 2007).

Indeed, Sutherland et al. (2017) report that goats preferred rubber mats and plastic slats to lie on, while wood shavings were used mainly for elimination rather than lying. The typical commercial housing environment of dairy goats offers very limited opportunity to naturally wear hooves, therefore a high prevalence of hoof overgrowth is common (84 - 100%: Hill et al., 1997; 79%: Anzuino et al., 2010). However, to date there are limited data assessing hoof overgrowth or other aspects of conformation in dairy goats.

1.8. Assessing hoof conformation

Due to the association of hoof conformation with hoof lesions and lameness accurate assessment of hoof conformation is imperative for the identification of at-risk animals. Aspects of hoof conformation can be assessed using objective measures or subjective scores.

1.8.1. Objective methods

Objective measures are suggested to provide superior assessments as they are accurate and repeatable (Vermunt and Greenough, 1995), allowing for thorough assessment of hoof conformation traits. However, objective measures are time consuming, require technical equipment (Flower and Weary, 2009) and require restraint of the animal (cows: Telezhenko et al., 2009; goats: Koluman and Göncü, 2016).

Objective methods of assessing hoof conformation used in dairy cows often include measurements of toe length (Somers et al., 2005; Telezhenko et al., 2009), claw length (Vermunt and Greenough, 1995; Gomez et al., 2015) and heel height (Vermunt and Greenough, 1995; Somers et al., 2005; Gomez et al., 2015) using callipers, and claw angle (Vermunt and Greenough, 1995; Somers et al., 2005; Gomez et al., 2015) using an angle gauge. Claw length and width have recently been objectively measured in 38 dairy goats on one farm in Portugal (Ajuda et al., 2019). However, prior to this there is only one study that has objectively measured other aspects of hoof conformation in dairy goats (Koluman and Göncü, 2016). Koluman and Göncü (2016), used the methodology described by Vermunt and Greenough (1995), however did not report any validation to support the use of the cow measurements in goats. Additionally, although the authors state that hooves were rescored to assess variance amongst observers, interobserver reliability was not reported.

1.8.2. Subjective methods

Subjective assessments of hoof conformation involve visual allocating a categorical score for aspects of conformation. They are quick to use, require no technical equipment, can allow assessment of a large number of animals and are therefore commonly used for live animal scoring on farm (Flower and Weary, 2009). Subjective scoring systems have been used to assess a number of aspects of hoof conformation such as abnormal overgrowth and splayed feet in sows (de Sevilla et al., 2008), misshaped hooves in sheep (Kaler et al., 2010) and fetlock shape in cows (Häggman and Juga, 2013). In dairy goats, subjective scores of hoof overgrowth (Anzuino et al., 2010; Muri et al., 2013) and claw deformation (Ajuda et al., 2019) have been reported, however to my knowledge no other aspects of hoof conformation have been subjectively assessed.

Potential limitations of subjective scores are poor inter- and intra-observer reliability as they are affected by both the scoring system used and previous experience (Flower and Weary, 2009). Therefore, intensive training is often required to achieve acceptable levels of reliability using subjective methods of assessment (March et al., 2007).

1.8.3. Radiographic assessments for evaluating aspects of internal hoof conformation

The changes in conformation associated with hoof overgrowth impacts on the internal structures of the hoof (Meimandi-Parizi and Shakeri, 2007). As previously described several objective and subjective methods have been developed to assess the external traits of the hoof, particularly in dairy cows. However, evaluating the shape and structure of the outer hoof capsule is not sufficient to be able to assess the impact of overgrowth on joint angles and bones within the hoof. Radiographic images are required to objectively determine the height and angles of joints, and the length of bones within the hoof (Kummer et al., 2006).

Research work has used radiographs to assess bovine foot disorders, such as new bone formation (exostosis), arthritis and solar penetration (Nigam and Singh, 1980) and to evaluate the impact of septic arthritis on the distal interphalangeal joint (DIPJ) of cows (Desrochers and Jean, 1996). Additionally, radiographic changes of bones and joints of cattle with claw abnormalities due to hoof overgrowth have been assessed (Meimandi-Parizi and Shakeri, 2007). In that study, rotation of the distal phalanx bone was reported in nearly 20% of hooves due to overgrowth, however the degree of rotation was not measured because it was a post-mortem study. For joint angles and conformation to be accurately determined they need to be assessed on live, weight-bearing animals (Meimandi-Parizi and Shakeri, 2007).

In goats, radiographs have been used to evaluate arterial patterns of the goat distal limb (Dehghani Nazhvani et al., 2007), and the impact of severe claw lesions on the remodelling of the distal phalanx (Crosby-Durrani et al., 2016). However, joint angles have not been assessed as a measure of hoof conformation in cows or goats.

Radiographic images are a common veterinary diagnostic tool used in horses to help determine causes of lameness and conformation issues (Colles, 1983). However, radiographs are not commonly used for this purpose in dairy animals outside of research applications (Tranter and Morris, 1991; Vermunt, 2004). Additionally, radiographs have been used to assess the variability in trimming procedure in horses (Kummer et al., 2009). A significant difference in measured hoof parameters were reported, highlighting that trimming technique can impact joint angles and positions within the hoof (Kummer et al., 2009). Radiographs have also been used in horses to evaluate the changes in conformation of the internal distal limb between trimming intervals, with frequent hoof trimming (every four to six weeks) recommended to avoid excessive loading and to reduce the risk of long term injury (Leśniak et al., 2017). This highlights the importance of avoiding prolonged periods of hoof overgrowth through frequent hoof trimming. However, to my knowledge radiographs have not been used to evaluate the impact of hoof trimming on the internal conformation of joint positions in either dairy cows or goats.

1.9. Hoof trimming

The aims of hoof trimming are to improve conformation by removing hoof overgrowth and to restore the hoof to an anatomically correct position and shape (Phillips et al., 2000; Bryan et al., 2012) (Figure 3). Hoof trimming should promote balanced weight distribution between the two claws, and target a reduction of local maximum pressures in such a way that the strongest parts of the claw capsule (i.e., the hoof wall) are exposed to the greatest pressures (Van Der Tol et al., 2004). Trimming improves the external conformation of the hoof (Phillips et al., 2000), and additionally in horses has been shown to improve internal structures, particularly the position of the distal phalanx (P3 bone) within the hoof capsule (Kummer et al., 2006). Hoof trimming is therefore suggested to be an important management tool for controlling claw horn lesions and subsequently lameness (Manske et al., 2002b; Hernandez et al., 2007; Bryan et al., 2012).

(a) **(b)**

Figure 3. (a) Photographs of a recently trimmed dairy goat front hoof (b) compared with an overgrown front hoof.

1.9.1. Frequency of trimming

Ruminant hooves are constantly growing, with cows hooves reported to grow approximately 5-7mm per month (Shearer and van Amstel, 2001) Consequently if the rate of hoof growth exceeds the rate of wear, hooves become overgrown

(Vermunt and Greenough, 1995). Therefore, for the reasons noted above, frequent hoof trimming should be used as a preventative approach in reducing lameness (Hernandez et al., 2007; Mahendran and Bell, 2015). Hoof trimming is reported to improve shape and prevents lesions for 4–8 months in cows (Shearer and van Amstel, 2001; Manske et al., 2002a). Thus, twice yearly trimming is recommended for dairy cows (Toussaint Raven et al., 1985), with trimming every four to six months common practice for high yielding dairy cows (Bell, 2015). Cows that received an extra hoof trim in autumn had shorter, steeper claws and lower likelihood of lameness compared with cows that only received a hoof trim in spring (Manske et al., 2002a).

In contrast, routine hoof trimming should be avoided in sheep (Winter et al., 2015), as trimming spreads the bacteria associated with the common infectious lesions among sheep, resulting in higher lameness prevalence (Sullivan et al., 2014). Instead of hoof trimming, sheep farmers are advised to focus on the treatment of the bacterial lesions (Green and Clifton, 2018).

Sheep reared for meat are managed very differently to commercially housed dairy goats. The extensive outdoor management of sheep results in natural hoof wear and less need for hoof trimming. For instance, one farmer who housed his sheep for several months over winter and who stopped routine foot trimming reported 'ewes are turned out with long toes and come in with short toes' (Smith et al., 2014). Therefore, providing sheep have the opportunity for sufficient exercise to naturally wear their hooves, they can self-regulate hoof length and hoof trimming is not beneficial (Smith et al., 2014). There are currently no published data on the rate of hoof growth in dairy goats. However, due to the indoor housing of dairy goats and lack of opportunity for natural wear their hooves need to be trimmed more frequently than twice a year (Smith and Sherman, 2009). Christodoulopoulos (2009) reported that goats trimmed every 6 months suffered from hoof overgrowth, suggesting that trimming twice a year is not frequent enough to prevent hoof overgrowth. Indeed, it is suggested that hooves may require trimming as often as every 6 weeks to 2 months depending on the housing environment (Pugh and Baird, 2002), as the required frequency is determined by exercise and opportunity to wear hooves (Smith and Sherman, 2009).

There are almost no data on the frequency of hoof trimming in dairy goats and how this may impact hoof conformation. In a survey of dairy goat farms in Ontario, Canada, nearly 80% of farmers reported trimming only 1 or 2 times a year (G. Zobel, unpublished data). If this finding is more broadly representative of dairy goat hoof management, it may explain why high prevalence of hoof overgrowth is common. In New Zealand specific data of trimming frequency and hoof conformation are needed.

1.9.2. Early life trimming regimes

Early life hoof management may be of particular importance as the hooves of young ruminants grow faster when compared to those of older animals (cows: Tranter and Morris, 1992; sheep: Dekker et al., 2005). Changes in hoof conformation because of hoof overgrowth in early life may have long term consequences (horses: Greet and Curtis, 2003), particularly in terms of increased injury and lameness risk (horses: Kroekenstoel et al., 2006). High numbers of dairy heifers become lame early in their first lactation (Webster, 2002). Therefore early life management including adequate hoof care is important to reduce the risk of initial lameness (Bell et al., 2009). In dairy cows lameness prevention needs to begin during heifer rearing

(Maxwell et al., 2015; Cook, 2016) as it may have beneficial effects on hoof conformation (Phillips et al., 2000), and prevent claws disorders and improve hoof health in older lactating cows (Offer et al., 2000; Kofler et al., 2011). However, to my knowledge there are currently no published data evaluating early life trimming management in dairy goats.

In this thesis, the term 'early life trimming' is used to describe whether goats were trimmed before first kidding; when cow literature is discussed, it refers to trimming heifers prior to first calving.

1.9.3. Possible negative effects of hoof trimming

While frequent hoof trimming is necessary in dairy goats, it is important to note that the process may cause stress or pain to the animal. Pain is difficult to evaluate because it is a complex and individualistic experience (Viñuela-Fernández et al., 2007). However, behavioural and physiological measures may provide some insight into the impacts of hoof trimming on animals. In cows, hoof trimming was associated with a decrease in milk yield on the day of hoof trimming and the day after, and increased faecal cortisol metabolites for 24 hours (Pesenhofer et al., 2006), suggesting a stress response. However, inclusion of lame cows in the study prevented the authors from concluding that the physiological changes were due to the trimming.

In terms of behaviour, an increase in lying time and gait score indicative of lameness have been reported in dairy cows following hoof trimming and may be interpreted as a pain response (Chapinal et al., 2010a; Van Hertem et al., 2014). For instance, the proportion of lame animals doubled from 16% to 32% in the first 2 weeks post trimming, but returned to pre-trimming levels by day 70 post trimming. (Van Hertem et al., 2014), suggesting the trimming process may have been painful. Chapinal et al. (2010b) reported that trimmed cows lay more than sham handled cows. As lame cows are reported to lie for longer (Ito et al., 2010) this may be a pain response. However, Chapinal et al. (2010b) included lame cows in the trimmed treatment groups, but not in the sham handling group. As the presence of hoof lesions and lameness may affect how an animal responds to hoof trimming (Van Hertem et al., 2014), it may be difficult to draw definitive conclusions about the reason for the difference in lying behaviors observed in that study. Additionally, poor trimming techniques have resulted in lameness in dairy cows (Shearer and van Amstel, 2001). Over trimming is reported to be an issue in sheep (Winter, 2008) and associated with granulomas toe lesions (Hodgkinson, 2010). Finally, the process of trimming can transmit disease between animals, therefore, disinfection of hoof trimming equipment between each animal is important (Sullivan et al., 2014).

1.10. Conclusion

There are few scientific publications on hoof conformation and lameness in dairy goats and virtually no New Zealand specific data. Lameness is prevalent in the dairy cow and dairy goat industry and is a significant concern to animal welfare. As dairy goats are typically permanently indoor housed on soft bedding, and with limited opportunities for exercise, their hooves can easily become overgrown; therefore, frequent hoof trimming is needed. However, there are currently no data investigating hoof trimming regimes in dairy goats. Additionally, there are no validated systems to assess hoof conformation or lameness in dairy goats. Lameness is currently evaluated using scales that do not include an uneven gait, a precursor to lameness, therefore prevalence in goats might be underestimated. Assessing the scope of the problem through the application of validated reliable scoring systems is the first step in developing treatment plans to manage poor conformation and lameness in dairy goats.

1.11. Rational for research and aims

As dairy goat milk production has grown in New Zealand, a need for science-based best management practices has followed. It is important to understand the factors that impact hoof conformation and lameness and to identify how we can best maintain a normally structured and functioning hoof in indoor-housed dairy goats. The overall objective of this thesis was to examine the hoof conformation and gait of New Zealand dairy goats and to evaluate how these factors are impacted by hoof trimming. Specifically, the aims of this thesis were to develop methods to assess hoof conformation and lameness in dairy goats. These methods were then used to facilitate an investigation into the immediate and long-term impacts of hoof trimming regimes on hoof conformation and lameness in dairy goats. Additionally, the impacts of hoof trimming on hoof growth, joint positions and lying behaviour were investigated.

1.12. Thesis structure

This thesis consists of a series of studies that were completed to meet the aims as outlined above. Chapter 2 and 3 have been published in peer-reviewed international journals. Chapter 4 and 5 are currently being finalised in preparation for submission to international journals.

Chapter 2: The aim of this study was to develop and validate a method to assess hoof conformation in dairy goats using objective measures and subjective scores. The assessment developed allowed toe length, heel shape, fetlock shape, claw shape and claw splay to be reliably assessed from photographs.

Chapter 3: This study aimed to develop the first 5-point gait scoring system to be reliably used in dairy goats. The system was adapted from the 3 and 4-point systems previously used in dairy goats and the 5-point systems commonly used in dairy cows. The system developed allowed detection of a full range of lameness from the early signs of an uneven gait to the more severe cases of lameness.

Chapter 4: This observational study applied the method for assessing hoof conformation developed in chapter 2. The aim of this study was to investigate the effect of different hoof trimming regimes on the hoof conformation of dairy goats on 16 New Zealand farms.

Chapter 5: The aim of this experimental study was to investigate the immediate and longer-term effects of early life hoof trimming on the structure and function (i.e., lameness) of the hooves of dairy goats. The study included assessing the impacts of trimming on hoof conformation, joint positions, hoof growth, lameness and lying behaviour.

Chapter 6: This chapter integrates the results from the experimental chapters and will provide a brief discussion of the main findings and their implications for dairy goat management in New Zealand. Additionally, limitations of the work and areas of future research are discussed.

1.13. Ethical statement

Approval from the AgResearch Animal Ethics Committee was sought prior to the commencement of any of the studies included in this thesis. Power analyses were completed to ensure the minimum number of animals were used while still ensuring any biologically relevant differences in the dependent variables being tested could be detected.

1.14. Declaration

Some of the chapters contained in this thesis are presented as papers following the style and formatting requirements of the journals in which they have been published.

1.15. References

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Chapter Two

The development of a hoof conformation assessment for use in dairy goats

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Abstract

The assessment of hoof conformation is important due to its recognised relationship with the biomechanical functionality of the hoof. Hoof conformation can be assessed using objective measures or subjective scores. However, to date there are limited data using either method in dairy goats. Therefore, the aims were to 1) develop a reliable method of assessing hoof conformation in dairy goats, and 2) compare two aspects of a subjective assessment against corresponding objective measures as a means of validation. A total of 1035 goats contributed photographs across sixteen commercial dairy goat farms. Photographs were taken of the left front and left hind hoof in the lateral and dorsal aspect at five assessments across the goats' first two lactations. Hoof conformation was assessed using five subjective scores (toe length, heel shape, fetlock shape, claw splay and claw shape) and two objective measures (toe length ratio, and claw splay distance). Following training of two observers, high levels of inter and intra-reliability were achieved for both the subjective scores (>0.8 weighted kappa) and objective measures (>0.8 Lin's Concordance Correlation Coefficient). Two aspects of the subjectively assessed ordinal scores were compared with the objective measures with high levels of accuracy (>0.8). This suggests that the subjective scores may be a suitable alternative to more time-consuming objective measures when assessment is completed using photographs.

Keywords: toe length; heel shape; claw splay; claw shape; subjective scores; objective measures; lameness; welfare

Introduction

Assessment of hoof conformation is important due to its recognised relationship with the biomechanical functionality of the hoof [1]. Hoof conformation refers to the physical dimensions and shape of the hoof. In dairy cows, desirable hoof conformational traits include a short toe and steeply angled hoof, a straight fetlock [2], an upright heel [3] and even claws [4], thus enabling even weight distribution between the medial and lateral claws of the hoof [5]. Poor hoof conformation is associated with an animal's susceptibility to hoof lesions and lameness [4,6,7], decreased reproductive performance [8], reduced milk production [9] and a greater risk of being culled [10,11]. Therefore, accurate assessment of hoof conformation is imperative for the identification of at-risk animals.

Hoof conformation can be assessed using either subjective scores or objective measures. Aspects of the objective hoof conformation assessment described by Vermunt and Greenough [12] are often used in dairy cows [12-14]. Features assessed commonly include measurements of claw/sole length, heel height and dorsal wall length using calipers, and claw angle using an angle gauge or protractor. Claw/sole length, is determined based on the length of the abaxial wall and bulb that are in contact with the floor [12,13]. Heel height is defined as the distance from the floor to the skin-horn junction [14,15], and dorsal wall length is measured as the distance from the tip of the toe to the dorsal skin-horn junction [12,14,16,17]. Claw angle is measured as the slope of the dorsal border of the claw with respect to the floor surface [14,15]. An animal with good conformation, will have even claw length, greater heel height, shorter dorsal wall length, and greater claw angle [2-4]. However, it should be noted that the naming of the different objective measures can vary between authors, for instance the dorsal wall length has previously been referred to as toe length [15,18] or claw length [19].

Objective measures are suggested to provide superior assessments compared to subjective scores as they are accurate and repeatable [12], allowing for thorough assessment of hoof conformation traits. However, objective measures can involve some subjective judgement by the observer. For instance, concave dorsal hoof walls are reported in dairy heifers [20], therefore when measuring the angle of the claw it results in the observer having to decide on the placement of the protractor. Bhardwaj et al. [13] report intra-observer (repeatability) and inter-observer (reproducibility) reliability when assessing hoof conformation in sheep using the Vermunt and Greenough method. Bhardwaj et al. [13] concluded that due to difficulties in defining measurement points, claw angle and heel height were aspects of hoof conformation that were unreliable for measurement in sheep. Despite the possible difficulties in defining measurement points, inter- and intra-observer reliability are rarely reported in studies using objective measures of hoof conformation in dairy cows.

To our knowledge there is only one previous study that has objectively measured hoof conformation in dairy goats [21], which also used the methodology described by Vermunt and Greenough [12]. Koluman and Göncü [21] did not report any validation to support the use of the cow measurements in goats. Additionally, although the authors state that hooves were rescored to assess variance amongst observers, inter-observer reliability was not reported.

Subjective assessments of hoof conformation involve visual assessments to allocate a categorical score for particular aspects of conformation [2,6,11]. They are quick and easy to use, require no technical equipment, can allow assessment of a large number of animals and are therefore commonly used for live animal scoring on farm [22]. Subjective scoring systems have been used to assess a number of aspects of hoof conformation such as abnormal overgrowth and splayed feet in sows [11], misshaped hooves in sheep [6] and heel height, toe overgrowth and fetlock shape in cows [2,23]. In dairy goats, subjective scores of hoof overgrowth [24,25] and claw deformation have been reported [26], however no other aspects of hoof conformation have been subjectively assessed. Potential limitations of subjective scores are poor inter- and intra-observer reliability as they are affected by both the scoring system used and previous experience [22]. Therefore, intensive training is often required for high levels of reliability to be achieved using subjective methods of assessment [27].

It is important that reliability testing is conducted for conformation scoring systems to ensure accurate and reliable results are obtained. Without evaluating repeatability and reproducibility, conclusions made from the results may be misleading [23]. Additionally, assessments of hoof conformation need to be validated to ensure results are accurately indicating how the allocated scores relate to poor conformation. A way to validate a subjective assessment is to compare allocated subjective scores against objective measures. This has been carried out in pain and lameness assessments [28] and body condition scores in dairy cows [29]. However, validation of many hoof conformation assessment methods has not been reported. Therefore, the aims were to 1) develop a reliable method of assessing hoof conformation in dairy goats, and 2) compare two aspects of the subjective scoring assessment against corresponding objective measures as a means of validation.

Materials and Methods

This study was approved by AgResearch Ltd, Ruakura Animal Ethics Committee (#13478, approved 07/05/2015) as part of a large longitudinal study of dairy goat longevity. Sixteen commercial dairy goat farms in the Waikato region of New Zealand participated (see Todd et al., 2019 for farm information) [30]. The number of farms was the maximum number that could be achieved through voluntary participation. The main variables of interest for the longitudinal study were IgG level during the first 24 hours of life and liveweight gain of doe kids. A power analysis could not be completed as there were no treatments to compare, however a regression of the two variables of interest (IgG and liveweight gain) was obtained. The analysis indicated 1200 animals (approx. 80 per farm) would detect a significant relationship between these variables at the 10% level.

On 12 of the farms, the goats were permanently housed in barns and bedded on wood shavings. One farm provided the goats with access to outdoor pasture up to first kidding (Assessment 2) but goats were permanently housed and bedded on wood shavings thereafter. On two farms the goats were housed in barns and bedded on shavings, however an outdoor area was provided for their adult goats once they were part of the milking herd. One farm housed the goats up to weaning and they were outdoors on pasture thereafter. All farms milked twice daily.

Farms were visited at five assessments throughout the goats' first two lactations (2016 – 2017) (Table 1). As part of these visits, photographs of hooves were taken. The goats were all born in the previous season (May - August 2015) and were therefore of a similar age at the first assessment (mean ± SD: 8.0 ± 0.7 months of age). The first assessment was made near the time of first mating, at which point

1099 goats were still present in the longitudinal study; however, due to issues with hooves being dirty, poor photo quality and missing goat identification 1035 goats were included in the first assessment of the present study. By assessment 2, the goats had kidded and entered the milking herd; the number of goats contributing photographs decreased throughout the study due to culling and ID issues. Each farm's housing and husbandry management protocol was maintained throughout the study, including their specific hoof management and trimming regimes.

Table 1. Stage of production, age (mean ± SD (months)) of the goats, the number of farms visited, the number of goats and number of hoof photographs scored at each of the 5 assessment across the first two lactations.

Assessment	Stage of Production	Age	Number of Farms *	Number of Goats Contributing Photos †	Number of Lateral Aspect Photographs **		Number of Dorsal Aspect Photographs **	
					Front	Hind	Front	Hind
1	First mating	8.0 ± 0.70	16	1035	1018	1011	998	990
2	Start of first lactation	14.8 ± 0.86	15	791	782	769	760	769
3	End of first lactation	21.9 ± 0.70	13	573	561	547	530	536
4	Start of second lactation	29.1 ± 1.00	13	576	566	564	540	547
5	End of second lactation	34.1 ± 0.90	13	629	624	616	594	599

* All 16 farms were included at assessment 1. Issues with photo quality and hoof cleanliness prevented scoring on 1 farm on assessment 2 and 2 farms on assessments 3 and 4. At assessment 5, farm visits could not take place on 2 of the farms and 1 farm had withdrawn from the trial (note: these are not the same farms missing at assessments 3 and 4, therefore goat numbers differ). †Goat numbers decline as the trial progressed due to culling and ID issues. **Not all the goats' photos were scored due to hooves being too dirty, or the photographs being of insufficient quality (e.g., blurry or too dark) for observers to accurately score.

Hoof Conformation Assessment

The hoof conformation assessment was adapted from subjective scores and objective measures previously reported for several species (Table 2). A digital camera (Canon Powershot, SX530) was used to take photographs of the left front and left hind hoof. For practicality and to reduce handling of the goats, only the left hooves were assessed. Photographs were taken in the yards outside of the milking parlour where goats were standing on a horizontal level concrete surface, which ensured they were bearing weight evenly on all four limbs. Two photographs per hoof were taken: 1) lateral aspect, and 2) dorsal aspect. Photographs were taken at approximately 50cm from the goat, ensuring the hoof up to the knee/hock was in view. The hooves were photographed against a whiteboard which had 2cm scale markers along the vertical and horizontal edges to allow the objective measures to be calculated.

Table 2. Aspects of hoof conformation adapted from previous subjective and objective assessments to create the current approach of assessment for dairy goats.

Species	Assessment type	Aspects of hoof conformation	References
Cows	Objective	Toe length, heel height	[15,18,31]
Sheep	Subjective	Shape of hoof	[6]
Sows	Subjective	Abnormal hoof growth, splayed feet, dipped pastern/fetlock	[11]
Goats	Subjective	Hoof overgrowth	[24,25,26]

The assessment included five subjective scores: 1) toe length, 2) heel shape, 3) fetlock shape, 4) claw splay, and 5) claw shape (Table 3 and 4). Each aspect was scored on a 3-point ordinal scale (0, 1, and 2), except for fetlock shape, which was scored on a binary scale (0 or 1); a 0 was ‘normal’ in all cases. Two objective measures were also made: 1) toe length ratio (i.e., the toe length compared with the length of the rest of the hoof (Figure 1a), and 2) claw splay distance (i.e., distance between the axial edge of the distal tip of both claws (Figure 1b). Claw splay was scored, and claw splay distance measured, only when claw shape was scored as a 0 (i.e., both claws were straight).

Two observers scored the photographs. Individual photographs were randomly allocated to each observer ensuring that both observers scored photographs from each farm at each assessment. Observers completed scoring in a cyclical manner: a set of 20 photographs from one farm were completed and then the observer moved on to the next set, to ensure photographs from several farms were scored on any given day. The subjective scoring and objective measures were performed in R 3.5.0 statistical software (R Core Team, 2018) [32]. An R code was developed using packages jpeg and tcltk2 to load and read the photographs, and packages zoo and latticeExtra for distance calibrations (see appendix one for a copy of the full R code used). The developed code streamlined the assignment of each subjective score at the same time as the objective measures were completed.

Using the developed code, a set of 20 photos were uploaded into R, the user firstly entered whether it was a lateral or dorsal aspect photograph they were viewing. A distance calibration was then completed using the scale bar marker on the whiteboard in the photographs. Four calibration points were selected on the scale bar. Two consecutive horizontal markers (x-distance) were firstly selected (cal1, cal2) and then two consecutive vertical markers (y-distance) were selected (cal3, cal4) (Figure 1a). The user input the width and height of the selected points as 2cm, allowing the distance in pixels to be converted to a distance in cm. A linear regression was then fit for both the x-distance ((0, width) ~ intercept + slope*(cal1, cal2)) and the y-distance ((0, width) ~ intercept + slope*(cal3, cal4)). The estimated slopes and intercepts from the linear regressions for the x-distance and y-distance were then used to calibrate selected points on the hooves.

For the objectively measured toe length ratio, three points were selected on a lateral aspect hoof photograph; one point on the end of the toe (point 1), one point in line with the front edge of the coronet band (point 2), and one point at the back edge of the heel where the heel meets the ground (point 3) (Figure 1a). The distance between point 1 and point 2 was divided by the distance between point 2 and point 3 as follows:

$$Toe\ length\ ratio = \frac{\mathrm{sqrt}((\mathrm{x}[2] - \mathrm{x}[1])^2 + (\mathrm{y}[2] - \mathrm{y}[1])^2)}{\mathrm{sqrt}((\mathrm{x}[2] - \mathrm{x}[3])^2 + (\mathrm{y}[2] - \mathrm{y}[3])^2)}$$

where (x[2]- x[1]) is the calibrated difference of the x-position of point 2 on the hoof minus the x-position of point 1, (y[2]- y[1]) is the calibrated difference of the y-position of point 2 on the hoof minus the y-position of point 1. Likewise, (x[2]-x[3]) is the calibrated difference of the x-position of point 2 on the hoof minus the x-position of point 3 and (y[2]- y[3]) is the calibrated difference of the y-position of point 2 on the hoof minus the y-position of point 3.

For claw splay distance, two points were selected on a dorsal aspect hoof photograph; one on the axial side of the distal tip of both claws, with the medial claw (inside) selected first (point 1) (Figure 1b). These two points were calibrated as described above and then the distance between the two points was calculated as follows:

$$Claw\ splay\ distance = \mathrm{sqrt}((x[2] - x[1])\text{^}2 + (y[2] - y[1])\text{^}2)$$

where (x[2]- x[1]) is the calibrated difference of the x-position of point 2 on the hoof minus the x-position of point 1 and (y[2]- y[1]) is the calibrated difference of the y-position of point 2 on the hoof minus the y-position of point 1.

Table 3. Hoof conformation aspects subjectively assessed from photographs taken of the lateral aspect of the left front and left hind hooves of dairy goats across their first 2 lactations, at up to 16 farms and 5 assessments: 1) 1st mating, 2) Start of 1st lactation, 3) End of 1st lactation, 4) Start of 2nd lactation, 5) End of 2nd lactation (n = 1035 contributing goats (median = 629, min = 573, Q1 = 576, Q3 = 791, max = 1035 contributing goats per assessment); n = 7058 total lateral hoof photographs (median = 1240, min = 1108, Q1 = 1130, Q3 = 1551, max = 2029 total of front and hind photographs per assessment); not all the goats' photos were scored due to hooves being too dirty, or the photographs being of insufficient quality (e.g., blurry or too dark) for observers to accurately score).

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

Table 4. Hoof conformation aspects subjectively assessed from photographs taken of the dorsal aspect of the left front and left hind hooves of dairy goats across their first 2 lactations, at up to 16 farms and 5 assessments: 1) 1st mating, 2) Start of 1st lactation, 3) End of 1st lactation, 4) Start of 2nd lactation, 5) End of 2nd lactation (n = 1035 contributing goats (median = 629, min = 573, Q1 = 576, Q3 = 791, max = 1035 contributing goats per assessment); (n = 6863 total dorsal photographs (median = 1193, min = 1066, Q1 = 1087, Q3 = 1529, max = 1988 total of front and hind photographs per assessment); not all the goats' photos were scored due to hooves being too dirty, or the photographs being of insufficient quality (e.g., blurry or too dark) for observers to accurately score).

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

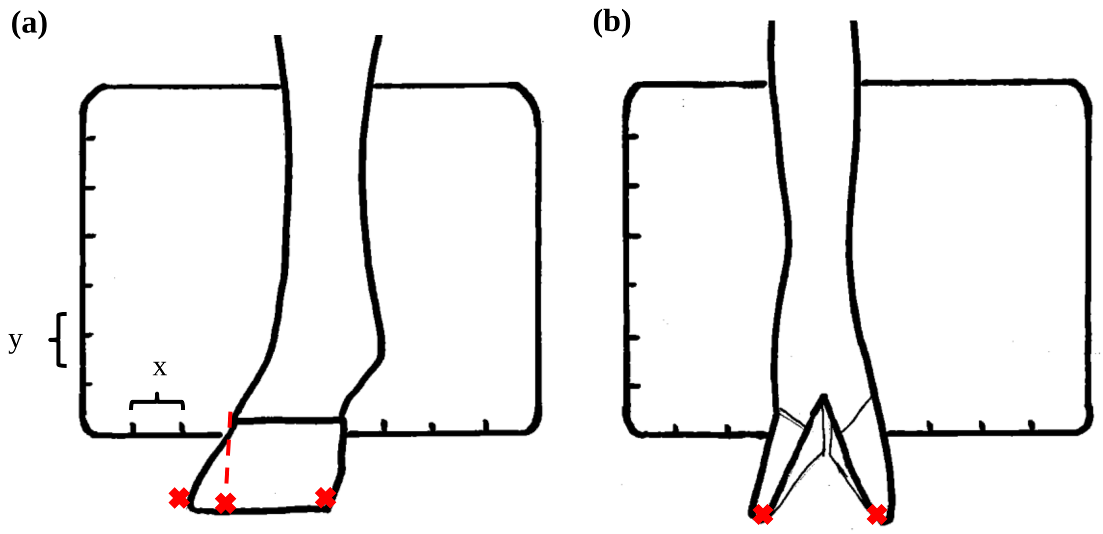


Figure 1. Methods to calculate objective measures of toe length ratio (a) and claw splay distance (b) using a developed R code and the 2cm horizontal and vertical scale markers as reference points (x-distance and y-distance) for distance calibration. (a) A mark was placed on the photograph at the end of the toe (point 1), in line with the front edge of the coronet band (skin-horn junction of the hoof) (point 2) and at the back edge of the heel (point 3), distance between point 1 and point 2 were divided by the distance between point 2 and point 3 to calculate the ratio. (b) A mark was placed on the photograph at the axial edge of the distal tip of both claws (point 4 and 5) to give claw splay distance.

Inter and intra-observer reliability

Training involved scoring 400 photographs over 10 training sessions undertaken over a one-month period until an acceptable level of inter- and intra-observer reliability was achieved. A training session involved both observers independently scoring several photographs, results were then compared and discussed before the next training session was conducted.

Of the 13,921 hoof photographs scored in total, observer 1 scored 7901 and observer 2 scored 6020. The number of photographs scored by each observer contained an equal balance of both lateral and dorsal aspect photographs.

Throughout the photograph scoring, on-going inter-observer reliability tests were completed after both observers had scored approximately 400 photographs. This resulted in 15 inter-observer reliability tests being completed. Intra-observer reliability was tested by observers re-scoring 10% of photographs from each farm at each assessment.

For the subjectively scored aspects of hoof conformation (toe length, heel shape, fetlock shape, claw shape, claw splay) weighted kappa (k_w) statistics were used to measure agreement. Acceptability was deemed as being above 0.8 (almost perfect agreeement; Dohoo et al., 2003).

For the objectively measured aspects of hoof conformation (toe length ratio and claw splay distance), the Bland-Altman method was used to graphically assess agreement (Bland and Altman, 1986). This involved plotting the average of the two observers' measurements (x-axis) against their difference (y-axis), as well as the 95% confidence interval around the mean differences (± 1.96 SD (standard deviation)). It is recommended that 95% of the data points on the Bland-Altman plot fall within ± 1.96 SD of the mean difference (Giavarina, 2015). Additionally, a Lin's Concordance Correlation Coefficient (CCC) (Lawrence and Lin, 1989) was calculated for the objective measures as this method contains measures of both accuracy and precision to determine how far the observed data deviate from the line of perfect concordance (Lawrence and Lin, 1989). Acceptability of CCC was deemed as being above 0.8 (high level of agreement; Altman, 1990).

At each inter-observer reliability test, if reliability went below a threshold of 0.8 for either k_w or CCC, further training was completed to ensure reliability was 0.8 or above before scoring of the photographs could continue.

Comparison of objective measures and subjective ordinal scores

Data processing and descriptive statistical analysis was performed using R 3.5.0 statistical package (R Core Team 2018). The objective measures of toe length ratio and claw splay distance were checked for outliers. If data points were 3 or more times the interquartile range away from the first and third quartile, they were considered outliers. There were 40 photographs identified as outliers for toe length ratio and 5 photographs identified for claw splay distance. One observer rescored these photographs and if the original measurement was accurate the data point remained in the data set. After rescoring, 34 outliers were deemed as accurate for toe length ratio and 4 for claw splay distance and thus remained in the data set.

To evaluate whether subjective scores were correctly assigned, thresholds were set for toe length ratio as follows: If ratio < 0.5 (length of toe was less than half of the length of the rest of the hoof) score = 0; if ratio > 0.5 and < 1 (length of the toe was greater than half, but less than the full length of the rest of the hoof) score = 1; if ratio > 1 (length of the toe was greater than the full length of the rest of the hoof) score = 2) (Table 3). Thresholds were set for claw splay distance as follows: If distance between claws < 4cm score = 0, distance >4cm and <6cm score = 1; distance >6cm score = 2 (Table 4).

Contingency tables were produced to examine the assigned subjective scores for toe length and claw splay to the actual scores (calculated using the above thresholds) for the front and hind hooves across all assessments and farms. An overall accuracy was calculated for each of the ordinal categories (0, 1, and 2) for the front and hind hooves. Accuracy was calculated at the level of each farm across the 5 assessments.

Box plots were used to visually assess the consistency of scoring across the five period assessments for the front and hind hooves.

Accuracy was calculated as follows using the number of true positive (TP), true negative (TN), false negative (FN) and false positive (FP) assessments (Zhu et al., 2010):

$$Accuracy = \frac{(TN + TP)}{(TN + TP + FN + FP)} = \frac{Number\ of\ correct\ assessments}{Number\ of\ all\ assessments}$$

Results

Training

Over the 10 training sessions, inter-observer reliability increased. For subjective scores over training sessions 1 – 4, k_w ranged from 0.32 - 0.86 (median = 0.59, Q1: 0.46, Q3 = 0.73). Over training sessions 5 – 7, k_w ranged from 0.53 – 0.88 (median = 0.71, Q1= 0.62, Q3 = 0.79). From session 8 – 10, k_w was consistently over 0.8. For the objective measures, over training sessions 1 – 4, CCC ranged from 0.52 – 0.79 (median = 0.79, Q1 = 0.66, Q3 = 0.84) for toe length ratio and 0.24 – 0.95 (median = 0.81, Q1 = 0.53, Q3 = 0.88) for claw splay distance. Over training sessions 5 – 7, CCC ranged from 0.79 – 0.91 (median = 0.79, Q1 = 0.73, Q3 = 0.85) for toe length ratio and 0.82 – 0.89 (median = 0.85, Q1 = 0.84, Q3 = 0.87) for claw splay distance. Over training session 8 – 10, CCC ranged from 0.79 – 0.92 (median = 0.86, Q1 = 0.83, Q3 = 0.89) for toe length ratio and 0.93 – 0.95 (median = 0.93, Q1 = 0.93, Q3 = 0.94) for claw splay distance. The Bland-Altman plots for the measures of toe length ratio and claw splay distance showed a random scatter of points with the majority of points falling within the limits of agreement (Figure 2).

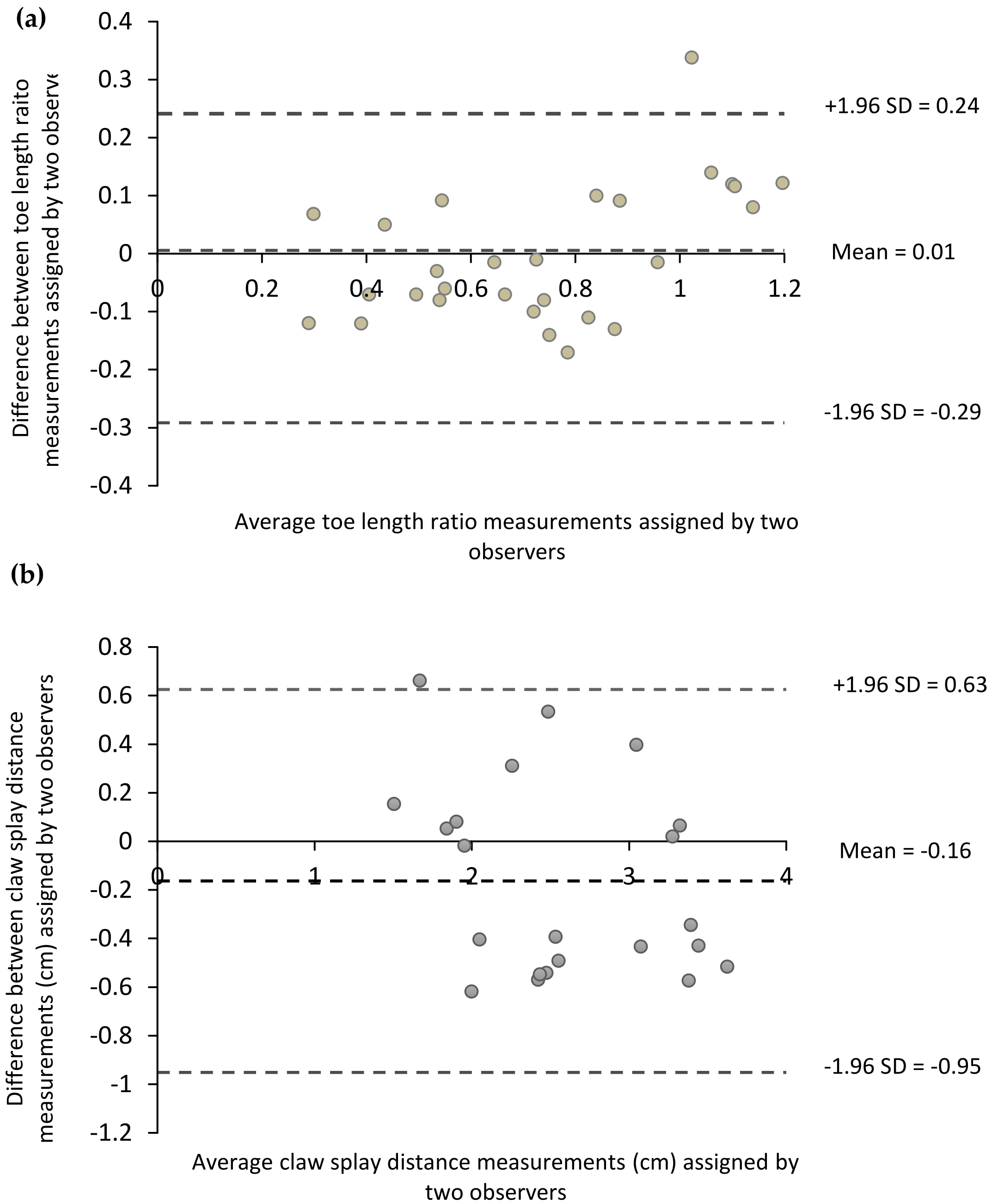


Figure 2. Bland-Altman plots showing the average of the two observers' objective measurements against their difference. (a) toe length ratio (n = 30 photographs), (b) claw splay distance (n = 22 photographs) at training session 10. The middle line represents the estimated bias between the two observers, measured as the mean of the differences. The upper and lower dashed lines show limits of agreement (± 1.96 SD of the observed differences).

Ongoing inter-observer reliability

Inter-observer reliability across the 15 reliability tests ranged from 0.63 – 1.00 (median: 0.81; Q1: 72; Q3: 91) (k_w) for the subjective scores and 0.76 – 0.99 (median: 0.88; Q1: 82, Q3: 0.93) for the objective measures throughout the study (Table 5). At test 2 and 10 CCC for toe length ratio went below the 0.8 CCC threshold (0.79 and 0.76, respectively). At test 5, claw splay score went below the 0.8 k_w threshold (0.63), and at test 8 claw shape went below the 0.8 k_w threshold (0.71) (Table 5).

High levels of reliability were achieved for the fetlock shape subjective score; however, it should be noted that very few dipped fetlocks were recorded during the scoring of the lateral hoof photographs. A total of 186 were recorded out of 7058 lateral photographs (median: 33; Q1: 29, Q3: 37 dipped fetlocks per assessment).

Ongoing intra-observer reliability

Intra-observer reliability was consistently over 0.8 for the subjectively scored aspects (ranged from 0.82 – 1.00 (median: 0.91; Q1: 0.87; Q3: 0.96) (k_w)) and the objectively measured aspects (ranged from 0.85 – 0.99 (median: 0.92; Q1: 0.89; Q3: 0.96) (CCC)) of hoof conformation.

Comparison of the objective measures and subjective scores

High levels of accuracy were achieved for the subjective assessments of toe length and claw splay (> 0.8) for each of the ordinal score categories when compared with the objective measures. Accuracy was highest when assigning a score of 0 and lower for score 1 and 2 for both toe length (Table 6) and claw splay (Table 7).

Scoring was relatively consistent across assessments (Figure 3 and 4) and over farms. Over the farms accuracy for toe length score ranged from 0.90 – 0.96 for score 0 (median = 0.95, Q1 = 0.95, Q3 = 0.96), 0.89 – 0.95 for score 1 (median = 0.93, Q1 = 0.92, Q3 = 0.93), and 0.88 – 0.98 score 2 (median = 0.93, Q1 = 0.90, Q3 = 0.94). Over the farms accuracy for claw splay score ranged from 0.90 – 0.97 for score 0 (median = 0.94, Q1 = 0.94, Q3 = 0.95), 0.78 – 0.95 for score 1 (median: 0.90, Q1: 0.89, Q3: 0.93), and 0.86 – 0.98 score 2 (median = 0.92, Q1 = 0.89, Q3 = 0.98).

Table 5. Results of 15 inter-observer reliability tests completed by the two observers for the subjective scores and objective measures of the hoof conformation assessment.

	Subjective scores (Weighted Kappa (95% CI)					Objective measures (Lin's Concordance Coefficient (95% CI)	
Test	Toe length	Heel	Fetlock	Claw shape	Claw splay	Toe length ratio	Claw splay distance
1	0.84 (0.72-1.00)	1.00 (1.00-1.00)	0.83 (0.73-1.00)	1.00 (1.00-1.00)	1.00 (1.00-1.00)	0.86 (0.70-0.97)	0.97 (0.87-0.99)
2	0.91 (0.73-1.00)	0.92 (0.77-1.00)	0.83 (0.73-1.00)	1.00 (1.00-1.00)	0.90 (0.71-1.00)	**0.79 (0.46-0.93)***	0.97 (0.81-1.00)
3	0.83 (0.70-1.00)	0.85 (0.78-1.00)	0.87 (0.61-1.00)	0.92 (0.76-1.00)	1.00 (1.00-1.00)	0.80 (0.62-0.93)	0.99 (0.94-1.00)
4	0.83 (0.69-1.00)	0.83 (0.71-1.00)	1.00 (1.00-1.00)	0.82 (0.72-1.00)	1.00 (1.00-1.00)	0.94 (0.82-0.98)	0.89 (0.79-0.99)
5	0.91 (0.75-1.00)	1.00 (1.00-1.00)	1.00 (1.00-1.00)	0.87 (0.71-1.00)	**0.63 (0.39-1.00)***	0.83 (0.67-0.91)	0.88 (0.63-0.96)
6	1.00 (1.00-1.00)	0.89 (0.68-1.00)	1.00 (1.00-1.00)	0.88 (0.64-1.00)	0.82 (0.60-1.00)	0.84 (0.64-0.94)	0.99 (0.95-1.00)
7	1.00 (1.00-1.00)	1.00 (1.00-1.00)	1.00 (1.00-1.00)	0.85 (0.68-1.00)	0.84 (0.72-1.00)	0.95 (0.82-0.98)	0.99 (0.86-0.99)
8	1.00 (1.00-1.00)	0.88 (0.77-1.00)	1.00 (1.00-1.00)	**0.71 (0.49-1.00)***	0.86 (0.73-1.00)	0.80 (0.53-0.92)	0.97 (0.90-0.98)
9	0.88 (0.65-1.00)	0.89 (0.74-1.00)	1.00 (1.00-1.00)	0.88 (0.65-1.00)	1.00 (1.00-1.00)	0.97 (0.92-0.99)	0.97 (0.81-0.99)
10	0.87 (0.72-1.00)	0.95 (0.88-1.00)	1.00 (1.00-1.00)	0.87 (0.71-1.00)	0.83 (0.59-1.00)	**0.76 (0.64-0.84)***	0.93 (0.83-0.97)
11	0.88 (0.74-1.00)	1.00 (1.00-1.00)	1.00 (1.00-1.00)	0.84 (0.74-1.00)	1.00 (1.00-1.00)	0.81 (0.69-0.92)	0.91 (0.78-0.97)
12	0.89 (0.78-1.00)	1.00 (1.00-1.00)	1.00 (1.00-1.00)	0.86 (0.81-1.00)	1.00 (1.00-1.00)	0.84 (0.66-0.95)	0.95 (0.73-0.99)
13	0.89 (0.78-1.00)	0.88 (0.75-1.00)	1.00 (1.00-1.00)	1.00 (1.00-1.00)	1.00 (1.00-1.00)	0.89 (0.72-0.96)	0.96 (0.84-1.00)
14	0.87 (0.72-1.00)	0.96 (0.88-1.00)	1.00 (1.00-1.00)	0.86 (0.71-1.00)	0.83 (0.79-1.00)	0.86 (0.67-0.94)	0.93 (0.79-0.98)
15	0.92 (0.77-1.00)	0.93 (0.80-1.00)	1.00 (1.00-1.00)	0.92 (0.75-1.00)	0.81 (0.74-1.00)	0.94 (0.88-0.97)	0.97 (0.88-1.00)

* Occasions where reliability went below 0.8

Table 6. The number of correctly assigned scores (in bold), the number of incorrectly assigned scores, and accuracy for toe length ordinal scores (0, 1, and 2) for the left front and hind hooves as compared with the measured toe length ratio (toe length (end of the toe to the abaxial edge of hoof in line with the front edge of the coronet band) compared with the length of the rest of the hoof (abaxial edge of hoof in line with the front edge of the coronet band to the back edge of the heel)). Scored from hoof photographs taken from a lateral aspect at up to 16 farms and 5 assessments (n = 1035 contributing goats (median = 629, min = 573, Q1 = 576, Q3 = 791, max = 1035 contributing goats per assessment); n = 7058 total lateral hoof photographs (median = 1240, min = 1108, Q1 = 1130, Q3 = 1551, max = 2029 total front and hind photographs per assessment)).

Assigned scores	Front hooves				Hind hooves			
	Actual toe length scores [a]			Accuracy	Actual toe length scores [a]			Accuracy
	0	1	2		0	1	2	
0	**2359 (98.6%)**	148 (15.1%)	0 (0.0%)	0.93	**1586 (96.0%)**	80 (5.9%)	1 (0.2%)	0.96
1	34 (1.4%)	**808 (82.3%)**	33 (22.9%)	0.91	63 (4.0%)	**1247 (92.2%)**	53 (11.8%)	0.93
2	0 (0.0%)	5 (0.6%)	**111 (77.1%)**	0.88	0 (0.0%)	25 (1.8%)	**395 (88.0%)**	0.94
Total scores	2393	981	144		1649	1352	449	

[a] Toe length scores: 0) Toe is not overgrown - the length of the toe is less than half of the rest of the hoof, 1) Toe is moderately overgrown - the length of the toe is greater than half, but less that the full length of the hoof, 2) Toe is severely overgrown – the length of the toe is greater than the full length of the rest of the hoof. Actual scores were calculated using the measured toe length ratios. If ratio <0.5 score = 0, ratio >0.5 and <1 score = 1, ratio >1 score = 2.

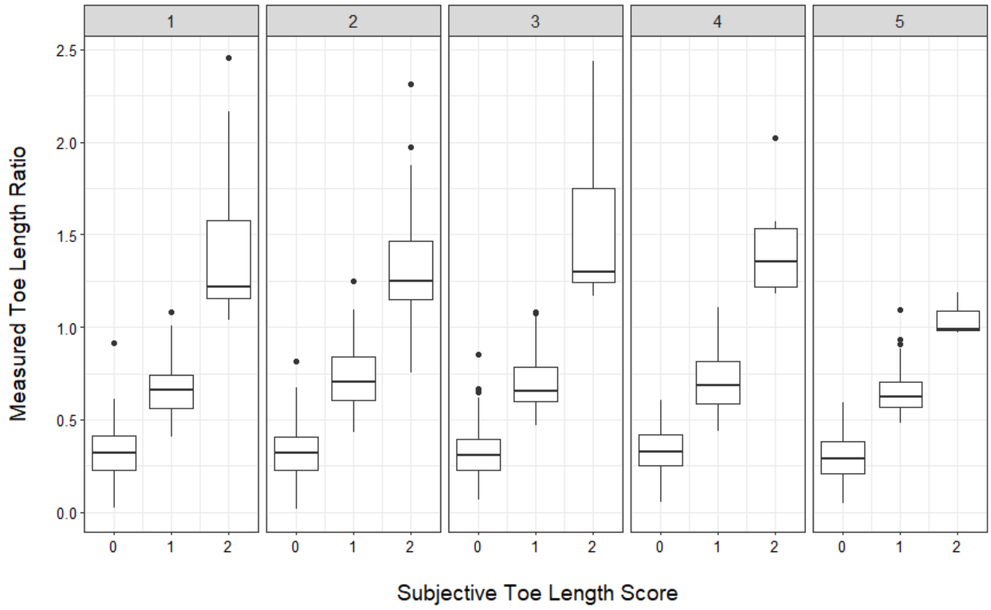
Table 7. The number of correctly assigned scores (in bold), the number of incorrectly assigned scores, and accuracy for claw splay ordinal scores (0, 1, and 2) for the left front and hind hooves as compared with the measured claw splay distance. Scored from hoof photographs taken from a dorsal aspect at up to 16 farms and 5 assessments. Claw splay was only scored if claws were not misshaped, therefore not all photographs/goats

are included (n = 1025 total number of goats that had at least 1 splay claw at any assessment (median = 511, min = 380, Q1 = 440, Q3 = 556, max = 758 contributing goats per assessment); n = 3579 total dorsal hoof photographs (median = 714, min = 486, Q1 = 600, Q3 = 738, max = 1041 total front and hind photographs per assessment)).

Assigned scores	**Front Hooves**				**Hind Hooves**			
	Actual claw splay scores [a]			Accuracy	Actual claw splay scores [a]			Accuracy
	0	1	2		0	1	2	
0	**809 (97.8%)**	116 (12.7%)	0 (0.0%)	0.95	**548 (96.3%)**	60 (11.0%)	0 (0.0%)	0.95
1	18 (2.2%)	**795 (87.2%)**	68 (17.0%)	0.90	21 (3.7%)	**481 (87.9%)**	45 (15.8%)	0.90
2	0 (0.0%)	1 (0.1%)	**332 (83.0%)**	0.91	0 (0.0%)	6 (1.1%)	**239 (84.2%)**	0.92
Total scores	827	912	400		569	547	284	

[a] Actual scores were calculated using the measured claw splay distance. If distance < 4cm, score = 0, distance > 4cm and < 6cm, score = 1, distance > 6cm, score = 2.

(a)



(b)

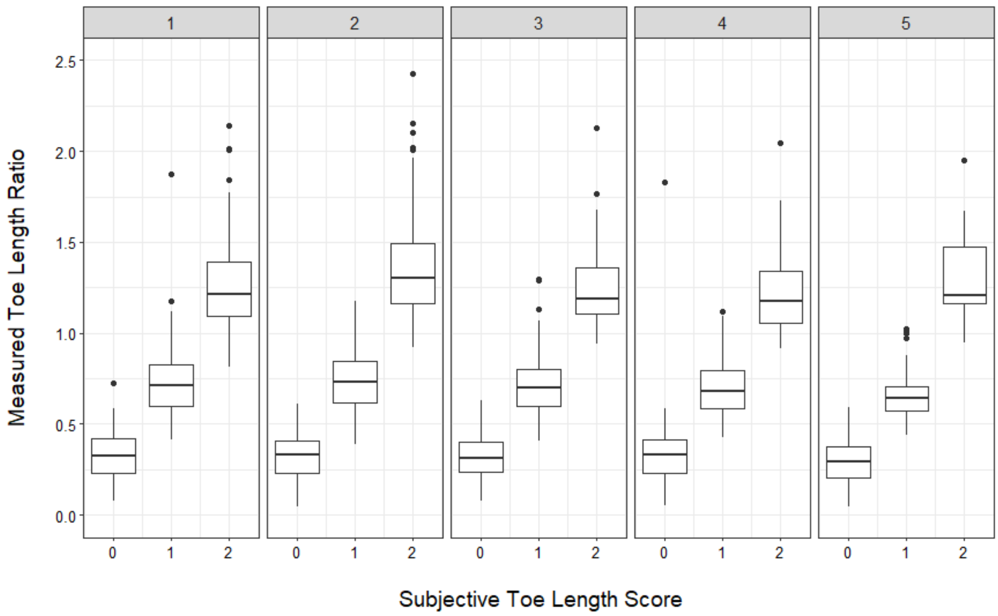
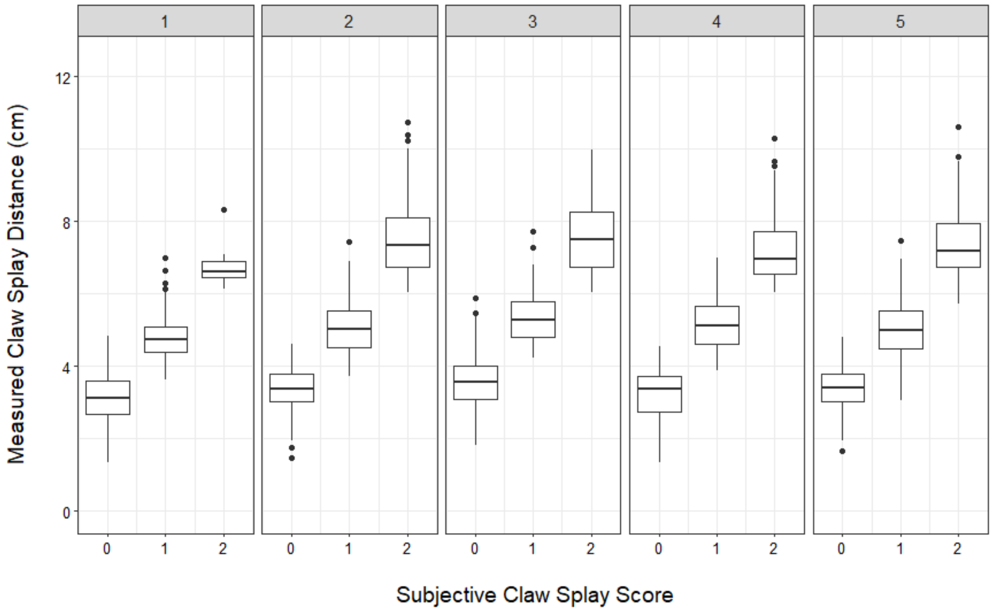


Figure 3. Box plots showing the distribution of assigned toe length scores (0, 1, 2) and the measured toe length ratio (toe length measurement relative to the length of the rest of the hoof) across 5 assessments for the left front (a) and hind (b) hooves. Box plots show the 25th and 75th percentile (box), median (centre line) and extreme values (whiskers). Possible outliers (dots) had been checked to ensure they fell within 3 interquartile ranges away from the first and third quartile (n = 1035 contributing goats (median = 629, min = 573, Q1 = 576, Q3 = 791, max = 1035 contributing goats per assessment); n = 7058 total lateral hoof photographs (median = 1240, min = 1108, Q1 = 1130, Q3 = 1551, max = 2029 total front and hind photographs per assessment)).

(a)



(b)

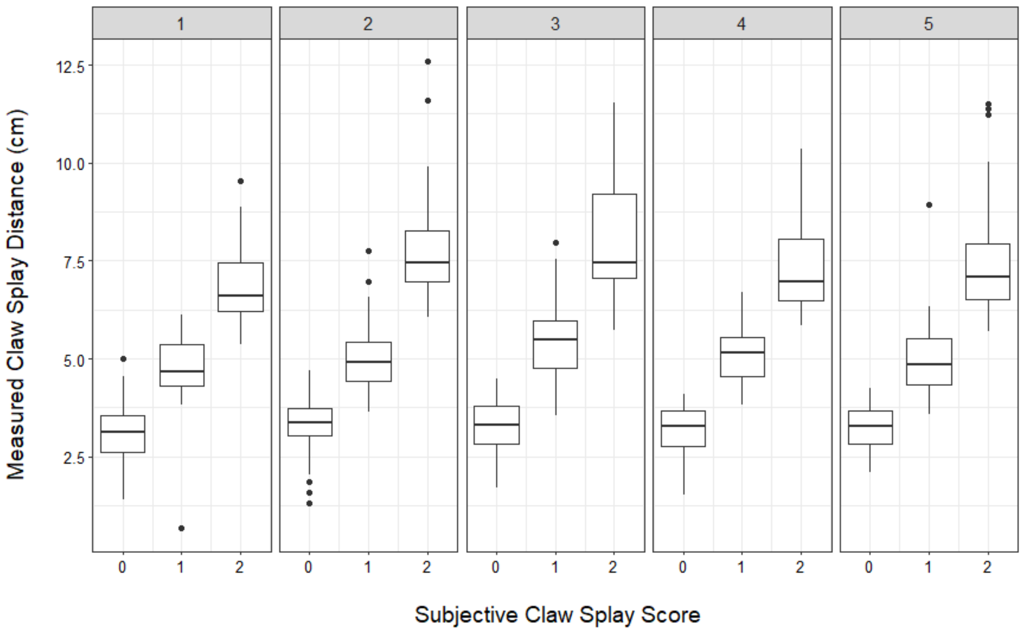


Figure 4. Box plots showing the distribution of assigned claw splay scores (0, 1, 2) and the measured claw splay distance (distance between the distal tip of both claws) across 5 assessments for the left front (a) and hind (b) hooves. Box plots show the 25th and 75th percentile (box), median (centre line) and extreme values (whiskers). Claw splay was only scored if claws were not misshaped, therefore not all photographs/goats are included. Possible outliers (dots) had been checked to ensure they fell within 3 interquartile ranges away from the first and third quartile (n = 1025 total number of goats that had at least 1 splay claw at any assessment (median = 511, min = 380, Q1 = 440, Q3 = 556, max = 758 contributing goats per assessment); n = 3579 total dorsal hoof photographs (median = 714, min = 486, Q1 = 600, Q3 = 738, max = 1041 total front and hind photographs per assessment)).

Discussion

The aim of this study was to develop a reliable method to assess hoof conformation in dairy goats. The results suggest that the assessment method developed is a suitable and reliable way to assess hoof conformation in dairy goats using photographs. After extensive training, both the subjective scores and objective measures were assessed reliably by the two observers. Two aspects of the subjective scores were compared with the corresponding objective measures and were found to be accurate. This suggests that the subjective scores, particularly the 0 and 2 scores, alone may be adequate to assess hoof conformation in dairy goats.

Toe length, as a proxy for hoof overgrowth, is the aspect of hoof conformation that has previously been focused on in dairy goats [24,25]. This is likely because hoof overgrowth is suggested to the be the most common cause of hoof deformation in goats [26,39]. However, other aspects of hoof conformation are also important due to the potential implications to the goat. For example, lower heel angles may significantly increase stress and deformation of the hoof capsule [horses: 40], and misshaped claws can result in local pressure concentrations, resulting in tissue overloading and increased risk of claw horn lesions [cows: 41]. Therefore, other aspects of conformation that were deemed as potentially impacting the welfare of the goat were also included in the current assessment, such as heel shape, fetlock shape, claw splay and claw shape.

Potential limitations of subjective methods of hoof conformation assessment are poor reliability between observers [18]. Previous subjective approaches to assess hoof conformation are commonly dichotomous (i.e., normal or abnormal; good or bad) [6,11]. This is likely because fewer scoring categories result in higher levels of agreement [42], due to less ambiguity. In the present study, high and consistent levels of reliability were achieved for the 3-point ordinal subjective scores of toe length, heel shape, and fetlock shape; however, consistent with previous research, the middle score (1) had overlap with the others (0 or 2). It should be noted that very few instances of dipped fetlock were reported in the present study; nevertheless, it is important to include fetlock shape in hoof conformation assessments, as dipped fetlocks have the potential to increase tension of the suspensory apparatus in the lower leg and hoof [43]. However, work demonstrating this association in ruminants is lacking. The claw shape and claw splay subjective scores in the present study were less reliable and intermittently required further training. This training involved observers discussing the disagreements and completing further reliability tests. Assessments of the photographs did not continue until agreement of over 0.8 between the observers was achieved. This ensured ongoing reliability in the following tests. When photographs were being taken, efforts were made to ensure that the goat was standing squarely and bearing weight on all four legs. However, care was also needed with the placement of the camera, particularly with the dorsal aspect view photographs. If the camera was not placed squarely in front of the hoof the angle of the photograph may make it more difficult to accurately score. Therefore, this may explain why lower reliability was achieved for claw shape and claw splay subjective scores.

Two aspects of hoof conformation, toe length and claw splay could be both subjectively scored and objectively measured, allowing comparisons between the two methodologies. When comparing the subjective scores and objective measures of toe length and claw splay, the observers in the present study were more accurate at assigning a score of 0 compared to 1 or 2, resulting in some overlap when looking at hooves with borderline scores. This highlights why a dichotomous score of "good" vs "bad" is commonly used in hoof conformation assessments. However, acceptable levels of accuracy (> 0.8) were still obtained for scores 1 and 2 and this may be due to the intensive training that was completed prior to assessment of the photographs. We caution other authors that if an accuracy level of over 0.8 is required collapsing scores to a binary assessment may be required. It should be noted that heel angle has also been previously objectively measured in hoof conformation assessments in dairy cows, however lower observer reliability than other measurements of hoof conformation have been reported [44], therefore in the present study heel angle was assessed as a subjective score only.

The present study highlights the need for considerable training to ensure inter and intra-observer reliability when scoring hoof conformation from photographs. Intensive training was required to attain initial reliability levels and then ongoing reliability checks were conducted to ensure any deviation between the observers scoring was quickly detected. In contrast, Murray et al. (1994) [23] used three or four categories to subjectively assess three aspects of hoof conformation in cattle and reported the highest percentage agreement achieved between two trained observers was 66% [22]. In that study, training was undertaken by assessing 50 post mortem hooves collected from the abattoir, while actual assessment was conducted on live animals in the milking parlour.

Repeatability (intra-observer variation) and reproducibility (inter-observer variation) are important when trying to validate a method of assessing hoof conformation. However, for many hoof conformation assessments repeatability and reproducibility have not been established. For example, Gomez et al. (2015) [14] evaluated the hoof conformation of 644 dairy cow heifers. However, all measurements were completed by one observer and no intra-observer reliability testing was reported. Intra-observer reliability is commonly more consistent than inter-observer reliability [23,45]. This is supported by the findings from the present study where intra-observer reliability was consistently above the 0.8 threshold for both kw and CCC. However, variance within an observer still needs to be reported. It is difficult to make definitive conclusions from studies where no evidence is provided to determine if the method is repeatable or reproducible.

Hoof conformation has previously been objectively assessed using photographs with scale markers included for other species [31,46], and with similar methods used in the present study. With the methodology used, the objective measures used in the present study would not be possible to apply on live animals; thus, their use is restricted on farm. Additionally, for objective measures to be completed on farm, animals are often restrained [21], using a crush and their hooves tied [15] or a tilt table [47]. Furthermore, lifting and tying hooves for objective measures to be completed may not give a true assessment of hoof conformation. The shape of the hoof is influenced by weight-bearing and load [48], therefore if the animal is not weight bearing on a limb it may not accurately reflect the animal's true conformation. In the present study, the use of photographs to obtain objective measures reduced the need for such restraint, and ensured the goats were weight bearing to give a true reflection of conformation.

The objective measure for claw splay distance was consistently reliable throughout the scoring of the hoof photographs. There were two occasions when the reliability for the objective measure of toe length ratio went below 0.8. This may have been due to difficulties in placing a point on the hoof in line with the front edge of the coronet band, especially if the hooves were particularly hairy or dirty. Due to time restrictions around milking and attempting to minimize the amount of time the goats were out of their pens; it was not feasible for hooves to be washed. However, if possible, we recommend cleaning of the hooves prior to photographs being taken to improve reliability. As the reliability for the subjective score for toe length was consistently high throughout the assessments, it suggests that the subjective score is more appropriate to use rather than the time-consuming objective measure; however, this needs to be validated on farm.

Conclusion

We successfully developed a reliable method of assessing hoof conformation in dairy goats using photographs. Two aspects of hoof conformation that were subjectively assessed were validated by the comparison of the subjective scores with objective measures. The use of photographs with scale markers allowed for objective measures to be completed, however, this was time consuming and required technical equipment. As two of the subjective scores were shown to correspond to objective measures, they are suitable methods for conformation assessment. High levels of accuracy and reliability (>0.8) were achieved on the photographs in this study; if higher levels were required than collapsing the scores into a binary method should be considered. Nevertheless, further work is required to test the reliability and practicality of subjective hoof conformation assessment on live animals and to determine if it is applicable in an on-farm setting.

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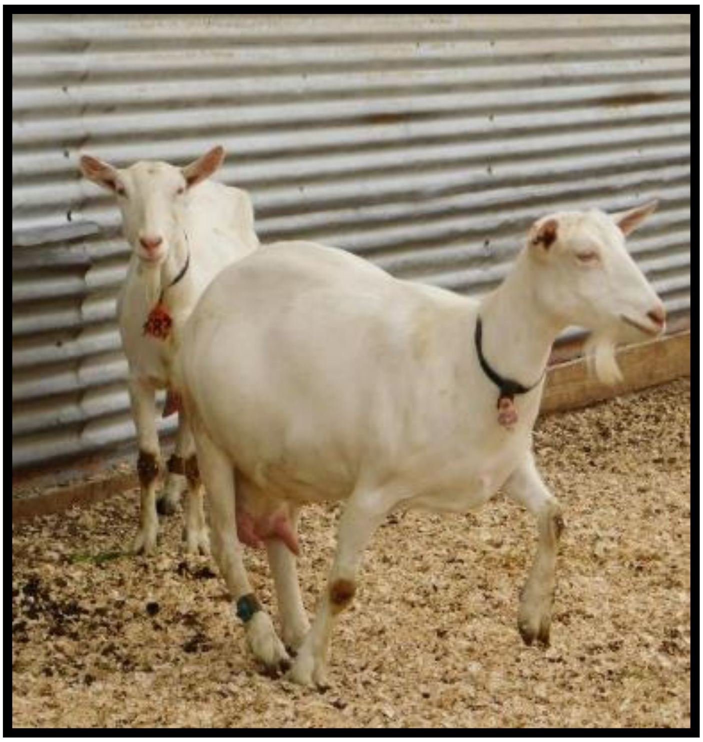
Chapter Three

The development of a five-point gait scoring system for use in dairy goats



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Abstract

Numerical rating scales are frequently used in gait scoring systems as indicators of lameness in dairy animals. The gait scoring systems commonly used in dairy goats are based on 4-point scales that focus on detecting and judging the severity of a definite limp. An uneven gait, such as a shortened stride or not “tracking up,” is arguably the precursor to the development of a limp; thus, identifying such changes in gait could provide opportunity for early treatment. The objectives of this study were (1) to develop a 5-point gait scoring system that included an “uneven gait” category and compare the distribution of gait scores generated using this system to scores generated using a 4-point system, and (2) to determine whether this system could be reliably used. Forty-eight Saanen cross 2- and 3-yr-old lactating does were enrolled from a commercial dairy goat farm. Two observers carried out weekly live gait scoring sessions for 7 wk using the developed 5-point scoring system. The first 2 wk were used as training sessions (training sessions 1–2), with the subsequent 5 wk completed as gait assessments (assessments 1–5). In addition to training session 1 being lived scored, the goats were also video-recorded. This allowed observer 1 to re-score the session 4 times: twice using the developed 5-point system and twice using the previously used 4-point system. Comparisons of score distributions could then be made. Using the 4-point system, 81% of the goats were assigned score 1 (normal gait). Using the 5-point system, only 36% of the goats were assigned score 1 (normal gait), with 50% assigned score 2 (uneven gait). High levels of intra-observer reliability were achieved by observer 1 using both gait scoring systems [weighted kappa (κw) = 1.00: 4-point, κw = 0.96: 5-point]. At training session 1 (wk 1), inter-observer reliability was only moderate (κw = 0.54), but this was improved during the subsequent training session 2 (κw = 0.89). Inter-observer reliability was high among assessments 1 to 5 (κw = 0.90–1.00). During the training sessions, sensitivity for gait scores 1 and 2 was 77 and 65% (training session 1) and 89 and 94% (training session 2), respectively. Sensitivity was high among assessments 1 to 5 (score 1: 83–100%, score 2: 97–100%). This highlights the likely reason why existing gait scoring systems for dairy goats do not include an “uneven gait” category, as distinguishing it from a normal gait was challenging without training. In conclusion, with training, a 5-point gait scoring system could be reliably used. The 5-point system was found to be more sensitive than the 4-point system, allowing for a potential precursor to lameness to be identified. Further work is needed to determine whether the score can be reliably used in an on-farm setting.

Key words: welfare; lame; uneven gait; limp

Technical Note

Lameness, a painful condition (Whay et al., 1997) that impedes a normal walking gait, is one of the most serious welfare issues faced by dairy animals (von Keyserlingk et al., 2009). As lameness compromises animal welfare (Whay et al., 2003), it is essential that the lameness status of dairy animals can be quickly and reliably identified to facilitate the prompt detection and treatment of lame animals.

Gait scoring systems, which use a numerical rating scale to rank an animal's walking ability, are commonly used as an indicator of lameness presence and severity. Systems assessing gait have been established for several species (sheep: Ley et al., 1989; chickens: Weeks et al., 2000; cows: Flower and Weary, 2006; goats: Anzuino et al., 2010; pigs: Nalon et al., 2014).

The 4-point gait scoring systems frequently used for dairy goats require a definite limp to be recognized (Hill et al., 1997; Anzuino et al., 2010; Muri et al., 2013) for an animal to be identified as lame. Gait scores are then assigned based on limp severity (Table 1). A limp can be defined as an altered gait due to reluctance to bear weight on the affected limb (Leach et al., 2009). This reluctance results in an uneven foot fall because a sound limb will be moved more quickly than the lame limb (Leach et al., 2010). With the exception of injuries, many cases of lameness develop over time (de Mol et al., 2013). Therefore, the development of an uneven gait could be a precursor to a limp developing. An uneven gait may be recognized as a shortening of stride, the animal not "tracking up" (i.e., the hind hoof not stepping into the placement of the front hoof) when walking, or as swinging of the affected leg inwards or outwards at each stride (van der Waaij et al., 2005; Haskell et al., 2006).

Table 1. Description of a 4-point gait scoring system previously used in dairy goats (Anzuino et al. 2010) and the 5-point gait scoring system used in this study (including an "uneven gait" category).

	Gait scoring system		Assessment criteria					
Category	4-point	5-point[1]	Limp[2]	Moving forward	Weight bearing	Head nod[3]	Identify affected leg(s)	Other descriptors
Normal gait	1	1	No	Yes	Yes	No	-	Even stride on all four legs, tracking up, walks with a fluid motion
Uneven gait	-	2	No	Yes	Yes	No	No	Shorter stride, not tracking up, joints slightly stiff, inward or outward swinging of a hoof at each stride
Mildly lame	2	3	Yes	Yes	Yes	No	Possibly	One or more legs may be affected. Observer may not be able to determine affected leg(s). Mild limp.
Moderately lame	3	4	Yes	Reluctant	Reluctant	Possibly	Yes	One or more legs may be affected. Moderate limp or slight goose stepping[4]
Severely lame	4	5	Yes	Unwilling/ unable	Unable	Yes	Yes	One or more legs may be affected. Severe limp or walking on knees, or pronounced high goose stepping

[1] 5-point scoring system adapted from Anzuino et al. (2010) (goats), Flower and Weary (2006) (cows), Kaler et al. (2009) (sheep), and Thomsen et al. (2008) (cows). [2] Limp refers to a reluctance to bear weight on the affected limb (Leach et al., 2009), resulting in an uneven foot fall as a favored limb will move more quickly than the lame limb (Leach et al., 2010). [3] Head nod refers to the movement of the head in a vertical plane as the affected limb makes contact with the ground (Nordlund et al., 2004); factor included based on AWIN (2015). [4] Goose step refers to walking with affected limbs stretched (AWIN, 2015)

A 5-point gait scoring system is frequently used as an indicator of lameness in dairy cows (O'Callaghan et al., 2003; Espejo et al., 2006; Flower and Weary, 2006). The dairy cow 5-point scoring system includes an “uneven gait” category, which allows for discrimination of slight variation from a “normal gait,” and therefore may facilitate earlier detection of developing lameness. Not including an “uneven gait” category in scoring systems such as the 4-point system often used in goats (Hill et al., 1997; Anzuino et al., 2010; Muri et al., 2013) may result in animals that have a slight variation from a normal gait being scored as “normal.” These animals will only be detected once a definite limp has developed.

An uneven gait is not necessarily indicative of lameness. For example, conformation, posture, and udder fill of the animal may affect gait (Flower and Weary, 2009). However, using a gait scoring system that includes this category provides an opportunity to investigate the cause of the unevenness. Then, if deemed necessary, interventions such as remedial hoof trimming or veterinary treatment can be administered, potentially preventing deterioration of the condition (Leach et al., 2012).

Simplifying a gait scoring system by reducing the number of categories may improve inter-observer reliability and repeatability (Schlageter-Tello et al., 2014). This could explain why the previously used dairy goat gait scoring systems have fewer than 5 categories and often focus on identifying severe lameness. However, for cows, it is reported that with extra training, similar inter-observer reliability can be achieved using a 5-point system and a 4-point system (Brenninkmeyer et al., 2007). This suggests that the repeatability of a gait scoring system is determined not just by the sensitivity of the score, but also by the observers and their level of training and experience.

This study had 2 objectives: (1) to develop a 5-point gait scoring system for goats that includes a category for "uneven gait" with no limp, and to compare the distribution of gait scores generated using this system to scores generated using a 4-point system that focuses on identifying a limp; and (2) to determine whether the 5-point system can be reliably used.

The study was conducted at the AgResearch Goat Research Facility (Hamilton, New Zealand) and was approved by the AgResearch Ltd. Animal Ethics Committee (#13700). Forty-eight Saanen cross 2- and 3-yr-old lactating does were enrolled in October 2016 and represented the total available population. The goats were housed singly or in pairs on rubber matting and shavings in the indoor facility as part of a larger feeding trial.

The same 2 observers carried out weekly gait scoring sessions for 7 consecutive weeks: the first 2 wk were training sessions, followed by 5 assessment sessions. All gait scoring sessions were conducted at approximately 1600 h, following the afternoon milking, to reduce any effect of milk fill and udder distention on gait (Flower et al., 2006). Goats were assessed while walking from the milking parlor back to their pens on a combination of hard rubber matting and concrete flooring. They left the milking parlor and walked toward the observers, passed them laterally at a distance of 3 to 5 m, and then continued away from the observers to their home pen. This allowed for at least 4 full strides of walk to be viewed. Efforts were made by the observers to keep an equal distance from the goats. However, due to the layout of the housing facility relative to the milking parlor, this was not always possible. Goats exited the parlor one at a time, enabling the observers to view and score each before another was allowed to exit. They exited in an indiscriminate order at each gait scoring session, which would have minimized the risk of observers becoming familiar with the order and recognizing individual goats.

In the first week, the 2 observers live scored the goats using the 5-point scale (see below) to evaluate reliability. This session was completed with the observers scoring independently, allowing an initial inter-observer reliability to be calculated. Inter-observer agreement was only moderate [weighted kappa (κw) = 0.54; Table 2]. The observers aimed to achieve almost perfect agreement (0.81–0.99; Viera and Garrett, 2005) before assessments could begin; therefore, further training was needed. Thus, training session 2 was completed, with the observers being able to discuss scores being assigned; this improved agreement (κw = 0.89; Table 2).

Table 2. Inter- observer reliability between the gait scores of two observers for the weekly assessments for a period of 7 wk (n = 48 goats).

Week	Agreements	Disagreements			Missed scores	McNemar's test *P*-value[3]	Weighted Kappa (95% CI)[4]
		Observer 1 < Observer 2[1]	Observer 1 > Observer 2[2]	Total			
1	28	8	6	14	6	0.59	0.54 (0.34 - 0.74)
2[5]	44	2	1	3	1	0.56	0.89 (0.77 - 1.00)
3	41	0	2	2	5	0.10	0.90 (0.76 - 1.00)
4	47	0	1	1	0	0.24	0.97 (0.91 - 1.00)
5	41	0	0	0	7	NA	1.00 (1.00 - 1.00)
6	47	1	0	1	0	0.24	0.97 (0.90 - 1.00)
7	48	0	0	0	0	NA	1.00 (1.00 - 1.00)

[1] Disagreements when Observer 1 assigned a gait score one category lower than Observer 2 (the difference between observers was never greater than one category)

[2] Disagreements when Observer 1 assigned a gait score one category higher than Observer 2 (the difference between observers was never greater than one category)

[3] McNemar's test $P > 0.10$ indicative of no consistent bias between observers within each assessment

[4] Weighted Kappa closest to 1.0 indicative of high levels of inter-observer reliability

[5] Assessment 2 used as a training session. Observers discussed scores being assigned

In wk 1, the goats were also video-recorded (n = 42; 6 missed due to goats rushing; HC-V270, Panasonic Camcorder, Osaka, Japan) to allow comparison of the distribution of scores generated using the 4- and 5-point systems. At the completion of the 7-wk trial, observer 1 scored these video recordings 4 times: twice using the 5-point system and then twice using a 4-point system (Anzuino et al., 2010). Each scoring occurred 1 wk apart to minimize the risk of observer 1 being familiar with the goats and the order they appeared on the video.

The PROC FREQ procedure of SAS (version 9.3, SAS Institute Inc., Cary, NC) was used to calculate κw and sensitivity (%). This enabled inter-observer reliability at each gait scoring session to be evaluated, as well as intra-observer reliability of observer 1 when training session 1 video was re-scored. McNemar's test was performed to evaluate disagreements between the 2 observers within each training session and within each assessment session to establish whether there was consistent bias between the observers (e.g., one observer always scoring higher than the other).

The 5-point gait scoring system was developed using key descriptors (Table 1) from a previously used goat gait scoring system (Anzuino et al., 2010), combined with features from published scoring systems used for other species (e.g., cows: Flower and Weary, 2006; sheep: Kaler et al., 2009). These features include the quality of the gait, such as whether it is normal or uneven or a limp is present. They also include the animal's ability to move forward, its ability to bear weight, and the observer's ability to identify the affected leg(s). For moderate and severe lameness, features such as head nodding, “goose stepping” (walking with affected limbs stretched; AWIN, 2015), and walking on their knees have been included. The current study had a relatively small proportion of goats with moderate to severe lameness; therefore, the inclusion of these factors was done in accordance with the Animal Welfare Indicators (AWIN) welfare assessment protocol (AWIN, 2015), which focuses entirely on the identification of severe lameness.

High levels of intra-observer reliability were achieved by observer 1 using the developed 5-point gait scoring system and the previously used 4-point system ($\kappa w = 0.96$, 5-point; $\kappa w = 1.00$, 4-point). Using the 4-point system, the majority of the goats (34/42, 81%; average of the 2 re-scores) were assigned score 1 (normal gait). However, using the 5-point scoring system, only 15 of 42 goats (36%) were assigned score 1, and 21 of 42 goats (50%) were assigned score 2 (uneven gait; Figure 1). The difference in the distribution of the assigned gait scores when using the 2 systems indicates that several goats did not have a definite limp but also did not have a normal gait. When using the 4-point system, these “in-between” goats must be assigned a score 1 (normal gait). It should also be noted that 2 of the goats (5%) scored as having a definite limp using the 4-point system were scored as having an uneven gait when the 5-point system was used. The observer considered these goats to be toward the higher end of the “uneven gait” category. Therefore, when using the 4-point system, it was considered more appropriate to assign a “mild lameness” category, rather than “normal gait.”

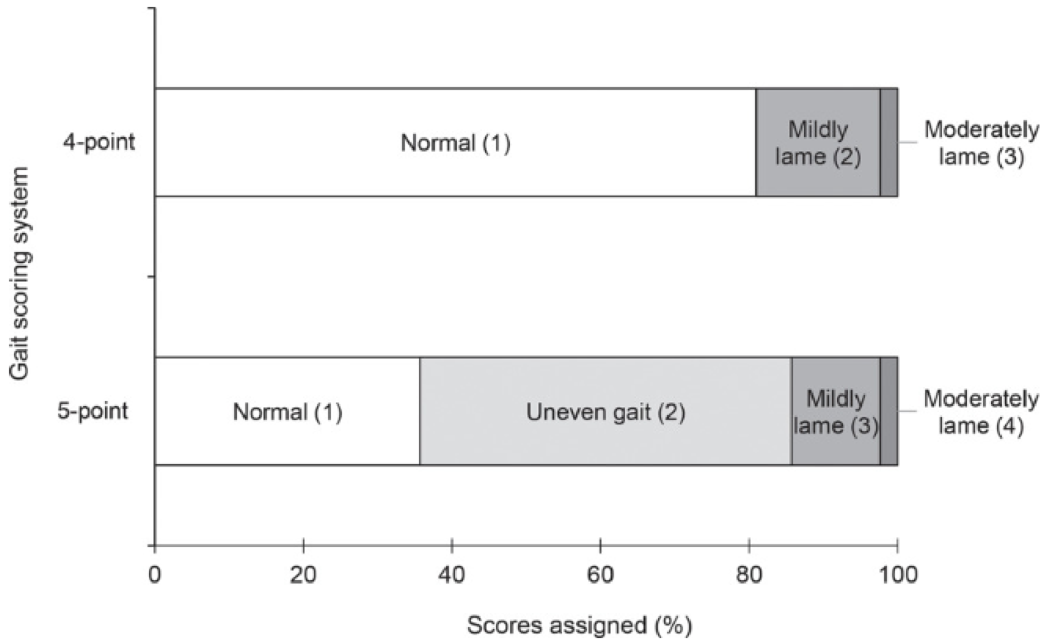

Figure 1. The distribution of gait scores assigned by observer 1 when re-scoring session 1 (wk 1) videos using the 5-point gait scoring system (including “uneven gait” category) system and the 4-point gait scoring system (no “uneven gait” category; Anzuino et al., 2010) (n = 42, 6 goats missed scoring). No goats were severely lame. Four-point score: 1 = normal gait, 2 = mildly lame, 3 = moderately lame, 4 = severely lame. Five-point score: 1 = normal gait, 2 = uneven gait, 3 = mildly lame, 4 = moderately lame, 5 = severely lame.

Study goats that were assigned a gait score of 2 (5-point scale; “uneven gait”) or above at any of the assessments were investigated and promptly treated by a veterinarian if necessary. Therefore, it was not possible to monitor lameness progression across the 7-wk period. Prompt treatment also reduced the possibility of observers being able to recognize individual goats by their gait score. Observers could not assume that a high gait score at one gait scoring session would result in a high gait score at the subsequent gait scoring session.

Nearly half of the goats (19/42; 44%) characterized as having a normal gait using the 4-point system were recognized as having an uneven gait using the 5-point system. Although this prevalence appears high, other studies have suggested that an uneven gait can be very common in dairy animals. For example, of 183 dairy cows, 93% presented with the mildest lameness, considered equivalent to the "uneven gait" category in the 5-point system (Thomas et al., 2015). This highlights the potential lack of discrimination of low levels of lameness when fewer categories are included in a gait scoring system. It is important that the system enables precursors of an obvious limp to be detected, as these animals should be targeted for treatment, rather than waiting until the lameness becomes more severe (Nalon et al., 2014; Thomas et al., 2015).

The 5-point system frequently used to assess gait in cows includes variables other than limping. For instance, the "uneven gait" category uses the presence of an arched back while walking as a criterion to assign the cow to this category (Thomsen et al., 2008). In the present study, back arching did not become obvious until goats were moderately lame (score 4 on the 5-point scale). Indeed, when goats presented with an uneven gait, the observers viewed no other physical changes besides the slight deviation from normal walking. This extra challenge in identifying these goats may help to explain why the scoring systems previously used for dairy goats do not include the "uneven gait" category.

Several different gait scoring systems have been used as indicators of lameness in small ruminants. Similar to our findings for goats, 4-point scoring systems developed for use in sheep are not sensitive enough to detect lower degrees of lameness (Angell et al., 2015). Although 5-point scoring systems have also been developed for use in sheep, the categories are not well defined. They either use subjective descriptors, such as "obvious lameness" (Welsh et al., 1993), or do not give full descriptions of the categories used (Ley et al., 1989), making reproducibility difficult. Interestingly, a more detailed (7-point) scale including categories to detect an uneven gait was developed and reliably used in sheep (Kaler et al., 2009). In that study, the 3 observers were already familiar with gait scoring of sheep and received one training session using 10 video clips. Although they were able to identify the sheep with uneven gait, it should be noted that this was done entirely from recorded video clips; these authors did not test the scoring system in a live, on-farm setting.

In contrast, simplification of scoring by the use of a 4-point scale, or to a greater degree, the binary approach (i.e., severely lame or not lame) used in the AWIN protocol, may allow scoring to be achieved readily on farm with less training (AWIN, 2015). A binary score is reported to be used in the AWIN protocol because of the challenges of gait scoring dairy goats, such as husbandry constraints and differences in management and resources at farms (AWIN, 2015). Although even binary systems may have consistency issues over time (Can et al., 2017), they may be the best option for large-scale on-farm work, because they allow the prevalence of severe lameness to be identified quickly and easily during welfare assessments. The drawback of utilizing scoring systems with reduced categories is that, in large studies, the prevalence of less severe lameness may be underestimated.

Early detection and treatment are reported to reduce the prevalence of severe lameness and aid faster recovery (sheep: Kaler and Green, 2009; cows: Leach et al., 2012). In addition, lameness is known to negatively affect milk production (cows: Warnick et al., 2001; goats: Christodoulopoulos, 2009), fertility (cows: Melendez et al., 2003), and longevity (cows: Booth et al., 2004). Therefore, being able to detect an uneven gait, a potential indicator of early lameness, allows for further investigation and early treatment if necessary. This may reduce the negative effect on animal welfare and productivity.

Our second objective was to determine the reliability of the gait scoring system developed. Of the possible 240 scores from the weekly assessments (assessments 1–5 completed in wk 3–7), 227 observations were recorded. High inter-observer reliability was achieved using the 5-point scale for assessments 1 to 5 ($\kappa w = 0.90$ to 1.00; Table 2). We detected no difference in the disagreements of the 2 observers within any of the assessments (McNemar's P-value range: 0.10–0.24; Table 2). This indicates no consistent bias between observers; that is, one observer did not consistently score higher or lower than the other observer.

Most (82%) of the live scores assigned using the 5-point scale over the 5 assessment sessions were scores 1 and 2. Scores 3, 4, and 5 comprised 13% of the total assigned scores, with 5% of goats missed. There were only 2 goats across the 5 assessments that each presented with severe lameness (score 5; 5-point system) at one of the assessments. The sensitivity between the 2 observers for scores 1 and 2 during the training sessions was 77 and 65% (training session 1) and 89 and 94% (training session 2), respectively. During assessments 1 to 5, sensitivity was high (score 1: 83–100%, score 2: 97–100%).

The low initial sensitivities during training highlights the likely reason that existing scoring systems do not include “uneven gait,” because both observers found that distinguishing “uneven gait” from “normal gait” was challenging. Identifying an uneven gait, the intermediate category between normal gait and a definite limp, is also challenging in other small ruminants. For example, the greatest disagreement between observers scoring sheep was found between the “normal gait” category and the “slight abnormal gait” category (Kaler et al., 2009). Nonetheless, in the current study, following 2 training sessions, the observers could use the 5-point gait scoring system reliably.

The 13 missing scores were attributed to goats rushing after exiting the milking parlor. Although we attempted to reduce this behavior by having an assistant walk in front of the goats, it was still not possible to achieve a steady walking pace for all goats to assign an accurate gait score. This is pertinent because rushing was found, on at least one occasion, to almost entirely mask a score 4 (moderately lame; 5-point scale) goat. The ability to assign an accurate gait score is reduced if goats move faster than a walk. This is particularly relevant for animals with lower levels of lameness because subtler changes in gait are more difficult to detect as speed increases. Gait scores were only assigned by the 2 observers if the goats walked at a steady pace to ensure scoring was not biased by the speed of the goat. Difficulties in assigning accurate gait scores due to the speed that goats exit the milking parlor have previously been reported and resulted in a simple binary scoring system (lame/not lame) being used (Crosby-Durrani et al., 2016). Therefore, we suggest that controlling the speed of goats and ensuring goats walk at a steady consistent speed is essential to ensure accuracy of the 5-point score. However, we acknowledge that this would not necessarily be feasible in all on-farm settings.

The observers developed the 5-point gait scoring system presented here and were therefore very familiar with the system before gait scoring was completed. However, further training sessions were required to improve inter-observer reliability. March et al. (2007) also found that considerable training, involving at least 5 farm visits and the scoring of between 200 and 300 live animals, was required to achieve high inter-observer repeatability when using a 5-point system to score gait in dairy cows. Less intensive training was required in the present study (2 training sessions comprising 42 and 47 animals, respectively). Although training can be time consuming, the result is a reliable 5-point gait scoring system. Nonetheless, it should be noted that the present study focused on a small number of animals in a controlled environment. Therefore, we caution that due to the challenges of gait scoring dairy goats, large-scale farm work needs to be completed to determine whether the 5-point gait scoring system presented here is applicable to on-farm settings and prevalence assessments.

In conclusion, we successfully developed a 5-point gait scoring system. After 2 training sessions, reliability was achieved between 2 observers scoring a small group of goats. Nearly half of the goats characterized as having a normal gait using a previously reported 4-point system were recognized as having an uneven gait using the developed 5-point system. Using a scoring system that enables the identification of an uneven gait could facilitate detection of early signs of lameness, allowing for early investigation and treatment if necessary. We encourage the testing of this 5-point gait scoring system in large, on-farm settings.

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Chapter Four

An observational study investigating the effects of early life trimming regimes and subsequent trimming frequency on hoof conformation of dairy goats

Abstract

Frequent hoof trimming promotes an anatomically correct hoof shape and balanced weight-bearing between the two claws. This reduces the risk of hoof lesions and lameness. There are limited data on the optimal frequency of hoof trimming for dairy goats, or the appropriate timing of first trimming in early life and how these factors affects hoof conformation. Therefore, the aims of this study were 1) to investigate if trimming before first mating affected hoof conformation (farms categorised into trimmed (n = 3) or untrimmed (n = 13)) and 2) to investigate if trimming before first kidding and the frequency of subsequent hoof trimming affected hoof conformation at the end of second lactation (farms categorised as 1) Early trimmed, ≥ 4 trims per year thereafter (n = 4), 2) Early trimmed, 2-3 trims per year thereafter (n = 6), 3) Late trimmed, 2-3 trims per year thereafter (n = 3). Sixteen dairy goat farms in the Waikato region of New Zealand were included as part of a 4-year longitudinal study. Hoof conformation was assessed from photographs taken at first mating (8.0 ± 0.70 months of age) (n = 1030 contributing goats, 16 farms) and end of second lactation (34.1 ± 0.90 month of age) (n = 627 contributing goats, 13 farms). Aspects were subjectively assessed using a binary system (good vs poor) for toe length, heel shape, claw shape and claw splay. Additionally, two objective measures (toe length ratio and claw splay distance) were completed. At first mating (8.0 ± 0.70) the toe length ratio was greater in the untrimmed hooves compared to trimmed hooves in the front (0.44 (95% CI: 0.30-0.53) vs. 0.27 (0.17-0.29), respectively; $F_{1, 13.52} = 6.41$, $P < 0.05$), and hind hooves (0.64 (0.53– 0.77) vs. 0.31 (0.21-0.45), respectively; $F_{1, 13.52} = 13.58$, $P < 0.01$). In addition, the hind hooves of goats that had not been trimmed before first mating had greater odds of being overgrown (odds ratio and 95% CI: 3.00 (1.41-6.38) $P < 0.01$) and having dipped

heels (8.94 (4.89-16.32) $P < 0.001$) and misshaped claws (1.68 (1.08-2.65) $P < 0.05$) than those that had been trimmed. At the end of second lactation the hind hooves of goats on farms that had not trimmed prior to first kidding (regime 3) had greater odds of having dipped heels compared to the other two regimes that did trim before first kidding (regime 1: 2.38 (1.23-4.60), $P < 0.01$) and 2.27 (regime 2: (1.22-4.21) $P < 0.01$), regardless of frequency of trimming thereafter. The present study was observational; however, the findings suggest that trimming before first mating is beneficial to hoof conformation in the short term. The functional significance of the differences in hoof conformation at first mating in terms of an increased risk of lameness should be considered in future studies. Trimming before first kidding had a long-term effect on the heel conformation of the hind hooves at the end of second lactation, and the subsequent frequency of hoof trimming had no observable effects. However, regardless of trimming regime high proportions of poor hoof conformation were observed at the end of second lactation, suggesting that management factors other than trimming may be strongly impacting hoof conformation of dairy goats.

Introduction

Hoof trimming aims to correct hoof overgrowth and improve conformation through the restoration of the claws to an anatomically correct shape (cows: Shearer and van Amstel, 2001). This promotes symmetry and balanced weight bearing between the claws (Bryan et al., 2012) and reduces the risk of hoof lesions and lameness (Hernandez et al., 2007) in dairy cows. Ideal hoof conformation should include a short toe with a steep angled claw, a high upright heel (van Amstel, 2017), a straight fetlock (Häggman and Juga, 2013), and both claws on the same hoof should be even sized (van Amstel, 2017).

Hoof and leg disorders become more prevalent with more confined management systems, as environmental conditions such as flooring substrate and poor hygiene can influence hoof conformation (cows: Bergsten, 2001). Commercial dairy goat systems are typically fully indoors, and are bedded with straw (UK: Anzuino et al., 2010; Italy: Battini et al., 2014) or wood shavings (New Zealand: Solis-Ramirez et al., 2011). Therefore, due to limited opportunities for housed dairy goats to naturally wear their hooves, a high prevalence of hoof overgrowth is common (84-100%: Hill et al., 1997; Anzuino et al., 2010).

Hoof overgrowth in dairy goats can have significant impacts on the conformation of the hoof resulting in deformation of the claws (Ajuda et al., 2014), with chronic overgrowth causing a slippered hoof where the toe curls up and the weight bearing surface transfers to the heel (Hill et al., 1997). In a recent study, hoof overgrowth and claw deformation were shown to be associated with lameness prevalence and lameness severity in dairy goats (Ajuda et al., 2019); therefore, frequent hoof trimming is necessary to prevent prolonged overgrowth and poor conformation (Smith and Sherman, 2009; Ajuda et al., 2019).

Frequent hoof trimming results in a shorter more upright hoof conformation; such hooves are associated with reduced risk of lameness (cows: Boettcher et al., 1998; Manske et al., 2002b). In dairy cows it is suggested that hoof trimming should be completed at least once a year (Manson & Leaver 1988), with twice yearly trimming generally recommended (Toussaint Raven, 1985, Manske et al., 2002a). Indeed, Manske et al. (2002a) report that trimming twice per year is beneficial to hoof health and conformation, with cows that received an extra hoof trim in autumn having shorter and steeper claws compared to cows that only received a hoof trim in spring.

In contrast, routine hoof trimming should be avoided in sheep (Winter et al., 2015), as trimming spreads the bacteria associated with the common infectious lesions among sheep, resulting in higher lameness prevalence (Sullivan et al., 2014). Additionally, providing sheep have the opportunity for sufficient exercise to naturally wear their hooves, they can self-regulate hoof length and hoof trimming is not beneficial (Smith et al., 2014). This highlights the need for species specific hoof management and trimming protocols.

The frequency of trimming in adulthood is important in dairy cows, however the timing of first trimming in early life (before first calving) also needs to be considered. It is recommended that heifers should receive their first trim prior to first calving (Hulsen, 2006; Cook, 2016). However, these claims are based on the authors' clinical experience and are not established from primary research. Nevertheless, there is some research evidence that trimming in early life may improve conformation and thus enable the hoof to better adapt to post calving changes such as new time budgets and walking surfaces (Gomez et al., 2013). For instance, trimming in early life reduced claw lesions during first lactation (Gomez et al., 2013), while trimming as early as first insemination in dairy heifers reduces claw disorders in later life (Kofler et al., 2011).

There are few data investigating the appropriate frequency of hoof trimming in dairy goats. Due to the indoor housing of dairy goats hoof trimming should be a priority (Ajuda et al., 2019), with hooves needing to be trimmed more frequently than twice a year (Smith and Sherman, 2009). This is in agreement with Christodoulopoulos (2009) who report that goats trimmed every 6 months suffered from hoof overgrowth. Goats' hooves may require trimming as often as every 6 to 8 weeks depending on the housing environment (Pugh and Baird, 2002).

Furthermore, there are no studies investigating timing of first trimming in dairy goats. Therefore, the aims of this observational study were 1) to investigate if there was a difference at first mating in the hoof conformation of goats that had been trimmed compared with goats that had not yet been trimmed, and 2) to investigate if hoof trimming before first kidding and subsequent hoof trimming regime impacted hoof conformation at the end of second lactation.

Materials and Methods

This work was approved by the AgResearch Ltd, Ruakura Animal Ethics Committee (#13478, approved 07/05/2015) as part of a 4-year dairy goat longevity study on 16 participating farms in the Waikato region of New Zealand (see Todd et al., 2019, for farm information). The number of farms was the maximum number that could be achieved through voluntary participation. The main variables of interest for the longitudinal study were IgG level within 24 hours of life and liveweight gain of doe kids. A power analysis could not be completed as there were no treatments to compare, however a regression of the two variables of interest (IgG and liveweight gain) was obtained. The analysis indicated 1200 animals (approx. 80 per farm) would detect a significant relationship between these variables at the 10% level. Of the total 1262 dairy goat kids enrolled at birth on the 16 participating commercial dairy goat farms, only those that stayed in the herd until mating were included in the present dataset (n = 1099 goats; mean ± SD: 64 ± 9 goats/farm).

Data were collected from farmers about the age at which they first trimmed their goats' hooves and the number of hoof trims per year thereafter. Farms were visited at five assessment periods throughout the goats' first two lactations for scheduled weighing. Hoof photographs were taken as part of these visits. Data from assessment 1 (First mating: 8.0 ± 0.70 months of age) (n = 1030 contributing goats, 16 farms) and assessment 5 (End 2nd lactation: 34.1 ± 0.90 month of age) (n = 627 contributing goats, 13 farms) were used to address the objectives of the present study. Due to issues with hooves being too dirty, or the photographs being of insufficient quality (e.g., blurry or too dark) not all goats could be scored. Additionally, the number of goats contributing photographs decreased from assessment 1 to assessment 5 due to culling and identification issues. At assessment 5, farm visits could not take place on two of the farms and one farm had withdrawn from the study.

Each farm’s housing and husbandry management protocol was maintained throughout the study, including their specific hoof management and trimming regimes.

Hoof conformation assessment

Photographs of the left front and left hind hooves were taken using a digital camera (Canon Powershot, SX530), while the goats stood on a horizontal level surface, ensuring they were bearing weight evenly on all four limbs. For practicality and to reduce handling of the goats, only the left hooves were assessed. Two photographs were taken per hoof, one of the lateral aspect and one of the dorsal aspect. The hooves were photographed against a whiteboard which had 2cm scale markers along the vertical and horizontal edges.

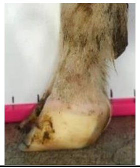
The assessment included five subjective scores: 1) toe length, 2) heel shape, 3) fetlock shape, 4) claw splay, and 5) claw shape (Table 1). Each subjective score was made on a 3-point ordinal scale (0, 1, and 2), except for fetlock shape which was scored on a binary scale (0 or 1), with a 0 being ‘normal’ in all cases. Two objective measurements were also made: 1) toe length ratio (the toe length compared to the length of the rest of the hoof and 2) claw splay distance (distance between the axial edge of the distal tip of both claws (Chapter 2).

The scoring and measurements were completed in R 3.5.0 statistical software (R Core Team, 2018) using methods described in Chapter 2.

Inter and intra observer reliability

The hoof photographs were scored by two trained observers. Inter and intra reliability were determined using the methods described in Chapter 2.

Table 1. Hoof conformation aspects subjectively assessed from photographs taken of the lateral aspect (toe length, heel shape, fetlock shape) and dorsal aspect (claw shape and claw splay) of the left front and left hind hooves of dairy goats at first mating (8.0 ± 0.70 months of age) and at the end of second lactation (34.1 ± 0.90 months of age) (adapted from chapter 2).

	Ordinal score					
Hoof aspect	Score 0		Score 1		Score 2	
Toe length		**Not overgrown** Length of the toe is less than half of the length of rest of the hoof		**Moderately overgrown** Length of the toe is greater than half, but less than the full length of the rest of the hoof		**Severely overgrown** Length of the toe is greater than the full length of the rest of the hoof
Heel shape		**Upright heel** Not walking on heels, coronet band parallel to ground		**Moderately dipped heel** Not walking on heels, but coronet band is angled towards the ground		**Severely dipped heel** Walking on heels, 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		
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 †		**Not splayed** the distance between the inside edges of claws are approximately <2 horizontal marks on the whiteboard		**Moderately splayed** the distance between the inside edges of claws approximately >2 and <3 marks on the whiteboard		**Severely splayed** the distance between the inside edges of claws > 3 marks on the whiteboard

* Fetlock scored as binary 0 or 1. † Claw splay only scored if claw shape scored as 0

Data handling and analysis

All data processing and statistical analysis were performed using R 3.5.0 statistical package (R Core Team, 2018). A binary variable indicating poor conformation (overgrown toes, dipped heels, misshaped claws and splayed claws) was formed for each of toe length, heel shape, claw shape and claw splay, by reclassifying the scores into a binary system of good conformation (score 0) vs poor conformation (score 1 and 2). Fetlock shape was not included in the analysis because few dipped fetlocks (at first mating: 60 dipped fetlocks; end of second lactation: 34 dipped fetlocks) were observed. Toe length ratio and claw splay distance were treated as continuous outcome variables. These variables were checked for outliers, ensuring all data points fell within 3 times the interquartile range away from the first and third quartile.

Objective 1: Effect of trimming before first mating on hoof conformation

Farms were categorised into one of two groups based on farmer-reported trimming status at assessment 1: 1) untrimmed before first mating (n = 13 farms, 822 goats), 2) trimmed before first mating (n = 3 farms, 208 goats). Of the three farms that had trimmed before mating, one farm trimmed at approximately 7 months of age and the other two farms trimmed at approximately 8 months of age.

For toe length ratio and claw splay distance box plots were used to explore differences within and between farms in the two different trimming groups. The LMER procedure was used to test the effect of trimming before mating on toe length ratio and claw splay distance at assessment 1, with goat within farm as the experimental unit. Trimming group was included as fixed effect, goat weight as a covariate, and farm as a random effect. Results are presented as mean and 95% confidence intervals.

The GLMER procedure was used to test for an effect of trimming before mating on the odds of a goat having poor conformation (overgrown toes, dipped heels, misshaped claws and splayed claws) between the two trimming groups, with goat within farm as the experimental unit. Trimming group was included as a fixed effect and farm as a random effect. An attempt was made to include weight as a covariate, however as it was being largely explained by farm, the models would not converge with weight included. A binomial distribution and logit link function were applied to the models. The results are presented as odds ratio and 95% confidence intervals.

In addition to the LMER and GLMER models the proportion of goats with poor conformation were calculated for each farm and then averaged for each trimming group; proportions are presented as overall mean and range (min – max).

Objective 2: Effect of trimming before first kidding and subsequent regime on hoof conformation

For the data collected at assessment 5, the 13 remaining farms were categorised into one of three different trimming regimes depending on whether they first trimmed before or after first kidding (14.8 ± 0.86 months of age) and then by the number of trims performed per year thereafter. The regimes were: 1) Trimmed before 1st kidding then ≥ 4 times per year thereafter (n = 4 farms, 183 goats), 2) Trimmed before 1st kidding, then 2 to 3 times per year thereafter (n = 6 farms, 287 goats), 3) Trimmed after 1st kidding, then 2 to 3 times per year thereafter (n = 3 farms, 157 goats).

For toe length ratio and claw splay distance box plots were used to explore differences within and between the trimming regimes. The LMER procedure was used to test the effect of trimming regime on toe length ratio and claw splay distance at assessment 5, with goat within farm as the experimental unit. Trimming regime was included as fixed effect, goat weight as a covariate, and farm as a random effect. Results are presented as mean and 95% confidence intervals.

The GLMER procedure was used to test for an effect of trimming regime on the odds of a goat having poor conformation (overgrown toes, dipped heels, misshaped claws and splayed claws) between the three trimming regimes, with goat within farm as the experimental unit. Trimming regime was included as a fixed effect and farm as a random effect. An attempt was made to include weight as a covariate, however as it was being largely explained by farm, the models would not converge with weight included. A binomial distribution and logit link function were applied to the models. The results are presented as odds ratio and 95% confidence intervals.

Additionally, the proportion of goats with poor conformation was calculated for each farm and then averaged for each of the three trimming regimes; proportions are presented as overall mean and range (min – max).

Model assumptions

All LMER models were evaluated for assumptions of homoscedasticity and normality of residuals. Homoscedasticity was assessed by visually examining a scatterplot of residuals against predicted values. Normality was assessed using histogram and normal probability plots, as well as checking the residuals for skewness and kurtosis. A log transformation was applied to the toe length ratio and claw splay distance LMER models for both objectives to improve homoscedasticity and to help normalize distribution of residuals. Results are presented as back-transformed means and 95% confidence intervals.

Results

Objective 1: Effect of trimming before first mating on hoof conformation

Toe length ratio and claw splay distance

At mating, goats on farms that had trimmed had shorter toe length ratios (i.e. length of toe relative to the rest of the hoof) in the front and hind hooves compared with goats on farms that had not yet trimmed.

In the front hooves of goats on farms that had trimmed before first mating, median toe length ratios were all below 0.5 (range of medians: 0.20-0.35) with individual goat ratios ranging from 0.06-0.91. Of the 13 farms that had not trimmed before mating 4 of the farms had median toe length ratios above 0.5 (range of medians: 0.10-2.45), while 9 of the farms had median toe length ratios below 0.5 (range of medians: 0.24-0.46) with individual goat ratios ranging from 0.10-1.95 (Figure 1a).

In the hind hooves of goats on farms that had trimmed before first mating the median toe length ratios were all below 0.5 (range of medians: 0.24-0.36) with toe length ratios ranging from 0.09-1.77. Of the 13 farms that had not trimmed before first mating, 10 of the farms had median toe length ratios above 0.5 (range of medians: 0.56-1.21) with individual goat ratios ranging from 0.10-2.14, while 3 of the farms had median toe length ratios below 0.5 (range of medians: 0.34-0.49) with individual goat ratios ranging from 0.08-1.88 (Figure 1b).

On average, the toe length ratio was shorter in the trimmed hooves compared to the untrimmed hooves in the front (0.27 (95% CI: 0.17 – 0.29) vs 0.44 (95% CI: 0.39 – 0.53), respectively; $F_{1, 13.52} = 6.41$, $P < 0.05$)), and in the hind (0.31 (95% CI: 0.21 – 0.45) vs 0.64 (95% CI: 0.53– 0.77), respectively; $F_{1, 13.52} = 13.58$, $P < 0.01$)).

There was no evidence of an effect of trimming before first mating on claw splay distance in the front (Figure 2a) or hind (Figure 2b) hooves. There was no difference in the trimmed hooves compared with the untrimmed hooves in the front hooves ((3.47 (95% CI: 3.16 – 3.80) vs 3.55

(95% CI: 2.95 – 4.17), respectively; $F_{1, 12.04} = 0.04$, $P = 0.85$)) and hind hooves ((3.72 (95% CI: 3.24 – 4.37) vs 3.39 (95% CI: 2.69 – 4.27), respectively; $F_{1, 11.95} = 0.49$, $P = 0.50$)).

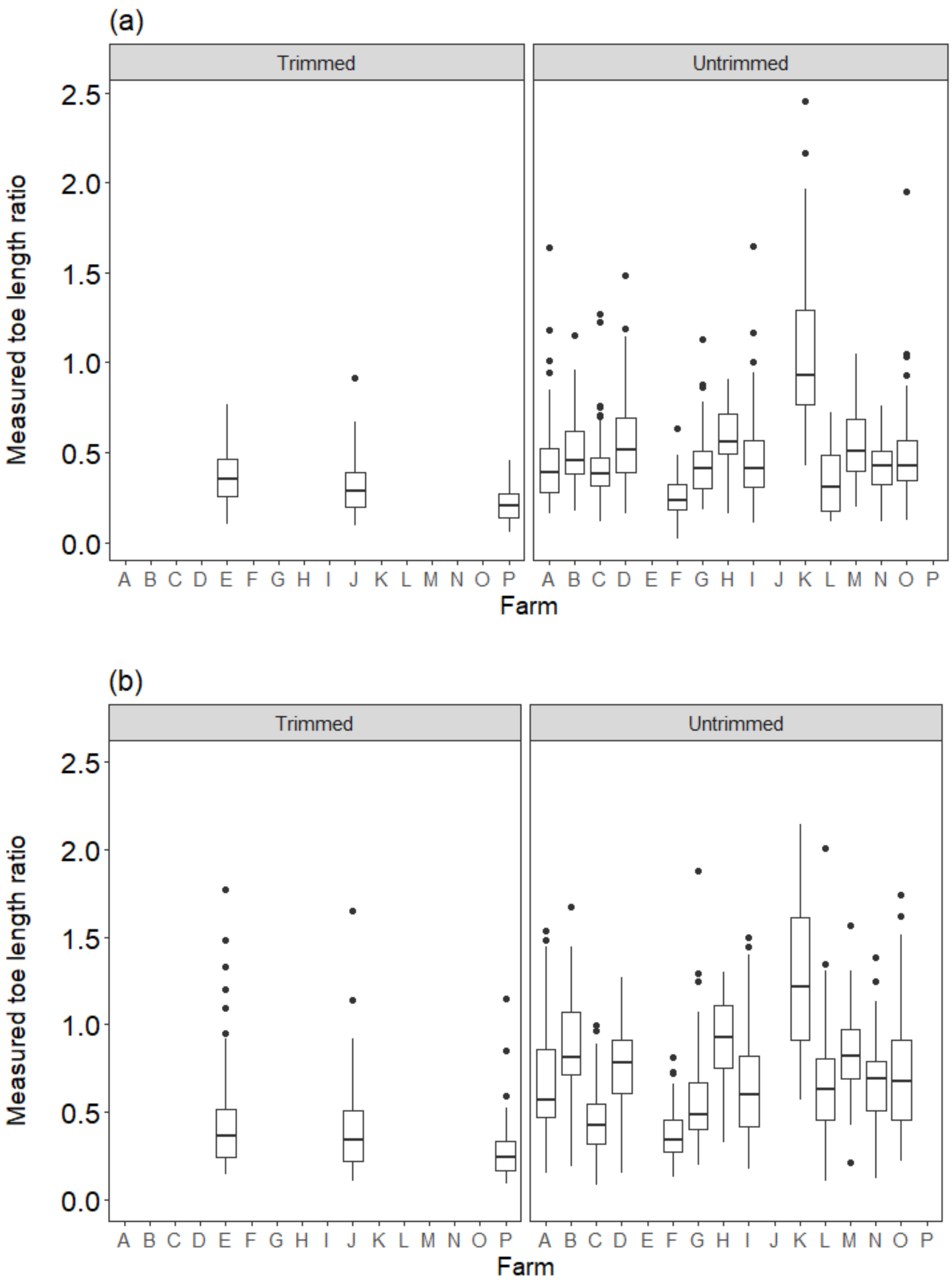


Figure 1. Box plots showing the 25th and 75th percentile (box), median (centre line), and extreme values (whiskers) for toe length ratio of the (a) front hooves and (b) hind hooves at assessment 1 of goats on farms that had been trimmed (Trimmed: n = 3 farms, 208 goats) and goats on farms that had not yet been trimmed (Untrimmed: n = 13 farms, 822 goats). Possible outliers (dots) had been checked to ensure they fell within 3 interquartile ranges away from the first and third quartile.

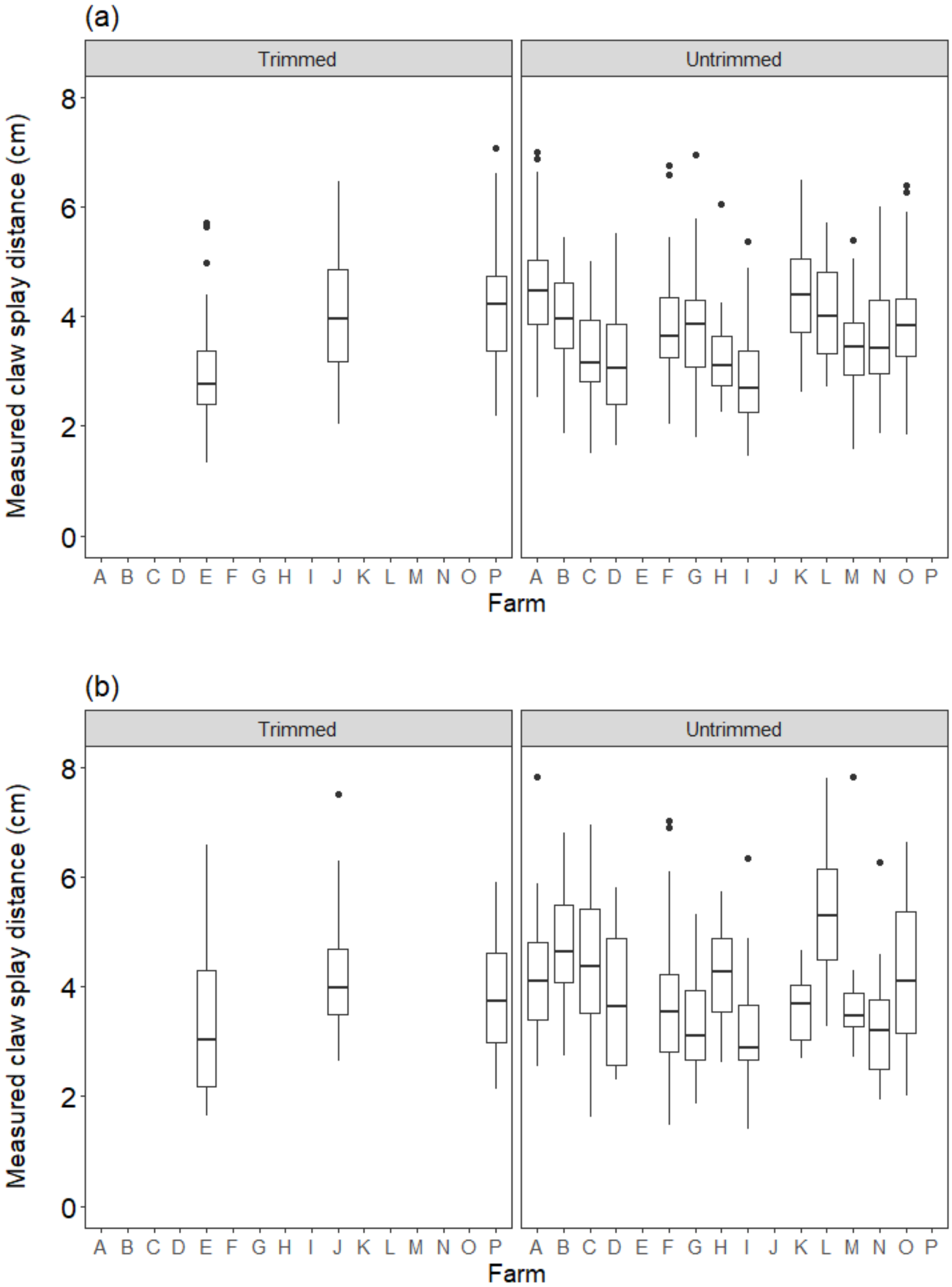


Figure 2. Box plots showing the 25th and 75th percentile (box), median (centre line), and extreme values (whiskers) for claw splay distance of the (a) front hooves and (b) hind hooves at assessment 1 of goats on farms that had been trimmed (Trimmed: n = 3 farms, 137 goats) and goats on farms that had not yet been trimmed (Untrimmed: n = 13 farms, 467 goats) . Claw splay distance was only measured if claw shape was scored as 0, therefore not all goats are included. Possible outliers (dots) had been checked to ensure they fell within 3 interquartile ranges away from the first and third quartile.

Toe length, heel shape, claw shape, claw splay

There were no differences in the odds of poor conformation in the front hooves of goats that had not been trimmed before first mating compared to those that had been trimmed. The odds of goats having overgrown hind hooves, dipped heels, and misshaped claws were greater by a factor of 3.00, 8.94 and 1.69 respectively, when they had not been trimmed prior to first mating (Table 2).

Table 2. The odds ratio (OR) and 95% confidence interval (CI) of goats' hooves having poor conformation (determined using a binary system comparing good vs poor conformation) on farms that had not trimmed (n = 13 farms, 822 goats) compared with farms that had trimmed (n = 3 farms, 208) before first mating (assessment 1).

	OR (95% CI)
Front hooves	
Overgrown	0.57 (0.25-1.28)
Dipped heels	0.39 (0.27-0.56)
Misshaped	0.64 (0.48-0.84)
Splayed	1.35 (0.98-1.86)
Hind hooves	
Overgrown	3.00 (1.41-6.38)**
Dipped heels	8.94 (4.89-16.32)***
Misshaped	1.69 (1.08-2.65)*
Splayed	0.53 (0.33-0.85)

Significance level: * P < 0.05, ** P < 0.01, *** P < 0.001

The highest proportions of poor conformation were observed in the hind hooves of the goats that had not been trimmed before first mating, with over 50% of hind hooves showing poor conformation for all variables (Table 3).

Table 3. Mean proportion and range (minimum and maximum) of goats' hooves with poor conformation (determined using a binary system comparing good vs poor conformation) on farms that had not trimmed (n = 13 farms) compared with farms that had trimmed (n = 3 farms) before first mating (assessment 1). Proportions > 50% are in bold.

	Untrimmed	Trimmed
Front hooves		
Overgrown	0.38 (0.01-0.98)	0.09 (0.00-0.19)
Dipped heels	0.30 (0.11-0.6)	0.12 (0.09-0.16)
Misshaped	0.42 (0.21-0.71)	0.34 (0.25-0.51)
Splayed	0.37 (0.15-0.68)	0.38 (0.22-0.47)
Hind hooves		
Overgrown	**0.69 (0.13-1.00)**	0.22 (0.10-0.28)
Dipped heels	**0.86 (0.47-1.00)**	0.45 (0.37-0.57)
Misshaped	**0.63 (0.24-0.89)**	0.45 (0.36-0.54)
Splayed	**0.53 (0.17-0.90)**	0.41 (0.63-0.47)

Objective 2: Effect of trimming before first kidding and subsequent regime on hoof conformation

Toe length ratio and claw splay distance

There was no evidence of an effect of trimming regime on toe length ratio for the front or hind hooves (Figure 3). Toe length ratio was not different among trimming regime 1, 2 or 3 for the front hooves ((0.34 (95% CI: 0.27 – 0.42) vs 0.30 (95% CI: 0.23 – 0.40) vs 0.29 (95% CI: 0.21 – 0.39), respectively; $F_{2, 9.49}$ = 0.54, P = 0.60)) or the hind hooves ((0.37 (95% CI: 0.29 – 0.48) vs 0.32 (95% CI: 0.23 – 0.43) vs 0.35 (95% CI: 0.25 – 0.49), respectively; $F_{2, 9.22}$ = 0.49, P = 0.62)).

There was no evidence of an effect of trimming regime on claw splay distance for the front or hind hooves (Figure 4). Claw splay distance was not different among trimming regime 1, 2 or 3 for the front hooves ((5.01 (95% CI: 4.27 – 6.03) vs 4.90 (95% CI: 4.07 – 6.03) vs 4.68 (95% CI: 3.63 – 5.89), respectively; $F_{2, 9.43}$ = 0.25, P = 0.78)) or the hind hooves ((4.68 (95% CI: 3.98

– 5.50) vs. 4.27 (95% CI: 3.47 – 5.25) vs 4.68 (95% CI: 3.72 – 5.88), respectively; $F_{2,10.67}$ = 0.31, P = 0.74)).

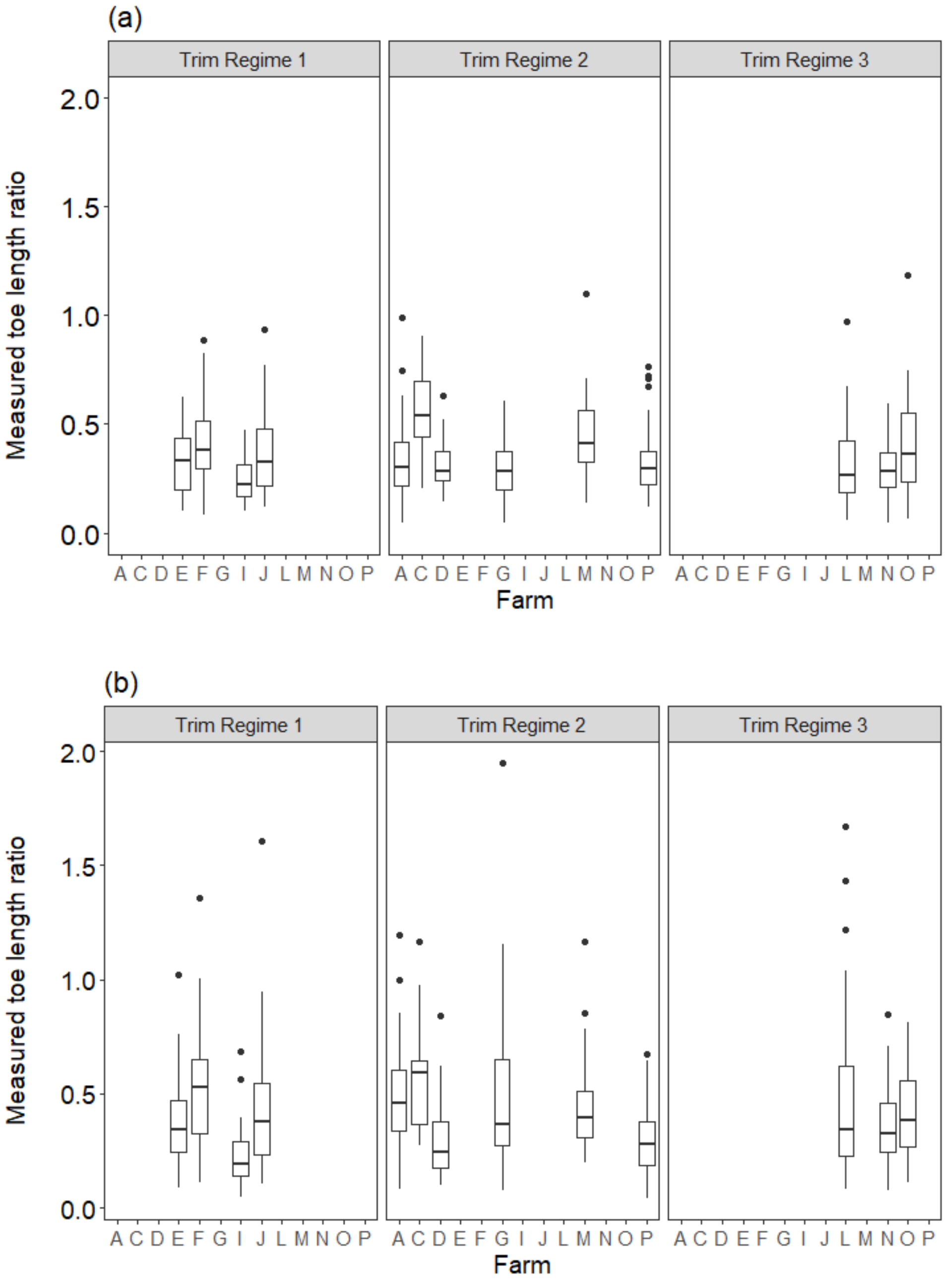


Figure 3. Box plots showing the 25th and 75th percentile (box), median (centre line), and extreme values (whiskers) for toe length ratio of the (a) front hooves and (b) hind hooves of goats at assessment 5 that had received three different hoof trimming regimes (regime 1, trimmed before 1st kidding then ≥ 4 times per year thereafter : n = 4 farms, 183 goats; regime 2, trimmed before 1st kidding, then 2 to 3 times per year thereafter: n = 6 farms, 287 goats; regime 3, trimmed after 1st kidding, then 2 to 3 times per year thereafter: n = 3 farms, 157 goats). Possible outliers (dots) had been checked to ensure they fell within 3 interquartile ranges away from the first and third quartile.

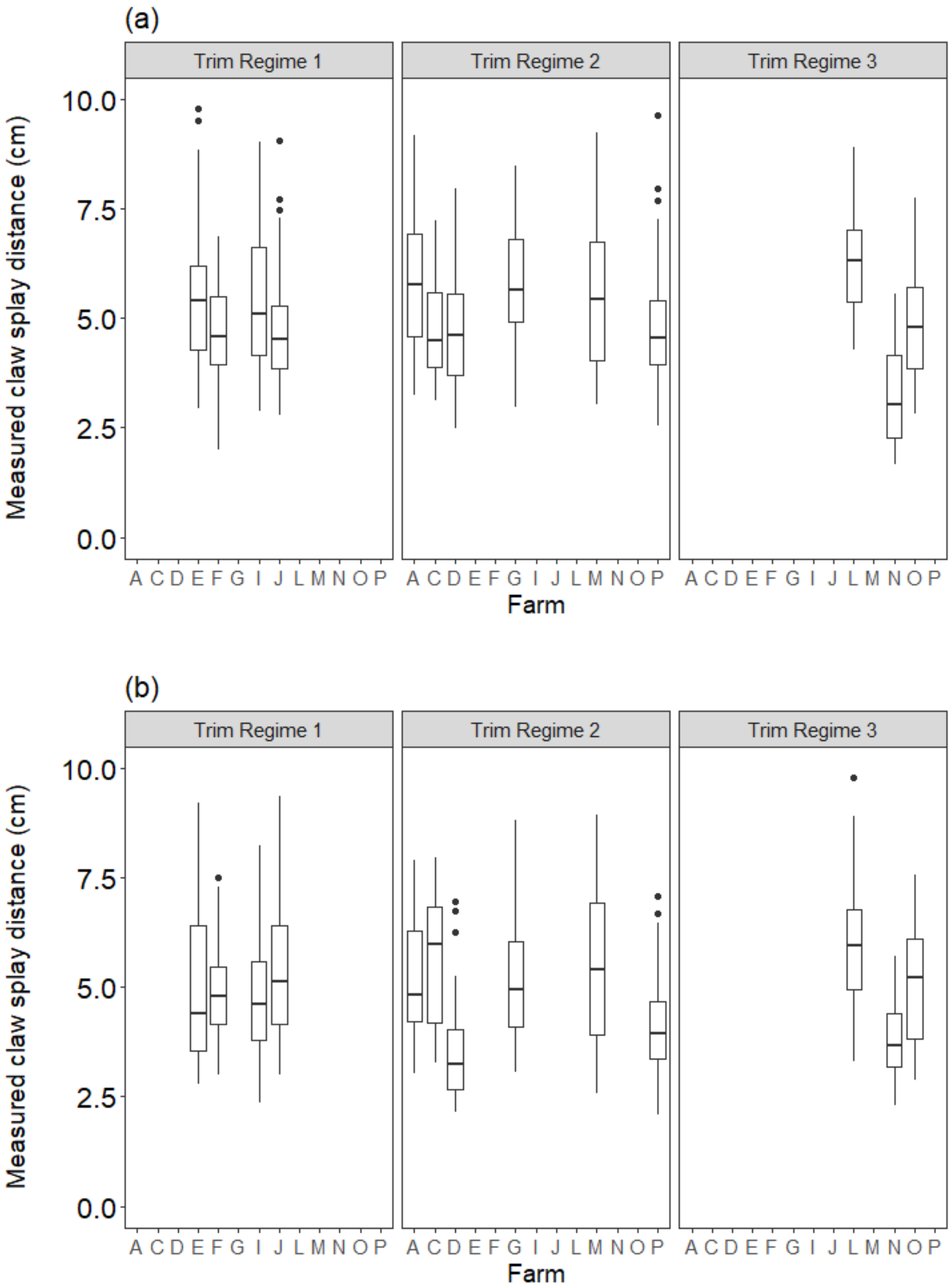


Figure 4. Box plots showing the 25th and 75th percentile (box), median (centre line), and extreme values (whiskers) for claw splay distance of the (a) front hooves and (b) hind hooves of goats at assessment 5 that had received three different hoof trimming regimes (regime 1, trimmed before 1st kidding then ≥ 4 times per year thereafter : n = 4 farms, 183 goats; regime 2, trimmed before 1st kidding, then 2 to 3 times per year thereafter: n = 6 farms, 287 goats; regime 3, trimmed after 1st kidding, then 2 to 3 times per year thereafter: n = 3 farms, 157 goats). Claw splay distance was only measured if claw shape was scored as 0, therefore not all goats are included. Possible outliers (dots) had been checked to ensure they fell within 3 interquartile ranges away from the first and third quartile.

Toe length, heel shape, claw shape, claw splay

At the end of second lactation the odds of goats' hind hooves having dipped heels were greater on farms that trimmed after first kidding compared with farms that trimmed before first kidding. The odds of goats having dipped heels on farms that used trimming regime 3 (trimmed after first kidding and then 2-3 times per year thereafter) were greater by a factor of over 2 compared to goats on farm that trimmed using regime 1 (trimmed before first kidding and then 4+ times per year thereafter) or regime 2 (trimmed before first kidding and then 2 to 3 times per year thereafter) (Table 4). Trimming regime had no effect on any of the other binary conformation variables in either the front or hind hooves.

Table 4. The odds ratio (OR) and 95% confidence interval (CI) of goats' hooves having poor conformation (determined from a binary system comparing good vs poor conformation) at the end of second lactation (assessment 5) when comparing farms using three different hoof trimming regimes (regime 1: n = 4 farms, 183 goats; regime 2: n = 6 farms, 287 goats; regime 3: n = 3 farms, 157 goats).

	OR (95% CI)		
	Regime 1 vs 2	Regime 1 vs 3	Regime 2 vs 3
Front hooves			
Overgrown	1.52 (0.31-7.44)	1.84 (0.29-11.52)	1.21 (0.23-6.46)
Dipped heels	1.47 (0.65-3.00)	1.623 (0.64-4.14)	1.10 (0.47-2.58)
Misshaped	2.15 (0.93-5.01)	1.45 (0.70-3.04)	1.48 (0.69-3.19)
Splayed	1.21 (0.34-4.29)	0.86(0.19-3.90)	0.71 (0.17-2.94)
Hind hooves			
Overgrown	1.33 (0.40-4.47)	1.23 (0.30-5.07)	0.93 (0.25-3.40)
Dipped heels	1.04 (0.62-1.77)	2.38 (1.23-4.60)**	2.27 (1.22-4.21)**
Misshaped	0.95 (0.43-2.08)	0.96 (0.38-2.41)	1.01 (0.43 -2.37)
Splayed	0.61 (0.15-2.51)	0.88 (0.16-4.73)	1.45 (0.31-6.81)

Significance level: ** $P < 0.01$
Regime 1 – goats were trimmed before first kidding and then 4+ times per year thereafter
Regime 2 – goats were trimmed before their first kid and then 2 to 3 times per year thereafter
Regime 3 – goats were trimmed after their first kid and then 2 to 3 times per year thereafter

On average there was a high proportion of goats that had splayed claws on the front (≥ 70%) and hind (≥ 68%) hooves at the end of second lactation irrespective of which hoof trimming regime they had received. Additionally, there was a high proportion of goats with dipped hind heels (≥ 66%) and over half of all goats had misshaped hind claws irrespective of trimming regime (Table 5).

Table 5. Mean proportion and range (minimum and maximum) of goats' hooves with poor conformation (determined from a binary system comparing good vs poor conformation) at the end of 2nd lactation (assessment 5) on farms using three different hoof trimming regimes (regime 1: n = 4 farms, 183 goats; regime 2: n = 6 farms, 287; regime 3: n = 3 farms, 157 goats). Proportions > 50% are in bold.

	Trimming regime[1]		
	1	2	3
Front hooves			
Overgrown	0.11 (0.09-0.25)	0.18 (0.02-0.55)	0.16 (0.01-0.25)
Dipped heels	0.18 (0.10-0.34)	0.23 (0.05-0.41)	0.27 (0.20-0.40)
Misshaped	0.26 (0.11-0.38)	0.35 (0.23-0.55)	0.42 (0.38-0.49)
Splayed	**0.75 (0.66-0.97)**	**0.78 (0.60-0.95)**	**0.70 (0.40-0.97)**
Hind hooves			
Overgrown	0.25 (0.05-0.49)	0.30 (0.05-0.54)	0.27 (0.16-0.32)
Dipped heels	**0.66 (0.59-0.76)**	**0.67 (0.56-0.82)**	**0.83 (0.75-0.90)**
Misshaped	**0.55 (0.32-0.73)**	**0.54 (0.35-0.65)**	**0.55 (0.46-0.72)**
Splayed	**0.78 (0.65-0.98)**	**0.68 (0.31-0.87)**	**0.75 (0.57-0.96)**

[1]Regime 1 – goats were trimmed before first kidding and then 4+ times per year thereafter; Regime 2 – goats were trimmed before their first kid and then 2 to 3 times per year thereafter; Regime 3 – goats were trimmed after their first kid and then 2 to 3 times per year thereafter

Discussion

This was an observational study with the aim of investigating whether there were any biologically relevant patterns in the hoof conformation of dairy goats on farms with different hoof trimming management. At first mating, goats on farms that had not yet trimmed had greater odds of poor hind hoof conformation compared with goats on farms that had already trimmed. At the end of second lactation, goats on farms that had not trimmed before first kidding had greater odds of dipped heels on the hind hooves compared to farms that had trimmed before first kidding. The results indicate that trimming before mating offers some temporary benefit for the hoof conformation of dairy goats, while trimming before first kidding may offer some long-term benefits.

Trimming before first mating improved hind hoof conformation. The hind hooves of goats on farms that had not yet trimmed had longer toe length ratios and an increased risk of hoof overgrowth, dipped heels and misshaped claws. Hoof overgrowth is linked to hoof deformation in dairy goats (Ajuda et al., 2019), therefore it is likely that the dipped heels and misshaped claws in the hind hooves may have been caused by the observed overgrowth. For example, an overgrown toe has a lever effect where the toe becomes rotated dorsally, and the heel depth is reduced (cows: Blowey, 1992; Gitau et al., 1997; goats: Hill et al., 1997). This long toe-shallow heel conformation increases the risk of lesions and lameness in dairy cows (Blowey, 1992; Gitau et al., 1997), and may influence functional herd life. For instance, shorter hooves with higher claw angles are associated with increased herd longevity (McDaniel, 1994), while low hoof angles decrease herd longevity (Sewalem et al., 2005). Additionally, hoof overgrowth increases the risk of hoof lesions such as sole ulcers (cows: Manske et al., 2002b). Preventing hoof overgrowth is therefore imperative, with hoof trimming a priority in dairy goats (Ajuda et al., 2019) to restore “normal” hoof shape and weight distribution between the claws (Pugh and Baird, 2002).

It was not within the scope of this study to investigate if the observed conformation traits at first mating were associated with an increased risk of lesions and lameness. However, the results indicate that overgrowth is an issue particularly in the hind hooves for commercially housed dairy goats as early as first mating (8.0 ± 0.70 months of age). Furthermore, proportions of dipped hind heels and misshaped hind claws were high (between 0.37 and 0.57, and 0.36 and 0.54, respectively) even in goats that had their hooves trimmed before first mating. This may be because commercially housed dairy goats have little opportunity to naturally wear their hooves (Zobel et al., 2019) hence, trimming early in life may be required to prevent hoof overgrowth and poor conformation. Indeed, the hooves of dairy heifers should be examined and trimmed as early as 6 months of age, especially if they are confined on soft bedding offering limited opportunities for exercise and hoof wear (Amstutz, 1985).

At first mating, goats on farms that had not trimmed had longer toe length ratios in the front and hind hooves compared with goats on farms that had trimmed. This pattern was seen in the hind hooves when assigned a binary score (overgrown or not), with goats on farms that had not trimmed having greater odds of overgrown hooves. However, this pattern was not seen when the front hooves were assigned a binary score (overgrown or not). The binary score considered hooves as overgrown if the toe length was over half of the rest of the hoof. This would correspond to a measured toe length ratio over 0.5. The average toe length ratio of the front hooves of goats on farms that had not trimmed yet was still below 0.5 (0.44, 95% CI: 0.39 – 0.53), and therefore they would not be scored as overgrown. Hoof overgrowth is associated with abnormal claw shape (Manske et al., 2002b), splayed claws (van Amstel and Shearer, 2006) and reduced heel depth (Gitau et al., 1997). Therefore, as hoof overgrowth was not observed in the front hooves, this may explain why there were no difference in the odds of dipped heels, misshaped claws and splayed claw in goats on farms that had not trimmed before first mating compared to goats on farms that had.

In chapter 5, I report similar growth rates in the front (4.39 ±0.04 mm/month) and hind hooves (4.20 ±0.03 mm/month) of dairy goats. This is supported by evidence in cows (Tranter and Morris, 1992) and sheep (Shelton et al., 2012) that report no difference in the growth rates of the front and hind hooves. I did not measure hoof wear in chapter 5, and to my knowledge there are no data evaluating the hoof wear of dairy goats. However, the rate of hoof wear may need to be considered to explain the reduced hoof overgrowth observed in the front hooves at first mating. In nonlactating animals, greater body weight is born by the front hooves compared to the hind (sheep: Kim and Breur, 2008; cows: Atkins, 2009). The greater weight carried by the front hooves may encourage greater wear (horses: Stachurska et al., 2008), resulting in less overgrowth. However, no difference in wear has been reported between the front and hind hooves of dairy cows (Tranter and Morris 1992). Therefore, I suggest work is required to determine the rate of wear of the front and hind hooves in dairy goats.

The results from the assessment at the end of the second lactation demonstrated that hoof trimming before first kidding may provide some longer term benefits on the conformation of the hind hooves. The odds of goats' hind hooves having dipped heels was higher on farms that had not trimmed before first kidding. The shape of the heel is important as it is the first part of the hoof that makes contact with the ground during locomotion, and its digital cushion is an important shock absorber, at least in cows (Atkins, 2009). However, dipped heels have an altered weight bearing surface, reducing the shock absorbing capacity of the digital cushion, which may result in damage to the solar corium and an increased risk of sole ulcers (cows: Blowey, 1992). Additionally, dipped heels are associated with stress on the suspensory apparatus of the hoof (horses: Hinterhofer et al., 2000).

Not trimming hooves until after first kidding means that the heels may have been dipped, and the suspensory apparatus under stress for a prolonged period. It is possible that the subsequent hoof trimming may not be able to recover the heels to a more upright position. Indeed, it is reported that for horses to recover from dipped heels, a long-term animal-specific hoof care treatment is required including frequent trimming alterations to facilitate regrowth and reorientation of the heels (Hunt, 2012). Farms that did not trim until after first kidding only trimmed 2-3 times per year thereafter, which may not have been frequent enough to re-orientate the heels to a more upright position by the end of second lactation.

Other factors may impact heel depth, for example, digital dermatitis reduces heel (cows: Laven, 2007; Gomez et al., 2015). Improper trimming may also result in low heel height in dairy cows

(Fjeldaas et al., 2006). In Chapter 5, I report lower heels angles in the hind hooves of dairy goats, a finding supported by Shearer et al (2005) who suggest that the hind hooves of dairy cows may naturally have a lower angle than the front hooves. However, as heel depth is a predisposing factor of lameness (Phillips and Schofield, 1994) further work would need to investigate if this conformation trait impacts the functionality (e.g. hoof lesions and lameness) of goats' hooves.

At the end of the second lactation high proportions of poor conformation particularly in the hind hooves were observed across all three trimming regimes. The dipped heels and misshaped claws are of particular concern as this conformation trait is frequently associated with hoof lesions and lameness (cows: Blowey, 1992; Gitau et al., 1997). Additionally, high proportions of splayed claws were observed in both the front and hind hooves irrespective of trimming regime. Hooves that are adapted to softer surfaces are more splayed (Zuba, 2012) and therefore claw splay may be determined by the environment, rather than hoof trimming regime. In dairy heifers confinement and lack of exercise can cause splayed claws (Amstutz, 1985). Therefore, providing goats with the opportunity to exercise, ideally on hard surfaces in early life may reduce the high claw splay observed.

When considering the three regimes included in the present study, trimming prior to first kidding had limited effects on hoof conformation, and the frequency of subsequent hoof trimming had no effect. However, it should be noted that time since last hoof trim was not taken into consideration. Of the 13 farms assessed at the end of second lactation, 9 trimmed between 2-3 times per year and 4 trimmed $\geq$ 4 times per year. Therefore, depending on when the assessment was completed, the goat's hooves could have potentially been trimmed within the same week, or 6 months prior. Furthermore, there may be variation in the time since last trim among farms within the same trimming regime. As time since last trim will influence the amount of hoof overgrowth and therefore conformation, I suggest that this is considered when interpreting the results. For example, goats on farms that had trimmed recently will have less overgrowth and better conformation than goats on farms that trimmed 3 months ago.

There was high variability in hoof conformation among farms in the same trimming group at assessment 1 (first mating) and among farms in the same trimming regime at assessment 2 (end of second lactation). Additionally, the boxplots highlight high levels of variability within and among farms for toe length ratio and claw splay distance at both assessments. The high variability indicates that factors other than hoof trimming are impacting hoof conformation. Due to the observational nature of the present study, my inability to access farm records to get accurate information, and the small number of farms included, farm-level housing and management factors could not be included in the statistical models. Additionally, weight was the only goat related factor measured and included in the statistical models; age was not included as all goats were of a similar age. Due to a number of the goats being Saanen cross, establishing breed was not within the scope of this study. However, I acknowledge that factors such as breed and milk production may have had an impact and it would be useful to include such goat-level factors in future research investigating hoof conformation in dairy goats.

It is important to note that management factors may have more effect on hoof health than trimming in dairy cows (Mahendran et al., 2017). For instance, Vermunt and Greenough (1996) report that the ground surface is the main environmental factor affecting claw conformation characteristics, with the abrasiveness of the flooring impacting both hoof wear and conformation (Hahn et al., 1986; Telezhenko et al., 2009). In the present study, some of the farms had access to a concrete strip in front of the feed rail, which may explain some of the variability in hoof conformation. Nutritional factors may also impact hoof conformation as higher protein diets are reported to increase hoof growth (Manson and Leaver, 1988). Information on diet was not recorded in the present study, however the composition of diets fed by dairy goat farmers in New Zealand differs among farms (Solis-Ramirez et al., 2011).

Furthermore, at the end of the second lactation, the goats were part of the milking herd and factors such as the distance walked to the milking parlour (Tranter and Morris, 1992) and time since parturition (Offer et al., 2000) may have impacted hoof conformation. Individual farm factors would need to be taken into consideration in future studies.

It is worth noting that the current study is exploratory in nature and limitations of the study discussed above should be considered when interpreting the results. In addition to the small sample size of farms, it should be noted that farms were not randomly selected and therefore may not be truly representative of the wider population of New Zealand goat farms. However, the results do provide evidence of a relationship between hoof trimming and hoof conformation in dairy goats that warrants further investigation.

Conclusion

This observational study provides preliminary evidence that trimming before first mating may provide at least some temporary benefit for dairy goat hoof conformation. The odds of goats having overgrown toes, dipped heels and misshaped claws on the hind hooves were lower on the farms that had trimmed before first mating compared to farms that had not trimmed. Additionally, trimming before first kidding reduced the odds of dipped heels in the hind hooves at the end of second lactation. However, high levels of variability were observed within and among farms at the second lactation assessment, and high proportions of hooves with poor conformation particularly in the hind hooves were observed regardless of trimming regime. This indicates that other animal and management factors may be strongly impacting the hoof conformation of dairy goats and the results should be interpreted with caution.

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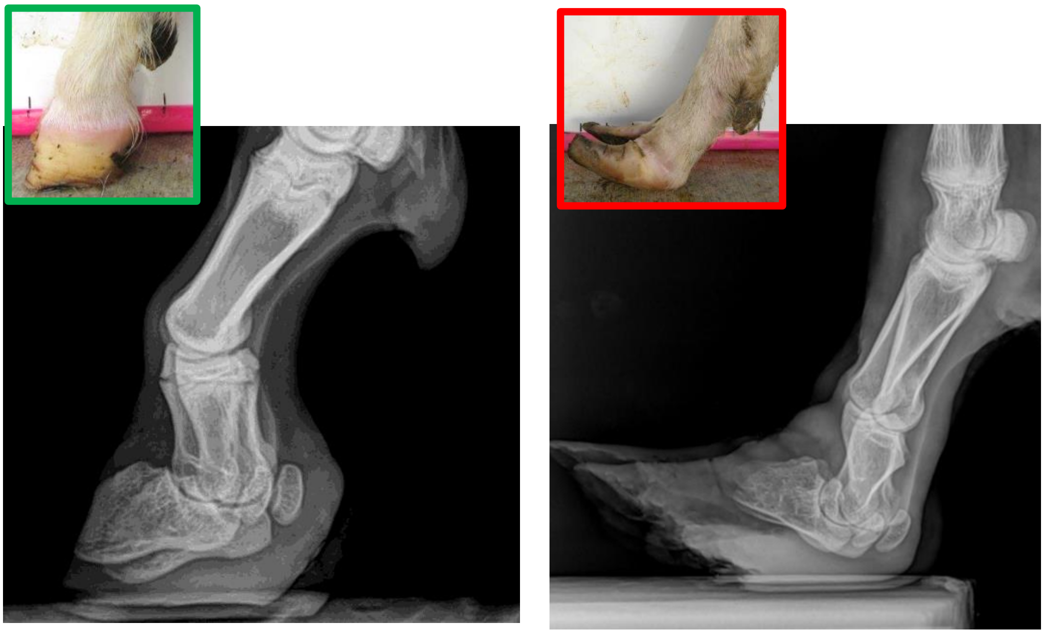
Chapter Five

Evaluating the immediate and long term-effects of hoof trimming regimes on the structure and function of the hooves of dairy goats



Abstract

Hoof overgrowth is associated with poor conformation and an increased risk of lameness. Therefore, preventing hoof overgrowth through appropriate trimming regimes may have immediate and long-term effects on the structure and function of dairy goats' hooves. The aims of this study were: 1) to evaluate the immediate effects of trimming on hoof conformation, joint positions and lying behaviour in dairy goats, 2) to evaluate the long-term effects of early life trimming regimes on conformation and joint positions, and 3) to investigate the pattern of gait score and hoof growth across the first two years of life in relation to trimming. Eighty female goats (approx. 5 months of age) from one New Zealand farm were randomly allocated to one of two treatments: A) Early trimmed (trimmed at 5, 9, 13, 17, 21 and 25 months) or B) Late trimmed (13, 17, 21 and 25 months). Aspects of hoof conformation and lying behaviour were assessed before and after trimming at 13, 17, 21- and 25-months. Joint positions in the distal limbs were determined from radiographs taken before and after trimming at 13- and 25-months. Pre-trimming gait scores were completed at each assessment, while hoof growth was evaluated every 12 weeks from 9 months of age.

Immediate effects of trimming were observed, with aspects of hoof conformation and joint positions being restored to a more anatomically correct state. The percentage of goats with overgrown toes decreased following trimming in the front and hind hooves at all four assessments ($P < 0.001$). In the hind hooves, fewer goats had dipped heels ($P < 0.001$) and misshaped claws ($P < 0.05$) after trimming at all assessments. Joint positions were altered following trimming in the front and hind hooves. Proximal interphalangeal joint (PIPJ) angle increased ($P < 0.001$), distal interphalangeal (DIPJ) angle decreased ($P < 0.001$), distal interphalangeal joint height (JH) decreased ($P < 0.001$), while heel angle (HA) increased ($P < 0.001$). At three out of four assessments, there was an increase in lying time on the day after trimming compared to the day before in both treatment groups ($P < 0.05$).

There were only minor long-term effects of early life trimming regimes, however these were not consistent across assessments. For instance, goats in the late trimmed treatment had greater HA in the hind hooves compared to the early trimmed treatment at the 13-month assessment (P <0.01), however this effect was not observed at the 25-month assessment. There was no effect of treatment on the prevalence of impaired gait (uneven gait or clinical lameness), however prevalence changed over the two-year study period (range: 13.6-47.5%). Compared to the 9-month assessment, the odds of a goat having an impaired gait were greater at the two assessments following kidding (Odds ratio, 95% CI: 13 months: 2.15, 1.02 - 4.54, P <0.05; 25 months: 3.79, 1.90 - 7.57, P <0.001), suggesting a parturition effect. Additionally, hoof growth slowed in the front and hind hooves between 19 and 22 months of age when the goats were in kid.

High proportions of poor conformation were observed before trimming at all assessments (e.g. 55-97% overgrown hooves, 85-98% dipped heels, on hind hooves). Prevalence of an impaired gait was low across the two-year study period. Trimming immediately improved many aspects of conformation and joint angles, but caused a transient increase in lying behaviour. There were minor and inconsistent longer-term effects of early trimming on conformation and, joint positions. As poor conformation was observed in both the early and late trimmed treatments, it suggests the subsequent hoof trimming (3 times per year) was not frequent enough to prevent overgrowth. Dairy goat hoof trimming protocols should include consideration of the timing of first hoof trimming and subsequent trimming frequency.

Introduction

Ruminant hooves are constantly growing. Consequently if the rate of hoof growth exceeds the rate of wear, hooves become overgrown (Vermunt and Greenough, 1995). It is important that prolonged periods of hoof overgrowth are prevented due to the association with changes in hoof conformation (Baggott, 1982) and increased risk of hoof lesions and lameness (Hill et al., 1997). However, it is reported in a number of ruminant species that if the housing environment does not provide opportunity for natural wear, then hoof overgrowth can become a health and welfare issue (chamois: Wiesner, 1985; sheep: Bokko et al., 2003; goats: Anzuino et al., 2010). Dairy goats are commonly permanently indoor housed, and bedded on straw (UK: Anzuino et al., 2010) or wood shavings (New Zealand: Solis-Ramirez et al., 2011), therefore a high prevalence of hoof overgrowth is common (84 - 100%: Hill et al., 1997; 79%: Anzuino et al., 2010).

The aims of hoof trimming are to improve conformation, restore the hoof to an anatomically correct shape by removing hoof overgrowth (Phillips et al., 2000; Shearer and van Amstel, 2001) and promote symmetry and weight bearing between the claws (Bryan et al., 2012). In dairy cows, overgrown hooves are associated with longer toe length, decreased heel depth (Glicken and Kendrick, 1977; Gitau et al., 1997), misshaped claws (Manske et al., 2002b) and splayed claws (van Amstel and Shearer, 2006); these changes in conformation may cause biomechanical stress on the hoof, altering the weight bearing surface and increasing the risk of hoof lesions and lameness (Manske et al., 2002b; van Amstel and Shearer, 2006). Similarly, in dairy goats, overgrowth and the resulting claw deformation negatively impact overall hoof conformation (Ajuda et al., 2014, Ajuda et al., 2019). For instance, chronic overgrowth in dairy goats results in a slippered hoof where the toe curls up and the weight bearing surface transfers to the heel (Hill et al., 1997). Frequent hoof trimming is important to maintain claw shape, and to promote shorter and steeper claws (cows: Manske et al., 2002a), and should be considered a priority in dairy goats (Ajuda et al., 2019) .

Changes in hoof conformation commonly caused by hoof overgrowth may result in significant changes to joint angles and positions (horses: Moleman et al., 2006). The external conformation of the hoof can be assessed from the exterior using subjective (sows: de Sevilla et al., 2008; sheep: Kaler et al., 2010) or objective methods (cows: Vermunt and Greenough, 1995; Somers et al., 2005). However, assessing the external conformation of the hoof is not sufficient to evaluate how the position and angles of the bones within the hoof are being impacted. Radiographic images are required to objectively determine the height and angles of joints within the distal limb and to determine the effects of hoof trimming on these measurements (Kummer et al., 2006). Radiographic images are a common diagnostic tool to help determine the impact of bone and joint positions on lameness and conformation issues in horses (Colles, 1983). However, radiographs are less commonly used in dairy animals as veterinarians not often involved in lameness diagnosis and treatment (Tranter and Morris, 1991; Vermunt, 2004), likely due to the high cost relative to the value of the animal. The impact of hoof trimming on the external conformation or the internal position of the joints within the distal limb of dairy goats has yet to be investigated.

The immediate effects of hoof trimming are associated with improved conformation and joint angles (horses: Kummer et al., 2006). However, the process of hoof trimming is also associated with immediate behavioural effects in dairy cows, such as a change in activity (Van Hertem et al., 2014) and lying behaviour (Chapinal et al., 2010b). For example, following hoof trimming by two trained trimmers the activity of dairy cows was significantly reduced the day after, returning to baseline levels by one week after trimming (Van Hertem et al., 2014). While this work does not elucidate whether behavioural disturbance occurred due to the trimming itself or because of the related animal handling, it does highlight that trimming has the potential to impact more than just the external and internal structures and function (i.e. lameness) of the hoof.

Early life hoof management may be of particular importance as the hooves of young ruminants grow faster when compared to those of older animals (cows: Tranter and Morris, 1992; sheep: Dekker et al., 2005). It is reported that high numbers of dairy heifers become lame early in their first lactation (Webster, 2002) and that animals that have previously been lame are more likely to go lame in the future (Hirst et al., 2002; Randall et al., 2015). As management failures such as inadequate hoof care are associated with claw lesions and lameness in heifers, early life trimming is suggested to reduce the initial lameness risk (Bell et al., 2009).

Hoof trimming of heifers prior to first calving is recommended (Bell et al., 2009; Cook, 2016). Trimming prior to first calving may improve the hoof conformation of heifers and thus enable the hoof to better adapt to post calving changes such as new time budgets and walking surfaces (Gomez et al., 2013). However, caution should be exercised when considering these recommendations as they are not based on primary research or peer reviewed studies. Indeed, Mahendran et al., (2017) found no beneficial effect of hoof trimming heifers pre-calving on lameness prevalence. However, this study focused solely on lameness as an outcome and did not consider conformation benefits. Furthermore, this study was based on a farm with high hoof wear and over-trimming of already thin soles may have resulted in some of the observed lameness.

Dairy goat farmers in New Zealand commonly begin hoof trimming between first mating (approx. 8 months of age) and first kidding (approx. 13 months of age). Of 16 farms surveyed, 4 delayed trimming until after first kidding (see chapter 4 for more details). It is unknown whether there are long-term implications of delaying trimming until after first kidding in goats. Therefore the aims of this study were to 1) to evaluate the immediate effects of hoof trimming, 2) to evaluate the long-term effects of an earlier start to hoof trimming , and 3) to investigate the pattern of gait score and hoof growth across the first two years of life in relation to trimming.

Materials and methods

Study design

A randomised controlled trial was designed to evaluate the immediate and long-term effects of two different hoof trimming practices on hoof growth, hoof conformation, joint positions and the behaviour of dairy goats. Based on a primary outcome measure (joint angle changes between trimming events), a power calculation suggested that treatment group sizes of 20 would detect a difference in joint angles between trimming practices (power value of 0.9, P = 0.05). The study was positively controlled (i.e., no animals were left untreated) and approved by AgResearch Ltd, Ruakura Animal Ethics Committee (#13686, approved 17/12/2015).

Primary objective

The primary objective was to evaluate the immediate impacts of hoof trimming using hoof conformation, joint positions and lying behaviour as outcome measures. The primary null hypothesis was that trimming would not affect these outcome measures.

Secondary objectives

The secondary objectives were twofold: 1) to evaluate the long-term effects of starting hoof trimming earlier in life (5 months of age) using hoof conformation and joint positions as outcomes measures. 2) to investigate patterns of the outcome measures gait score and hoof growth in relation to trimming across the first two years of life. The secondary null hypotheses were that trimming in early life would not affect hoof conformation and joint positions, and that hoof trimming would not impact gait score or hoof growth.

Animals and Housing

In December 2015, 80 female goats of approximately 5 months of age from one commercial dairy goat farm in the Waikato region of New Zealand were enrolled in the study. The 80 goats were randomly selected from a potential of 109 animals available to use. This was completed prior to the researchers visiting the farm and having any interactions with the goats. The farm had approximately 700 Saanen cross milking does. The herd was maintained indoors in four separate groups and bedded on wood shavings, with a concrete strip in front of the feed rail. The milking parlour was attached to the housing barn; therefore, the goats walked a short distance (< 50m) on a concrete surface twice a day to be milked.

The enrolled goats were randomly assigned to one of two trimming treatments with 40 goats per treatment: A) Early trimmed: beginning at 5 months of age, hooves were trimmed every 4 months thereafter, and B) Late trimmed: beginning at 13 months of age, hooves were trimmed every 4 months thereafter. Due to the nature of the intervention the operators were not blind to the treatment administered. Goats in both treatments were monitored until 25 months of age. Housing and husbandry management was maintained as per the farm's standard protocol. Goats were first mated at approximately 8 months of age and first kidded at approximately 13 months of age, at which point they entered the milking herd. Goats were dried off at approximately 21 months of age and had their second kidding at 25 months.

Hoof trimming

A veterinarian experienced in hoof trimming of goats completed all trimming. Each hoof was lifted and trimmed according to the technique described by Pugh and Baird (2012). Any dirt that had become packed into the toe was removed to determine the amount of overgrowth to be removed and the hoof wall was trimmed parallel to the coronary band. As the outer wall is a weight bearing surface, it was left slightly longer than the inner hoof wall. If the toe was starting to curl upwards due to overgrowth, the solar surface was carefully trimmed to keep it level, rather than "dubbing" or shortening the toe. The rubbery heel was trimmed if it was excessively long or overgrown. At the assessments at 13 and 25 months of age, trimming was completed following kidding.

Data collection

Goats were weighed at each of the 6 assessments prior to trimming and any of the other measures being completed. Hoof conformation, joint positions and hoof growth of the left front and left hind hooves were assessed at various time points (Table 1). Radiographs were taken on a subset of animals (20 goats per treatment, randomly selected at the beginning of the study). For practicality and to reduce handling of the goats, only the left hooves were assessed. In addition to the variables detailed in Table 1, hoof growth was measured.

Table 1. Details of each trimming treatment and the measurements that were completed at each of the six assessments.

Assessment	Trimming treatment			Measurements					n*
	Age (months)	Early Trimmed	Late Trimmed	Radiographs	Hoof photographs	Gait scores	Lying behaviour	Weight	
1	5	✓	✗	✗	✗	Pre-trim	✗	Pre-trim	80
2	9	✓	✗	✗	✗	Pre-trim	✗	Pre-trim	78
3	13	✓	✓	Pre and post trim	Pre and post trim	Pre-trim	Pre and post trim	Pre-trim	67
4	17	✓	✓	✗	Pre and post trim	Pre-trim	Pre and post trim	Pre-trim	66
5	21	✓	✓	✗	Pre and post trim	Pre-trim	Pre and post trim	Pre-trim	63
6	25	✓	✓	Pre and post trim	Pre and post trim	Pre-trim	Pre and post trim	Pre-trim	61

* Numbers declined due to goats being removed from the herd for health and production reasons

Hoof conformation

A digital camera (Canon Powershot, SX530) was used to take photographs of the hooves immediately prior to and one day following hoof trimming. Photographs of the left front and left hind hooves were taken while the goats were standing in a holding pen of the milking parlour on a flat concrete surface, ensuring they were bearing weight evenly on all four limbs. Two photographs per hoof were take: 1) lateral aspect, and 2) dorsal aspect. The hooves were photographed against a whiteboard which had 2cm scale markers along the vertical and horizontal edges.

The assessment included five subjective scores: 1) toe length, 2) heel shape, 3) fetlock shape, 4) claw splay, and 5) claw shape (see Table 1 from Chapter 4). Each subjective score was made on a 3-point ordinal scale (0, 1, and 2), except for fetlock shape which was scored on a binary scale (0 or 1), with a 0 being ‘normal’ in all cases. Two objective measurements were also made: 1) toe length ratio (the toe length compared with the length of the rest of the hoof, and 2) claw splay distance (distance between the axial edge of the distal tip of both claws (see Figure 1, Chapter 2 for methods to calculate objective measures).

The subjective scoring and objective measurements were completed in R 3.5.0 statistical software (R Core Team 2018), using methods previously described in Chapter 2. The R code enabled a distance calibration to be completed using the scale bar marker on the whiteboard in the photographs. This allowed for distances between selected points on the hooves to be calculated and the objective measurements determined (see Chapter 2 for full description).

Two observers scored the photographs. High inter-reliability and intra-reliability levels were achieved prior to scoring of the hoof photos and confirmed following completion of the sets of photos from each assessment. For the subjectively scored aspects of hoof conformation, weighted kappa (K_w) statistics were used to measure agreement, ensuring $K_w \geq 0.8$ (almost perfect agreement; Dohoo et al., 2003) was achieved. For the objectively measured aspects of hoof conformation, a Lin's Concordance Correlation Coefficient (CCC) was calculated ensuring CCC $\geq$ 0.8 (high level of agreement, Altman, 1990).

Radiograph measurements – joint positions

All radiographs were taken by an equine veterinarian immediately prior to, and one day after hoof trimming at the 13-month assessment and again at the 25-month assessment. A wooden platform was used to ensure that goats were in a square standing position, with their heads straight and forward. Standardised radiographs of the left front and left hind distal limb in a lateromedial direction including the proximal phalanx (P1), the middle phalanx (P2) and the distal phalanx (P3) were taken, with the x-ray beam aimed through the fetlock.

The digital radiographs were analysed using eFilm 3.3.0 software (Merge Healthcare, Heartland, WI) to determine internal joint positions of the distal part of the lateral claw. The following parameters of the lateral claw were determined: 1) proximal interphalangeal joint (PIPJ) angle 2) distal interphalangeal joint (DIPJ) angle, 3) distal interphalangeal joint height (JH), 4) heel angle (HA). These were adapted from methods previously used in the analysis of equine hoof radiographs (DIPJ and PIPJ angle: Kroekenstoel et al., 2006; JH: Kummer et al., 2006; heel angle: Drumond et al., 2016). Firstly, centres of rotation of the PIPJ and DIPJ were determined. This was achieved by placing a circle on the end of the P1 and P2 bone, ensuring the circle passed through the most palmar and dorsal aspects of the bone (Kroekenstoel et al., 2006). The centre of rotation was determined as the central point of the drawn circle. The parameters were then determined as follows:

PIPJ angle: A line was drawn through the middle of the P1 bone passing through the centre of rotation of P1. A line was drawn linking the centre of rotation of the P1 and P2 bone and the angle of the intersecting lines calculated (Figure 1a).

DIPJ angle: A 180^{o} vertical reference line was drawn through the centre of rotation of the P2 bone. A line was then drawn from the tip of the toe through the reference line at the centre rotation of the P2 bone and the angle of the intersecting lines calculated (Figure 1b).

JH: The distance from the bottom of the hoof to the lowest point on the circle of the P2 bone was measured (Figure 1c).

HA**:** A horizontal line was placed at the bottom of the hoof; a line was then drawn following the following shape of heel and the angle of the intersecting lines calculated (Figure 1d).

All radiograph analysis was completed by one observer. Intra-reliability was assessed prior to analysis commencing, using a random selection of approximately 15% (n = 43 radiographs) of the radiographs ensuring CCC $\geq$ 0.8 (high level of agreement, Altman, 1991) was achieved. To ensure on-going reliability CCC was assessed again halfway through analysis using a random subset of approximately 12% (n = 34 radiographs) of the radiographs.

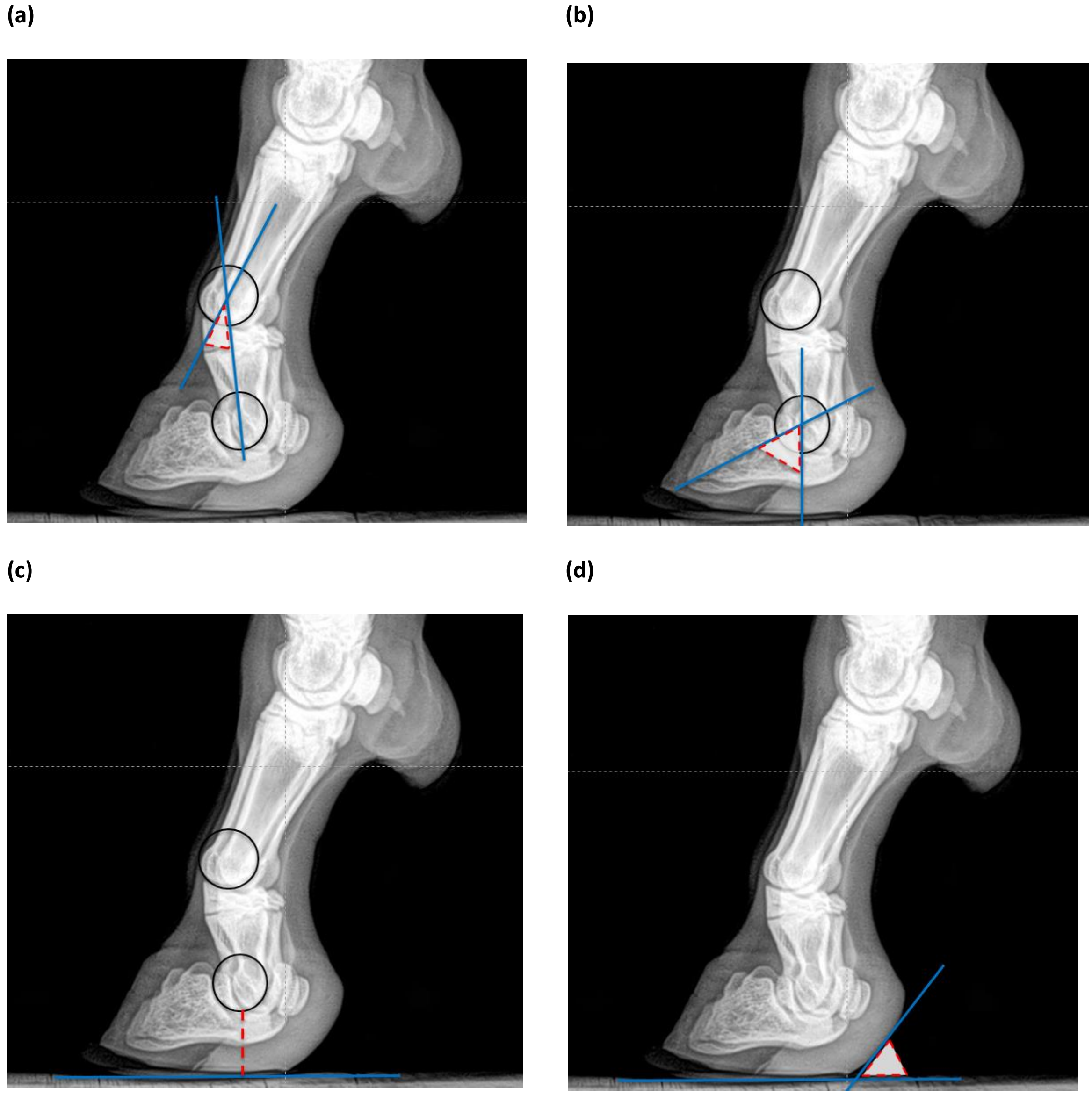


Figure 1. Methods determining (a) the angle of the proximal interphalangeal joint (PIPJ), (b) the angle of the distal interphalangeal joint (DIPJ), (c) the height of distal interphalangeal joint (JH), (d) the heel angle (HA).

Lying behaviour

One week prior to each hoof trimming event, all goats were fitted with a HOBO Pendant G data logger (Onset Computer Corporation, Bourne, MA). The logger was placed into a durable padded fabric pouch and attached to the left hind leg above the metatarsophalangeal joint using a velcro strap. Loggers were set to record x and z-axis at 1-minute intervals. The loggers were removed approximately 8 days following hoof trimming, ensuring 7 full days of post trimming data were recorded. The HOBO data were downloaded using Onset HOBOware Pro software (Onset Computer Corporation, version 3.4.1). Data were summarised in SAS 9.2 (SAS Institute Inc., Cary, NC) following the methodology described in Zobel et al. (2015) for use in dairy goats. The summarised data were used to calculate total daily lying time and number of lying bouts per day for each goat.

Gait score

Gait scoring was completed one week prior to hoof trimming at each of the six assessments. Scoring was completed following morning milking, to reduce any effect of milk fill and udder distention on gait. Goats were video recorded (HC-V270, Panasonic Camcorder, Osaka, Japan) walking along a concrete raceway from the milking parlour back to towards their pens. The video camera was set up on a tripod to allow an area of approximately 4.5m of the walkway to be in view. This allowed at least 4 full strides of walk to be recorded. Each of the videos were watched separately by two trained observers and gait scores assigned using a 5-point gait scoring system (Numerical Ranking Scale; where 1 = normal gait, 2 = uneven gait, 3 = mildly lame, 4 = moderately lame, 5= severely lame (for full description of gait scoring system used see Chapter 3). Inter-observer and intra-observer reliability was determined following the completion of each assessment to ensure $K_w \geq 0.80$ (almost perfect agreement; Dohoo et al., 2003). As both observers scored every goat, all data from each assessment was included in the reliability tests.

Hoof growth measurement

Hoof growth was measured using similar methods to that described by Manson and Leaver (1988). Briefly, at approximately 6 months of age a hacksaw was used to make a small mark under the periople. Every 12 weeks another mark was made, and callipers used to measure the distance between the new mark and the previous mark. The same veterinarian marked all hooves at each assessment. To avoid the mark growing out, hoof growth was measured approximately every twelve weeks rather than every four months like the other measurements. The measurements were used to calculate hoof growth rate (mm/month).

Data handling

The joint positions (PIPJ, DIPJ, JH and HA), toe length ratio and claw splay distance were treated as continuous outcome variables. As there were a low number of 2s assigned the subjective aspects of conformation were reclassified and treated as binary outcome variables. Scores of 1 and 2 from the original ordinal scale of 0, 1, 2 were collapsed for toe length, heel shape, claw shape and claw splay. This allowed comparison of "good" (score 0) to "poor" (scores 1 and 2). Therefore, classifications were as follows: toe length (not overgrown or overgrown), heel shape (upright heel or dipped heel), claw shape (straight claws or misshaped claws), claw splay (not splayed or splayed). Fetlock shape was not included in analysis due to only three dipped fetlocks being observed across the four assessments. As there were a low number of 3, 4 or 5 gait scores assigned this was also reclassified and treated as a binary outcome variable comparing non-lame (score 1) to an impaired gait (score 2-5). Due to goats moving faster than a walk at the 5-month assessment this was excluded from the analysis. Lying behaviour data included 10 days in total, the three days immediately prior to hoof trimming and the seven days following hoof trimming. Day of trimming (day 0) was excluded. Due to goats being removed for health and production reasons throughout the study, the n value for all variables measured decreased over time.

Data analysis

All statistical analyses were performed using SAS 9.2 (SAS Institute Inc., Cary, NC). Statistical analyses were completed separately for the front and hind hooves due to the acknowledged differences between the limbs (Andersson and Lundström, 1981).

Objective 1: To evaluate the immediate effects of hoof trimming on hoof conformation, joint position and lying behaviour.

The data from the 13, 17, 21, and 25-month assessments were used to address this objective. As radiographs were only taken at 13 and 25 months, just these two assessments are included when evaluating joint positions. The main effect for all models was the hoof trimming event (pre vs post trimming), however, trimming treatment was forced into models regardless of significance. Linear mixed models (PROC MIXED) were used to assess the effects of hoof trimming (pre vs post trimming) on toe length ratio (n = 67 goats), PIPJ, DIPJ, JH, HA (n = 37 goats for all x-ray variables) and lying behaviour (lying time and lying bouts) (n = 67 goats). A repeated measures statement with hoof trimming event (pre vs post trimming) nested within assessment was specified in these models to account for the correlation among multiple assessments. Goat was included as a random effect to account for within-goat correlation. Interactions between assessment and trimming treatment and hoof trimming event (pre vs post trimming) were tested.

Claw splay distance measurements were conditional on claw shape being scored 0, resulting in a different number of goats with claw splay measurements at each assessment. Therefore, separate models were constructed for each assessment (no repeated statement was included in these models).

For subjectively scored hoof conformation, frequency tables (PROC FREQ) were generated to compare pre and post trim scores. The proportions of poor conformation scores (overgrown toes, dipped heels, misshaped claws and splayed claws) at pre vs post trimming were tested using the Chi-squared (X^2) test or Fisher's exact test (if expected count was less than 5 in any category).

Objective 2: To evaluate the long-term effects of early life hoof trimming treatment on hoof conformation and joint positions

The data from the 13- and 25-month assessments were used to address this objective, with separate models constructed for each assessment. Firstly, differences by trimming treatment at 13 months were examined, as this was the assessment predicted to have the greatest differences (n = 67 goats for toe length ratio and claw splay distance, n = 37 goats for the radiograph measurements). Secondly, differences at the 25-month assessment were examined to investigate the longer-term effects of trimming treatment (n = 61 goats for toe length ratio and claw splay distance, n = 37 goats for the radiograph measurements). The main effect was trimming treatment. Analyses were completed for the pre and post trimming data separately due to anticipated differences in hoof conformation and joint positions following hoof trimming (Kummer et al., 2006). Linear regression analyses (PROC MIXED) were used to model the effects of trimming treatment on the objectively measured aspects of hoof conformation (toe length ratio and claw splay distance) and on radiograph measurements (PIPJ, DIPJ, JH, HA).

For subjectively scored hoof conformation, frequency tables (PROC FREQ) were generated to compare the scores between the two hoof trimming treatments. The proportions of poor conformation scores (overgrown toes, dipped heels, misshaped claws and splayed claws) for the early vs late trimming treatment were tested using the Chi-squared (X^2) test or Fisher's exact test (if expected count was less than 5 in any category) for each assessment separately.

Objective 3: To investigate the pattern of lameness prevalence and hoof growth across the first two years of life and to determine if there was an effect of trimming.

A logistic regression (PROC GLIMMIX) was used to model the effects of assessment and trimming treatment on the binary gait score variable (n = 78 goats, as data were included from the 9-month assessment onwards). A binary distribution and a logit link function was used to test if there was a difference in the proportion of goats with an impaired gait between trimming treatments and among the assessments. Goat within assessment was included as a random effect. The 9-month assessment was used as the reference category. The results are presented as odds ratios and 95% confidence intervals. In addition to the logistic regression, the number and percentages of goats with a none lame gait (score = 1), an uneven gait (score = 2) and lame gait (score > 3) at each assessment are presented.

Linear regression analyses (PROC MIXED) was used to model the effects of assessment and trimming treatment on hoof growth (n = 78 goats, as data were included from the 9-month assessment onwards, goat numbers decreased over the course of the study as per table 1). A repeated measures statement of goat nested within assessment was specified. Interactions between assessment and trimming treatment were tested.

Procedures for building and assessing the fit and assumptions of models

Univariable screening was first carried out, applying a liberal p-value ($P < 0.2$). A backwards stepwise method was then used to determine variables to be included in the models, whilst still considering the biological relevance of the factors. Trimming treatment was treated as a fixed effect and forced into all models regardless of significance. All biologically relevant interactions were considered but removed from the model if not significant (significance set at $P < 0.05$ for significant and $P < 0.1$ for a tendency). Weight was included as a covariate in all models regardless of significance. No other goat level factors were included in the models. Age was not included as all goats were of the same age, additionally there was high collinearity between age and assessment. Model fit for objective 1 and 3 (repeated measures models) was examined by identifying the correlation structure that resulted in the smallest Akaike Information Criterion. All models were evaluated for assumptions of homoscedasticity and normality of residuals. Homoscedasticity was assessed by visually examining a scatter-plot of residuals against predicted values. Normality was assessed using histogram and normal probability plots, as well as checking the residuals for skewness and kurtosis. A log transformation was applied to improve homoscedasticity and to help normalize distribution of residuals for claw splay distance of the hind hoof models at the 13-month, 17-month and 25-month assessments. Results for these assessments are presented as back-transformed means and 95% confidence intervals (CI). The claw splay distance data of the hind hooves at the 21-month assessment were normally distributed. For consistency all claw splay distance results are presented as means and 95% CI.

All continuous outcome variables were checked for outliers. As all data points fell within 3 times the interquartile range away from the first and third quartile none were considered outliers.

I did consider the construction of one model to address both objective 1 and 2 simultaneously. However, due to complex models and contrast statements being required it was decided to address each objective separately.

Results

Objective 1: To evaluate the immediate effects of hoof trimming on hoof conformation, joint position and lying behaviour in dairy goats

Hoof conformation – toe length ratio and claw splay distance

Toe length ratio of the front hooves decreased following hoof trimming at all four assessments ($P < 0.001$), and there was also an interaction with assessment ($F_{3, 320} = 13.48$, $P < 0.001$). Pre-trimming toe length ratio was consistent across the four assessments; however, post trimming between toe length ratio was greater at 17 months than at 13 months (Figure 2a). For hind hooves, trimming ($P < 0.001$) and assessment ($P < 0.05$) affected toe length ratio and there was an interaction between these factors ($F_{3, 328}$ = 7.79, P <0.001). Pre-trimming, toe length ratio was greater at 13 months than at 17 or 25 months; however, post-trimming toe length was consistent across assessments (Figure 2b).

Claw splay distance in the front hooves decreased following hoof trimming at the 13-month and 25-month assessments and tended to decrease at the 17-month assessment. In the hind hooves claw splay distance decreased at all four assessments following hoof trimming (Table 3).

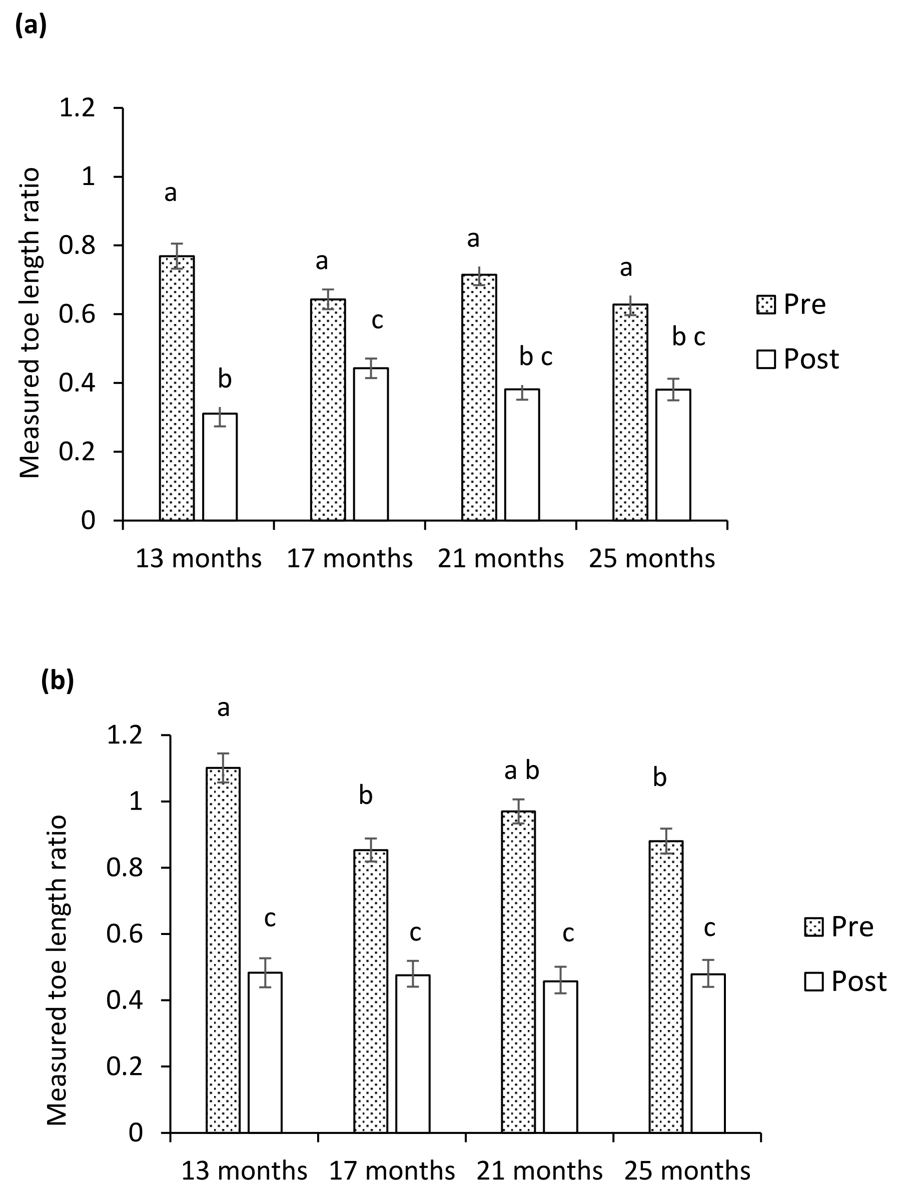


Figure 2. Mean ± SEM of toe length ratio pre and post trimming for (a) front hooves and (b) hind hooves at four assessments across the goats first two lactations. Different letters (a, b, c) indicate significant differences between or within assessments (n = 67 goats).

Table 3. Means and 95% CI of measured claw splay distance (cm) at pre and post hoof trimming at four assessments

		Front hooves				Hind hooves				n[a]
Assessment	Age (months)	Pre	Post	F-value	P-value	Pre	Post	F-value	P-value	
3	13	5.32 (4.88-5.75)	4.50 (4.10-4.91)	10.72	< 0.01	4.79 (4.27-5.37)[b]	3.39 (3.16-3.63)[b]	48.06	< 0.001	47
4	17	5.26 (4.84-5.66)	4.75 (4.38-5.14)	3.91	0.05	4.57 (4.07-5.13)[b]	3.55 (3.24-3.98)[b]	12.99	< 0.01	55
5	21	4.97 (4.54-5.39)	4.60 (4.20-5.01)	2.68	0.11	5.25 (4.75-5.76)	4.36 (3.91-4.82)	8.91	< 0.01	51
6	25	5.62 (5.17-6.08)	5.13 (4.69-5.58)	4.95	< 0.05	5.75 (5.25-6.31)[b]	4.68 (4.27-5.01)[b]	31.53	< 0.001	44

[a] Claw splay distance was only measured if claw shape was score as 0, therefore not all goats are included

[b] Back transformed means and 95% confidence intervals for hind hooves at the 13, 17- and 25-month assessment

Hoof conformation – toe length, heel shape, claw shape and claw splay scores

Table 4 summarizes the proportion of goats with poor hoof conformation pre- and post-trimming across assessments. The majority of goats had overgrown toes on both front and hind hooves prior to trimming at each assessment; hoof trimming decreased this proportion

Dipped heels were uncommon on the front hooves. At each assessment, the proportion of goats with dipped heels on their hind hooves decreased following hoof trimming, however, this poor hoof conformation characteristic remained in over 40% of the goats.

The proportion of goats with misshaped claws on their front hooves decreased following hoof trimming at the 21-month assessment and tended to decrease at the 13-month and 25-month assessment. Hoof trimming reduced the proportion of goats with misshaped claws on their hind hooves. While trimming had an impact on reducing splayed claws at some assessments, the proportion of goats with splayed claws on front and hind hooves remained high.

Table 4. Proportion (%) of goats with aspects of poor conformation (overgrown toes, dipped heels, misshaped claws, splayed claws) pre and post trimming at four assessments.

		Front hooves			Hind hooves			n
Conformation Variable	Assessment	Pre (%)	Post (%)	P-value	Pre (%)	Post (%)	P-value	
Overgrown toes	13 months	79	3	< 0.001[a]	97	12	< 0.001[b]	67
	17 months	55	7	< 0.001[b]	82	13	< 0.001[b]	66
	21 months	63	3	< 0.001[a]	93	15	< 0.001[b]	63
	25 months	56	5	< 0.001[a]	92	15	< 0.001[b]	61
Dipped heels	13 months	19	0	< 0.001[a]	98	45	< 0.001[b]	67
	17 months	2	1	1.00[a]	92	68	< 0.01[b]	66
	21 months	2	0	1.00[a]	85	42	< 0.001[b]	63
	25 months	5	2	0.61[a]	89	52	< 0.001[b]	61
Misshaped claws	13 months	33	22	0.06[b]	67	17	< 0.001[b]	67
	17 months	17	11	0.11[b]	45	33	< 0.01[b]	66
	21 months	23	10	< 0.05[b]	38	19	< 0.05[b]	63
	25 months	34	18	0.06[b]	39	21	< 0.05[b]	61
Splayed claws[c]	13 months	76	64	0.08[b]	66	29	< 0.01[b]	47
	17 months	75	68	0.13[b]	57	35	< 0.05[b]	55
	21 months	67	60	0.51[b]	74	54	0.06[b]	51
	25 months	81	63	< 0.05[b]	84	78	0.49[b]	44

[a] Fisher's exact test

[b]Chi-squared test

[c] Claw splay only scored if claw shape scored as 0, therefore, not all goats are included

Joint positions

There was an effect of hoof trimming (pre- vs post-trimming) ($P < 0.001$) on the PIPJ angle of the front hooves, however, this was dependent on assessment ($F_{1,96}$ = 11.21, $P < 0.01$; Figure 3), no assessment effect was noted. Trimming also affected the PIPJ angle of the hind hooves ($F_{1,98}$ = 53.04, $P < 0.001$); no assessment effect or assessment by trimming interaction were noted. On average the PIPJ angle of the front hooves was 30.9 ± 1.04^{o} pre trimming and 38.5 ± 1.03^{o} post trimming, while the PIPJ angle of the hind hooves was 38.5 ± 1.32^{o} pre trimming and 46.4 ± 1.32^{o} post trimming. Trimming decreased the DIPJ joint angle and joint height in the front and hind hooves, while heel angle increased (Table 5). There were no assessment effects or interactions with pre- vs post-trimming.

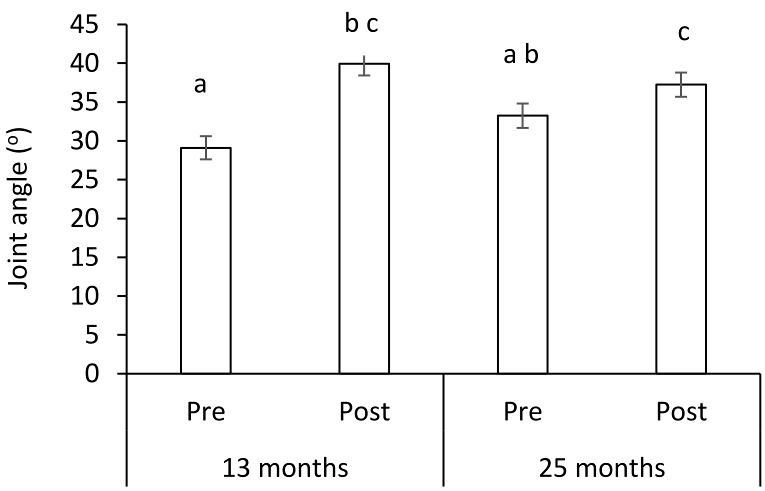


Figure 3. Mean ± SEM of the proximal interphalangeal joint (PIPJ) joint angle of the front hooves pre and post trimming at the 13-month and 25-months assessment. Different letters (a, b and c) in the graph indicate significant differences between assessments and pre vs post trimming (n = 37 goats).

Table 5. Overall mean angles ± SED of the distal interphalangeal joint (DIPJ), height of the distal interphalangeal joint height (JH) and heel angle (HA) pre and post hoof trimming at two assessments (13 and 25 months of age) (n = 37 goats)

	Front hooves				Hind hooves			
Variable	Pre-Trim	Post Trim	F-value	P-value	Pre-Trim	Post-Trim	F-value	P-value
DIPJ angle (^{o})	66.00 ± 0.75	58.70 ± 0.75	$F_{1, 96}$ = 94.56	P < 0.001	79.20 ± 1.03	68.42 ± 1.03	$F_{1, 98}$ = 110.46	P < 0.001
JH (cm)	2.21 ± 0.05	1.97 ± 0.05	$F_{1, 96}$ = 27.97	P < 0.001	1.72 ± 0.04	1.53 ± 0.04	$F_{1, 98}$ = 21.42	P < 0.001
HA (^{o})	56.39 ± 0.72	64.48 ± 0.72	$F_{1, 96}$ = 125.64	P < 0.001	43.43 ± 1.00	53.14 ± 1.00	$F_{1, 98}$ = 94.11	P < 0.001

Lying behaviour - daily lying time

There was an effect of assessment (P <0.001), day (relative to trimming) (P <0.001) and trimming treatment (P <0.01) on daily lying time, as well as an overall interaction between the three variables ($F_{66,1503}$ = 12.48, P <0.001). At the 13-month assessment, the goats in the late trimmed treatment lay longer on day 1, 2, 3 and 4 post trimming than goats in the early trimmed treatment. There was no evidence of a difference in daily lying time between goats in the late and early trimmed treatments at day 5, 6, or 7 post trimming. (Figure 4a).

At the 17-month and 25-month assessments, lying time increased at day 1 post trimming (Figure 4b and 4d) compared to the day before trimming (day -1). At the 21-month assessment no difference was detected in lying time between day 1 post trimming compared to the day before trimming (Figure 4c). However, lying time decreased at day 2, 3 and 4 compared to the day before trimming.

Lying behaviour - daily lying bouts

There was an effect of assessment (P <0.001), day (relative to trimming) (P <0.001) and trimming treatment (P <0.05) on the number of daily lying bouts, as well as an interaction between the three variables ($F_{66,1503}$ = 6.58, P <0.001). At the 13-month and 25-month assessment daily lying bouts increased at day 1 following hoof trimming compared to the day before trimming (day -1) for both the late and early trimmed treatments (Figure 5a and 5d). However, there was no evidence of a difference in the number of lying bouts between trimming treatments for goats on any other days or at any of the other assessments.

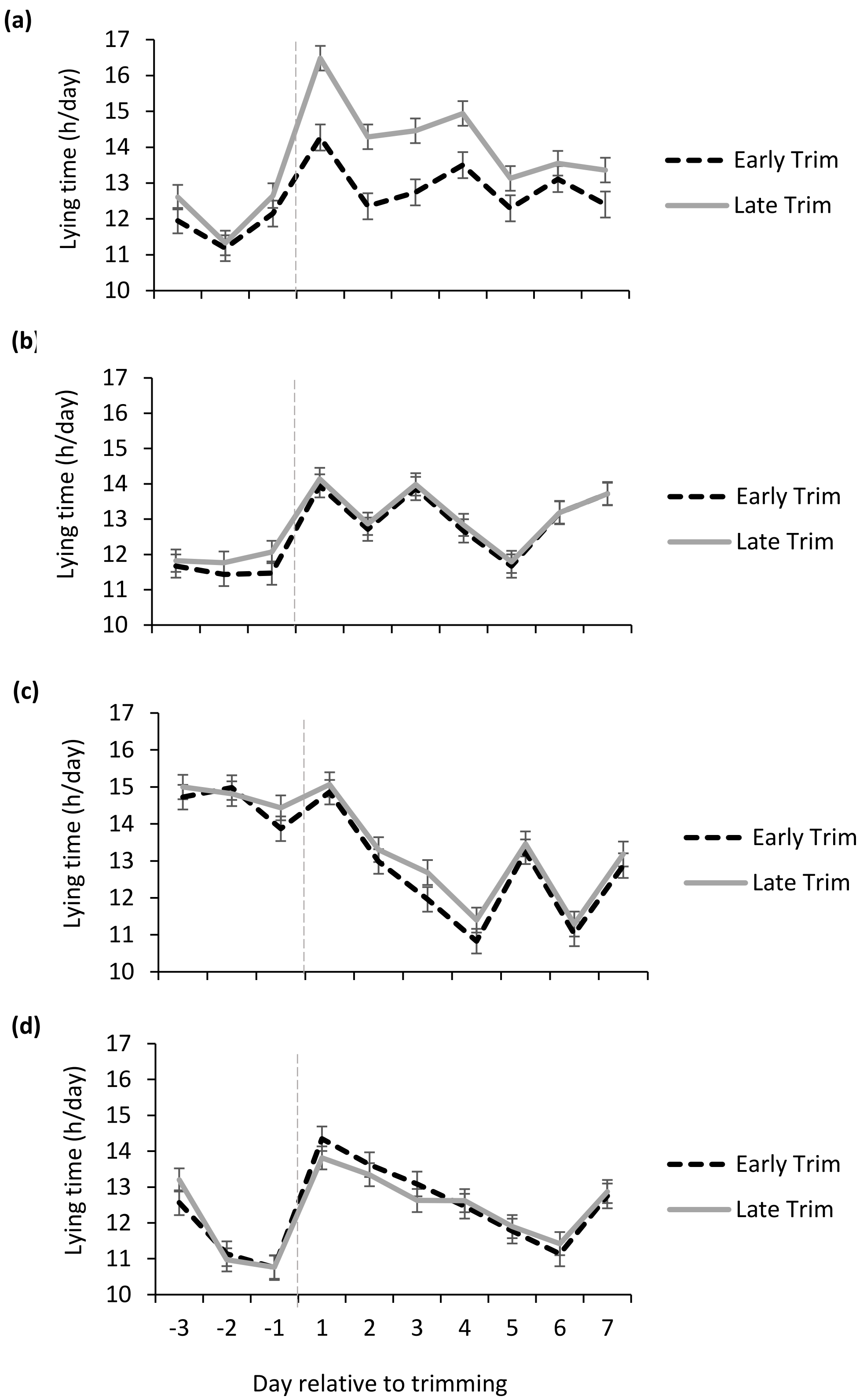


Figure 4. Mean ± SEM daily lying time (h/day) 3 days pre-trimming and 7 days post trimming at four assessments (a) 13 months, (b) 17 months, (c) 21 months, (d) 25 months. Day 0 removed as it was the day of trimming. The light grey dashed line signifies a trimming event (n = 67 goats).

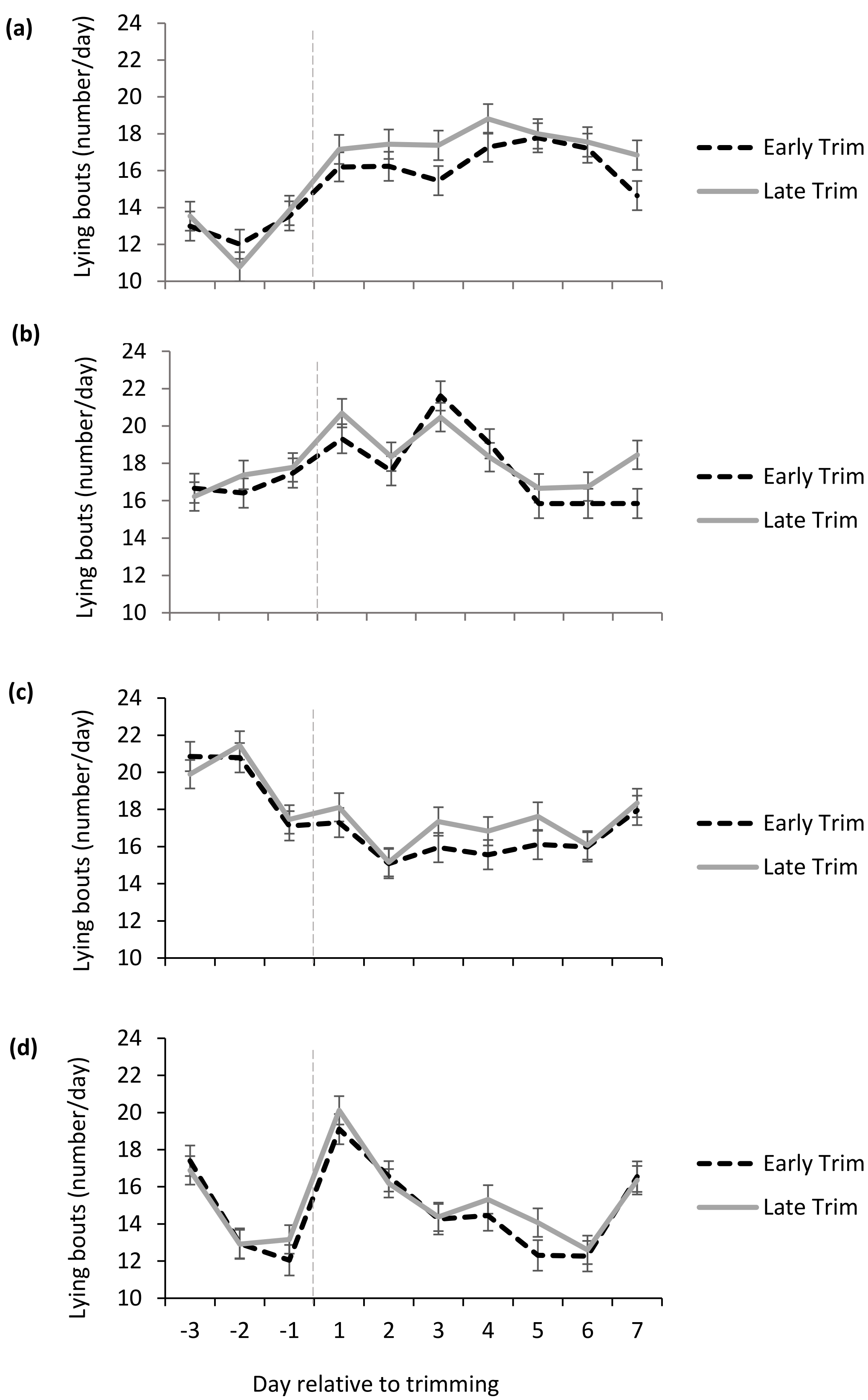


Figure 5. Mean ± SEM daily lying bouts 3 days pre-trimming and 7 days post trimming at four assessments (a) 13 months, (b) 17 months, (c) 21 months, (d) 25 months. Day 0 removed as it was the day of trimming. The light grey dashed line signifies a trimming event (n = 67 goats).

Objective 2: To evaluate the long-term effects of early life hoof trimming treatment on hoof conformation and joint positions

Hoof conformation

There was no evidence of a treatment effect on toe length ratio or claw splay distance on the front or hind hooves at either pre or post trimming for the 13-month or 25-month assessment. However, at the 13-month assessment, one goat in the late trimmed treatment had an undue influence on the post trimming statistical model for the front hooves. Though not considered an outlier by the criterion applied, when this animal was removed, claw splay distance of the early trimmed treatment was 4.9 ± 0.25cm, while the late trimmed treatment was 4.1 ± 0.27cm ($F_{1,43} = 4.53$, $P < 0.05$). This is in agreement with the binary claw splay score at the same assessment, where a higher proportion of goats in the early trimmed treatment (80%, n = 20 goats) had splayed claws on the front hooves after trimming compared with the late trimmed treatment (48%, n = 12 goats) (Chi-squared $P < 0.05$). No further effects of trimming were detected for binary claw splay scores.

At the 13-month assessment a higher proportion of goats tended to have misshaped hind hooves in the late trimmed treatment (24%, n = 8 goats) post trimming compared with the early trimmed treatment (10% n = 3 goats) (Chi-squared, $P = 0.08$).

No other trimming treatment effects were detected for any of the other subjectively scored hoof conformation variables either pre or post trimming for the 13-month or 25-month assessment.

Radiograph measurements

At the 13-month assessment no evidence of a treatment effect was detected on PIPJ, DIPJ or JH for the front or hind hooves. Post-trimming, heel angle of the hind hooves of the early trimmed treatment was 6.8^{o} ± 2.39 (mean ± SED) greater than that of the late trimmed treatment (early trimmed: 54.9 ± 1.61 vs late trimmed: 48.2 ± 1.72) (mean ± SEM) ($F_{1, 29}$ = 8.01, P <0.01).

At the 25-month assessment, the pre-trimming PIPJ joint angle of the front hooves of the early trimmed treatment was 7.0^{o} ± 2.86 (mean ± SED) less than that of the late trimmed treatment (early trimmed: 30.98 ± 1.90 vs late trimmed: 37.95 ± 2.09 (mean ± SEM) ($F_{1, 30}$ = 5.96, P <0.01). No other treatment effects were detected for any of the radiograph measurements either pre- or post-trimming for the 25-month assessment.

Objective 3: To investigate the pattern of lameness prevalence and hoof growth across the first two years of life and to determine if there was an effect of trimming.

Gait scores - description of all gait scores

Few goats were clinically lame (gait score ≥ 3) at each of the assessments, the majority were either not lame or showed an uneven gait (Table 6).

Gait scores -analysis of binary outcome data

There was no evidence of a treatment effect; trimming in early life did not affect the odds of goats having an impaired gait, however the odds changed over assessments ($F_{4, 248}$ = 6.97, P <0.001). The highest proportions of goats classified as having an impaired gait were observed at the 13-month (37.3%) and 25-month assessment (47.5%) (proportions of goats with an impaired gait were 24.1%, 13.6% and 25.4% for the 9, 17- and 21-month assessments respectively). The odds of a goat having an impaired gait were greater by a factor of 2.15 (95% CI: 1.02 – 4.54, $P < 0.05$) at the 13-month assessment and 3.79 (95% CI: 1.90 – 7.57, $P < 0.001$) at the 25-month assessment compared to the 9-month assessment.

Table 6. Number of goats (%) that were scored as being not lame, having an uneven gait or a lame gait using a 5-point gait scoring system at six assessments.

		Gait score			n
Assessment	Age (months)	1 (not lame)	2 (uneven gait)*	3 + (lame gait)*	
1[†]	5	-	-	-	-
2	9	60 (76.9)	17 (22.8)	1 (1.3)	78
3	13	42 (62.7)	19 (28.4)	6 (8.9)	67
4	17	57 (86.4)	8 (12.1)	1 (1.5)	66
5	21	47 (74.6)	16 (25.4)	0 (0.0)	63
6	25	32 (52.5)	26 (42.6)	3 (4.9)	61

* For analysis, goats with an uneven gait and lame gait were grouped, to create a binary variable comparing non-lame to impaired gait.
[†] Assessment 1 was excluded from analysis as accurate gait scores could not be assigned due to goats moving faster than a walk

Hoof growth

There was no evidence of a trimming treatment effect on front hoof growth ($P = 0.14$). Hoof growth increased between 13 and 19 months of age, decreased from 19 to 22 months of age and increased again between 22 and 25 months of age ($F_{5, 376} = 13.43$, $P < 0.001$) (Figure 6a). Hind hoof growth was affected by trimming treatment ($P < 0.05$) and assessment ($P < 0.001$). There was an interaction between these two variables ($F_{5, 369} = 3.09$, $P < 0.01$); hoof growth increased between 13 and

16 months of age in the late trimmed treatment, but no increase was detected during this time for the early trimmed treatment. At all other assessments, there was no treatment difference in hind hoof growth. Hoof growth decreased between 19 and 22 months of age in both the early and late trimmed treatment ($F_{5, 376} = 22.08$, $P < 0.001$ (Figure 6b).

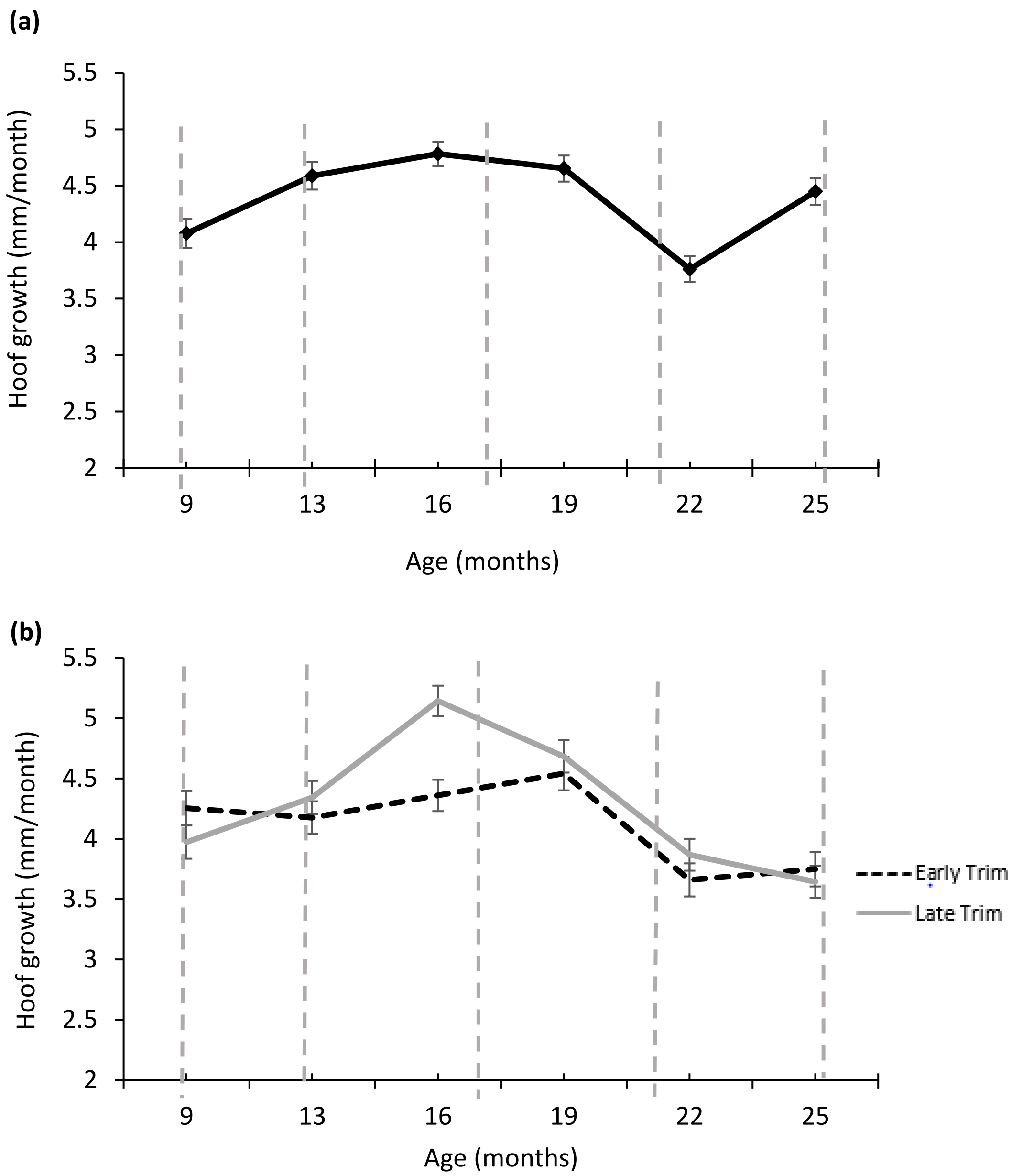


Figure 6. Mean ± SEM of growth rate of the (a) front hooves showing an assessment effect and (b) hind hooves showing an assessment by trimming treatment interaction at 6 hoof growth assessments across the goats' first two years of life, starting from 9 months of age (n = 78 goats). The light grey dashed lines signify a trimming event.

Discussion

The aims of this study were to determine the immediate impacts of hoof trimming and the long-term effects of starting hoof trimming at an earlier age on hoof conformation, joint positions, lying behaviour, gait scores and hoof growth in dairy goats. Overall, hoof trimming had beneficial effects on hoof conformation in the short term. Unexpectedly, starting hoof trimming earlier in life had only minor and inconsistent effects on hoof conformation and joint positions. On this farm, clinical lameness prevalence was found to be low over the 2-year study period, though prevalence of an impaired gait (uneven gait and lame gait) peaked after both kidding events. Each of the objectives will now be explained in more detail.

Immediate effects of hoof trimming

The purpose of hoof trimming is to improve conformation by the removal of hoof overgrowth (Phillips et al., 2000). In the present study, high proportions of the front and hind hooves were subjectively scored as overgrown prior to hoof trimming at all assessments. Additionally, toe length ratios were over 0.5 (toe length greater than half the length of the rest of the hoof) in the front and hind hooves before trimming at each assessment. Hoof trimming every four months was therefore not frequent enough to prevent hoof overgrowth.

Before trimming, the toe length ratio differed between assessments, however, after trimming, toe length ratio was consistently below 0.5. This indicates that regardless of how much growth was present pre-trimming, the process of trimming restored the toe to a consistent length. The commonly used ‘Dutch method’ (Van Der Tol et al., 2004; Frankena et al., 2009) of hoof trimming in cows recommends that the claw length should be trimmed to 75mm (Toussaint Raven, 1985). However, this does not account for individual cow difference in the shape and size of claws and may lead to over trimming of some cows (Archer et al., 2015). Therefore, using a ratio that accounts for individual claw shape may reduce the risk of over trimming.

The authors acknowledge that the objective toe length ratio measurement would not be practical for use on farm, however the subjective score for toe length may be appropriate if validated for use on live animals (rather than from photographs).

As hooves become overgrown heel depth is reduced (cows: Glicken and Kendrick, 1977; Gitau et al., 1997) and fetlocks may become hyperextended (cows: Shearer et al., 2012). In the present study this was particularly evident in the hind hooves with over 80% of heels being dipped before trimming at each of the four assessments. While the proportions of dipped heels reduced following trimming in the hind hooves, over 40% of goats' heels at each assessment had not recovered to an upright position.

The impacts of dipped heels in dairy goats is unknown. However, in horses lower heel angles are reported to significantly increase stress and deformation of the hoof capsule (Hinterhofer et al., 2000), leading to increased tension on the suspensory apparatus (Riemersma et al., 1996), and an increased risk of hyperextension (dipping) of the fetlock (Gibson and Steel, 2002). Despite high proportions of dipped heels, few dipped fetlocks were observed in the present study. However, it is possible that dipped fetlocks become more apparent with age following prolonged stress on the hoof and lower leg.

There are reported differences between the front and hind hooves in dairy cows, with the hind hooves suggested to have a lower heel angle than the front hooves (Shearer et al., 2005). My data indicate that the hind hooves may also have a lower heel angle in dairy goats, which may explain why some of the dipped heels were not recovered following trimming. In horses, it has been shown that recovery from dipped heels requires a long-term, animal specific hoof care management (Hunt, 2012); while this is not practical in goats, I suggest that a better approach would be to determine a more appropriate hoof trimming frequency that promotes heels to maintain an appropriate upright position.

Hoof overgrowth creates a cascade of follow-on effects; in dairy cows claw shape becomes abnormal (Manske et al., 2002b) and claws become splayed (van Amstel and Shearer, 2006). In the present study, I identified that the shape of the hind hooves improved following trimming, with a tendency for the front hooves to improve. As hoof overgrowth is reported to be one of the main causes of hoof deformation in dairy goats (Ajuda et al., 2014), the removal of overgrowth through the trimming process has beneficial effects for overall claw conformation. Furthermore, there were decreases in claw splay distance following hoof trimming. In the present study a distance less than 4cm between the axial edge of the distal tip of both claws would be considered non splayed. However, on average the claw splay distances were still over 4 cm for all of the front hoof assessments post trimming and for half of the hind hoof assessments post trimming. Consequently, high proportions of goats were subjectively scored as having splayed claws following hoof trimming. Claw splay may be largely determined by the environment rather than hoof trimming; hooves that are responding to softer substrates are more splayed (Zuba, 2012). Therefore, the high proportion of splayed claws even following hoof trimming may be due to the goats' hooves becoming accustomed to their bedding (e.g., soft wood shavings). The claw splay of goats' hooves in a more natural environment would need to be assessed to determine a "normal" distance of claw splay.

This study highlights the immediate beneficial effects hoof trimming had on joint positions within the distal limb and the value of objectively assessing these effects.

Hoof overgrowth impacts joint positions and angles (horses: Moleman et al., 2006), and is reported to be the main cause of displacement of the distal phalanx (cows: Meimandi-Parizi and Shakeri, 2007). All the radiograph measurements were immediately altered by hoof trimming, suggesting that hoof overgrowth had resulted in deviations of the joints. Restoring the displacement of the DIPJ joint angle and heel angle are of particular importance due to their reported association to structures within the hoof. For instance, an increased DIPJ angle is caused by displacement of the distal phalanx resulting in the caudal edge of the bone becoming a more prominent weight bearing surface, which can increase the risk of sole ulcers (cows: Blowey, 1992; Lischer et al., 2002) and also results in increased loading of the deep digital flexor tendon (horses: Moleman et al., 2006). In horses, just an 8-week interval between two trimming sessions resulted in an increase in DIPJ angle (Moleman et al., 2006) and lower heel angles (van Heel et al., 2006). This highlights the importance of frequent hoof trimming to prevent hoof overgrowth and to maintain anatomically correct conformation and joint positions.

As well as influencing anatomical features of the hoof and distal limb, trimming also influenced the goats' behaviour. In the present study daily lying time increased at day 1 post trimming compared to the day prior to trimming at the 13 and 17- 25-month assessments. An increase in lying time following hoof trimming has been reported in cows, with trimmed cows lying more than sham cows (Chapinal et al., 2010b). However, as lame cows were included in the trimmed group, but not in the sham group it is difficult to draw conclusions about the reasons for the difference in lying behaviour in that study.

An increase in lying time immediately following hoof trimming may be interpreted as a pain response as lame animals lie more (Ito et al., 2010). However, it is difficult to make conclusions about pain using behaviour as it is such a complex and individualistic experience (Viñuela-Fernández et al., 2007). Nevertheless, an increase in gait score has been reported following hoof trimming, which further supports a pain response (Van Hertem et al., 2014). Furthermore, goats in the late trimmed treatment lay more in the four days following hoof trimming at the 13-month assessment compared with the goats that were in the early trimmed treatment. As this was the first time the goats in the late treatment had been trimmed it suggests that lack of experience of the trimming process may be impacting lying behaviour, with a possible increased pain response compared to the early trimmed goats that had been trimmed twice before.

As gait scores were not assessed following hoof trimming, it is not possible for me to conclude whether the difference in lying time is due to a pain response. Another explanation for an overall increase in lying time at day 1 following hoof trimming may be that it is compensatory response due to the goats spending approximately 4 hours out of their pens the previous day. Further work is needed in a more controlled setting to determine the immediate effects of hoof trimming on dairy goat behaviour.

Although a statistical effect of time was detected, there was high variability in both lying time and lying bouts even in the 3 days prior to hoof trimming and across assessments. This was evident at the 21-month assessment, with high lying bouts and lying time observed in the days before trimming compared to the other assessments. As the goats were in kid and therefore dry at this assessment, they would not have been leaving the barn for milking, which may explain the increased lying behaviour before trimming compared to the other assessments. However, the much more erratic daily lying time pattern following hoof trimming at 21-months, cannot be explained. Farm management factors that I could not control for may have been impacting lying behaviour on a given day, for instance groups of goats could have been mixed which may increase agonistic interactions and thus reduce lying behaviour (Miranda-de La Lama and Mattiello, 2010). Conversely, fresh bedding may have been added which could promote greater lying behaviour.

Longer term effects of early life trimming

Starting hoof trimming of goats at five months of age appeared to confer little consistent advantage over beginning trimming following first kidding (13 month of age) in terms of hoof conformation and joint positions. Unexpectedly, there were more goats with splayed claws of the front hooves after trimming in the early trimmed treatment compared to the late trimmed treatment at the 13-month assessment. However, it should be noted this effect was not observed at the 25-month, likely due to high proportions of splayed claws in both trimming treatments. Differences were observed in the hind hooves, with goats in the late trimmed treatment having lower HA compared to the early trimmed treatment at the 13-month assessment. At the 25-month assessment PIPJ angle was smaller in the early trimmed treatment compared to the late trimmed treatment.

The power analysis conducted for this study was based on horse data due to the lack of data in either dairy cows or goats. I acknowledge that the sample size may have been suitable to detect immediate effects of hoof trimming (primary objective), however longer-term effects may have been masked due to too few animals, with the potential for Type II errors being introduced. Indeed, a retrospective power analysis highlighted that 40 goats per treatment were inadequate to find a long-term effect on the objective measures of hoof conformation. A larger scale study would be required to determine the longer-term impacts of trimming prior to first kidding in dairy goats.

Nevertheless, as high proportions of overgrown hooves, dipped heels, misshaped claws and splayed claws were observed across both treatments, it suggests neither trimming treatment was successful at preventing poor hoof conformation. The subsequent frequency of hoof trimming of every 4 months was included in the present study as this is commonly implemented in the industry (Chapter 4). However, my results suggest more frequent trimming is required; indeed, it is suggested that as often as every 6-8 weeks is necessary depending on the housing environment (Pugh and Baird, 2012).

Interestingly, caution should be taken to not over trim; trimming can have negative effects. For instance, over-trimming causing bleeding of the hoof is associated with increased lameness in sheep (Winter et al., 2015). Along with a potential pain response following trimming (Van Hertem et al., 2014), hoof trimming, and the necessary handling, causes stress reactions in dairy cows (Rizk et al., 2012); increased faecal cortisol for up to 24 hours following hoof trimming, and reduced milk production on the day of, and the day following, hoof trimming have been reported (Pesenhofer et al., 2006). We therefore suggest that controlled research in dairy goats is required to first determine the potential detrimental effects of hoof trimming in general, and second to determine ideal trimming frequency. It is likely that adequate trimming regimes need to include consideration of when trimming begins, the frequency of subsequent trimming, but also the provision of opportunities for goats to naturally wear their hooves.

An environment that promotes natural hoof wear will encourage self-maintenance of the hooves (Florence and McDonnell, 2006), as hard substrates that promote hoof wear result in shorter toe lengths and more upright hooves (horses: Hampson et al., 2013). For example, dairy cows' exposure to an abrasive concrete surface resulted in 35% more hoof wear than cows exposed to a dirt surface (Hahn et al., 1986). While in cows prolonged standing on concrete promotes lameness (Somers et al., 2003), goats in their natural environment populate hilly and rugged environments and often rest directly on rocks in steep terrain (Zobel et al., 2019). In an alpine environment milking goats are reported to travel upward of 3km in a 24 hour period (Zobel et al., 2018) and despite not being hoof trimmed for 5 months it was reported their hooves were not overgrown (Zobel et al., 2019). Therefore, providing substrates to promote hoof wear may reduce the need for such frequent hoof trimming of dairy goats.

Hoof growth and lameness prevalence

Early trimming did not impact hoof growth in the front hooves and did not have a consistent effect on growth in the hind hooves. However, hoof growth did slow in the front and hind hooves at the 22-month assessment when the goats were in late gestation. Similar results have been reported in dairy cows with hoof growth decreasing during the second trimester of pregnancy (Dietz and Prietz, 1981). Nevertheless, the hoof growth measurements were taken every 12 weeks and therefore were not consistently spaced around trimming events. As hoof growth is reported to significantly increase following trimming (cows: Manson and Leaver, 1988) this may have had an impact on the hoof growth measurements recorded. Furthermore, we caution that only hoof trimming was controlled for, all other farm management continued as per normal farm practice. Management aspects such as provision of clean bedding, cleaning of the concrete skirt, and dietary changes, were not controlled for; the authors acknowledge these factors may have impacted hoof growth.

Most of the goats across the assessments were either not lame (gait score = 1, assessment range: 52 – 77%) or showed an uneven gait (gait score = 2, assessment range: 12 - 43%), thus clinical lameness (gait score ≥ 3) prevalence was low over the study period. The prevalence of clinical lameness was less than 9% of goats at all assessments over 2 years. Although limited, there are data that reports an association between poor conformation and increased gait score in dairy goats (Ajuda et al., 2014; Ajuda et al., 2019), therefore, I expected lameness prevalence to be higher in the present study due to the high proportions of poor conformation observed. It may be possible that the goats are able to adapt to some deviation of conformation from an anatomically correct shape without gait being impacted. However, I suggest that lameness may become more apparent with age, following chronic, prolonged periods of poor conformation. Indeed, Ajuda et al (2019) report an association between hoof overgrowth, poor conformation and lameness in dairy goats aged 2-5 years of age. Further work is required to evaluate if there is an association between poor conformation and lameness in New Zealand dairy goats.

Many goats walked faster than a walk at the 5-month assessment because of their young age. Difficulty in assigning accurate gait scores due to the speed the goat moves at has previously reported (Chapter 3), and therefore it was decided to exclude the 5-month assessment from the analysis. At the 9-month assessment and subsequent assessments, the goats moved at a steady walking pace.

Gait scores did not differ between the early trimmed goats and the late trimmed goats. However, I caution that as discussed above the power of the study to find such an association was low. There was a time effect, with goats having greater odds of an impaired gait at the 13-month and 25-month assessments compared to the 9-month assessment. There is evidence that lameness risk significantly increases following calving in dairy cows (Offer et al., 2000; Tarlton et al., 2002). Metabolic and hormonal changes associated with calving weaken the connective tissue of the hoof suspensory apparatus, leading to an increased risk of lameness due to sole ulcers and white line disease (Tarlton et al., 2002). At the 13 and 25-month assessments in my study, the goats had recently kidded, suggesting parturition may be impacting gait. However, I caution it was not within the scope of the present study to investigate the exact cause of the observed lameness. Future work should focus on the effect of age and stage of lactation on lameness and whether further intervention is needed around kidding, a potentially critical time point.

Conclusion

In conclusion, there were immediate beneficial effects of hoof trimming, with hoof conformation and joints restored to more anatomically correct shapes and positions. There were no meaningful long-term effects of starting trimming prior to kidding in terms of hoof conformation, joint positions or gait scores; however, I caution that my study may not have had enough power to assess this. Goats had greater odds of having an impaired gait following kidding, suggesting a parturition effect. Additionally, hoof growth slowed when the goats were in kid, suggesting an effect of stage of life and gestation. Changes in lying behaviour following hoof trimming were observed suggesting a possible pain response, however as other management factors may have been having an impact, conclusions about the behaviour changes cannot not be made. The results provide evidence that trimming every 4 months (3 trims per year) is not frequent enough to prevent hoof overgrowth, poor conformation and changes in joint positions. Therefore, trimming protocols may need to be revised to include when trimming should start and how often it needs to happen in order to produce long-term improvements to the hooves. Further work is needed to be carried out for definitive conclusions about early life trimming regimes to be drawn and to determine if hoof trimming does negatively impact dairy goat behaviour. Additionally, work should investigate if the provision of an environment that allows for natural hoof wear, thus promoting anatomically correct hoof conformation and joint positions, reduces the need for such frequent hoof trimming.

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Chapter Six

General Discussion

The overall focus of this thesis was to examine the hoof conformation and gait of dairy goats and to evaluate how these factors are impacted by hoof trimming. The aims were to firstly develop and validate a hoof conformation assessment for use in dairy goats, and secondly to develop a reliable gait scoring system to allow detection of an uneven gait and varying degrees of lameness. Following on from the development of these methods, I then aimed to use the hoof conformation assessment and gait scoring system to aid in evaluating the impact of hoof trimming regimes on the structure and functioning of dairy goats' hooves. The hoof conformation assessment was used in an observational study across 16 farms to explore the relationship between timing and frequency of hoof trimming and hoof conformation. Finally, in an experimental study on one farm, both the hoof conformation assessment and gait scoring system were used in conjunction with other measures to evaluate the immediate impacts of hoof trimming on anatomical (i.e. hoof conformation, joint positions) and behavioural variables (i.e. lying behaviour). Additionally, the longer-term effects of trimming prior to first kidding on anatomical variables and gait were evaluated.

The lack of data on aspects of dairy goat hoof health became apparent during my literature review in Chapter 1. Notably, there were few published data investigating hoof conformation, lameness, and hoof trimming in goats, thus most of the literature discussed in my review was based on dairy cow research. Furthermore, it should be noted that the published literature on the benefits of preventative hoof trimming in dairy cows is limited. The literature available largely reflects opinions based on clinical experience rather than the findings of primary research, and therefore I acknowledge a number of the references used within this thesis are not from evidence-based literature. However, I have endeavored to reference primary research where possible.

In this final chapter, I will discuss the findings of each of the chapters by considering the literature gaps they aimed to address, and the wider implications of the results. I will also discuss limitations of the work and highlight possible areas of future research.

6.1. Main findings and implications

6.1.1. Prevalence of clinical lameness and uneven gait

There are currently no published peer reviewed data reporting lameness prevalence in New Zealand dairy goats. In an industry survey from the 2013-2014 season (n = 30 farms), dairy goat farmers reported a lameness prevalence of 2% or less (Ganche et al., 2015). However, farmers commonly underestimate lameness within their herds (cows: Whay et al., 2002; Espejo et al., 2006). As lameness can be more difficult to detect in dairy goats due to their quick movement (Chapter 3), I suggest that there may be greater potential for underestimation of lameness by dairy goat farmers. Additionally, this industry survey did not provide a standardised definition of lameness, and therefore it is unknown what levels/degrees of lameness are represented.

A systematic survey of lameness prevalence on New Zealand dairy goat farms is needed. However, reliable methods of identifying and grading lameness and its precursors are required to accurately estimate prevalence. More specifically this requires gait scoring systems that facilitate the detection of the full range of gait abnormalities. The previous gait scoring systems that have been used in dairy goats focus on the presence of a distinct limp and do not allow for the detection of an uneven gait, a potential precursor to lameness. Lameness often develops over time, for instance, there is a delay of weeks between the time corium damage occurs and the time a sole ulcer becomes apparent in dairy cows (Bradley et al., 1989). Therefore early detection of subtle signs of lameness promotes early treatment, which increases the chance of a full recovery (cows: Groenevelt et al., 2014) and may reduce suffering by preventing the cause of the lameness from worsening (cows: Leach et al., 2012).

The purpose of chapter 3 was to develop a reliable gait scoring system that also detected an uneven gait, a potential precursor to lameness.The developed 5-point gait scoring system was compared to the 4-point system previously used in dairy goats (Anzuino et al., 2010) and was determined to be more sensitive. For instance, in the 1st training session using the 4-point system 81% of the goats were assigned score 1 (normal gait), while using the developed 5-point system only 36% of the goats were assigned score 1 (normal gait), with 50% assigned score 2 (uneven gait). Thus, the 5-point system provides a method to allow identification of animals that may be predisposed to developing clinical lameness.

6.1.1.1.Preliminary information on the prevalence of clinical lameness

Clinical lameness refers to an animal with an obviously lame gait and a definite limp (gait score ≥ 3) (Espejo et al., 2006). In the study completed at the AgResearch goat facilities (Chapter 3), I report a prevalence of clinical lameness of 14% at the week 1 training session when using the 5-point score. When the subsequent 5 assessments are considered, a similar prevalence of clinical lameness was observed (range: 10-17% across 5 consecutive weekly assessments). This is similar to levels reported from UK studies where between 9.1% (Hill et al., 1997) and 19.2 % of goats had a definite limp (Anzuino et al., 2010). In contrast, the prevalence of animals with a lame gait (score ≥ 3) on one commercial farm (Chapter 5) was lower than I expected (range: 0 – 9%, across 5 assessments, during first two years of life).

The data presented in my thesis regarding clinical lameness was from one AgResearch research herd and from one commercial farm. I suggest it is not representative of the New Zealand dairy goat industry. However, a lameness prevalence of 5% or more should prompt an investigation of the cause and implementation of a control programme (sheep: Winter, 2004). Indeed, the Farm Animal Welfare Council proposed that the prevalence of lameness in sheep should fall from 10% to 5% by 2016, and to 2% by 2021 (FAWC, 2011). Therefore, further investigation into the prevalence of lameness on New Zealand dairy goat farms is required.

6.1.1.2.Preliminary information on the prevalence of an uneven gait

Using the developed 5-point gait scoring system I have provided some preliminary information on the prevalence of an uneven gait in New Zealand dairy goat herds. There were high proportions of uneven gait reported in the research herd (Chapter 3) at training session 1, and this persisted over the 7-week study period (range: 52-75% across 5 assessments, n = 48 goats).The goats enrolled in that study were 2 and 3-year-old lactating does from a local farm where they had been permanently housed on wood shavings. During the study period they were housed on rubber matting and shavings. Therefore, the high proportions of uneven gait observed may be due to the hooves being sensitive while they acclimated to the different flooring substrates. The goats' hooves acclimatising may have also accounted for some of the clinical lameness observed in the research herd.

However, a similar prevalence of score 2s were observed at the 25-month assessment (Assessment 6) on one commercial farm, where goats were permanently housed on shavings, with 43% of 2-year-old goats assigned an uneven gait (Chapter 5). In contrast, prevalence of an uneven gait ranged from 8 – 26% at the previous assessments completed across the first two years of life on this farm. At the 25-month assessment the goats were a similar age to the goats for whom results are reported in Chapter 3. This highlights that many dairy goats do not walk in a sound manner and an uneven gait may become more prevalent as the goats get older.

It should be noted that an uneven gait is not necessarily linked to lameness. For example, this movement pattern may be caused by udder fill causing abduction or adduction of the hind legs in the swing phase of the stride (cows: Greenough et al., 1997; Flower et al., 2006). However, all gait scoring in Chapter 3 and 5 was completed following milking to try to minimise these effects. Additionally, hoof overgrowth is associated with altered biomechanics (cows: van Amstel and Shearer, 2001) and may cause an altered gait, such as paddling of the limbs (sheep: Bokko et al., 2003). As gait assessments in Chapter 5 were completed prior to trimming, hoof overgrowth may be responsible for the high prevalence of uneven gait. Nevertheless, the cause of the gait unevenness should be investigated, and treatment provided if deemed necessary.

6.1.1.3. Possible parturition effect impacting lameness prevalence

An interesting pattern in the prevalence of lameness was observed on one commercial farm (Chapter 5). There was a possible parturition effect, with the odds of goats having an impaired gait (uneven or lame gait) increasing following kidding. A parturition effect causing an increase in lameness has been reported in dairy cows (Offer et al., 2000; Tarlton et al., 2002) and there is limited evidence previously reported in dairy goats (Groenevelt et al., 2015).

High proportions of overgrowth and poor conformation were observed at all four assessments before trimming. I suggest this may have a greater impact at kidding than at the other assessments which were completed during lactation. For instance, the long-toe dipped heel conformation caused by hoof overgrowth results in rotation of the distal phalanx, thus increasing the risk of sole ulcers in dairy cows (Blowey, 1992). Dairy cows may lose body condition during gestation (Markusfeld et al., 1997), which in turn can reduce the thickness of the digital cushion (Bicalho et al., 2009). A thinner digital cushion has less shock absorbing capacity which may further increase the risk of sole ulcers and other lesions (Bicalho et al., 2009). To my knowledge, there are no data investigating the role of the digital cushion in the hooves of dairy goats. However, a thinner digital cushion around parturition may explain the higher prevalence of uneven and lame gait following kidding and suggests that more attention to hoof management is required around this time.

Other factors may contribute to the higher observed prevalence of impaired gait after kidding. Prior to parturition a nonlactating period (dry period) is believed necessary to allow mammary tissue time to recover and repair (Capuco et al., 1997). The dry off period for dairy goats is commonly 50-60 days long (Pugh and Baird, 2002; Caja et al., 2006). During this time their exercise regime is altered as they are not visiting the parlour twice a day for milking, resulting in many goats spending

24 hours of the day in their shaving bedded barns. After kidding there may be an acclimation period during which the hooves must adapt to walking on concrete again once the goat joins the milking herd.

Furthermore, there are a number of other factors during the period when an animal transitions from dry to the milking herd that can lead to lameness (cows: Bell, 2015). During this transition period in dairy cows, the hormonal changes that impact the suspensory apparatus within the hoof are a major contributory factor to the development of sole lesions (Tarlton et al., 2002). Additionally, negative energy balance (Collard et al., 2000) and needing to compete in a different social hierarchy and environment can increase the likelihood of lameness around parturition in dairy cows (Mahendran and Bell, 2015). As there are currently no data investigating hoof health during the transition period in dairy goats, I suggest this is an area that warrants further investigation.

6.1.2. Hoof conformation

In dairy goats, hoof deformation resulting from hoof overgrowth is a key cause of lameness (Ajuda et al., 2014; Ajuda et al., 2019). Therefore, it is important that animals with poor conformation can be identified. Prior to my research there were no validated goat specific methods of assessing hoof conformation.

As reported in Chapter 2, I developed a reliable hoof conformation assessment for use in dairy goats. Both the objective measures and subjective scores used to assess aspects of hoof conformation could be accurately applied to photographs of hooves. Additionally, two subjectively scored aspects of conformation were validated against the objective measurements. These findings indicated that the subjective scores may be appropriate to use rather than the more time-consuming objective measures. Furthermore, the subjective scores would be more applicable to an on-farm setting, as the objective scores require photographs and technical equipment.

6.1.2.1. Preliminary information on the prevalence of poor conformation

Previous studies in the UK have reported high prevalence of hoof overgrowth in dairy goats (84-100%: Hill et al., 1997; Anzuino et al., 2010; Ajuda et al., 2019) and the results of the studies reported in this thesis have found similar prevalence levels. Prior to trimming the prevalence of overgrown hooves on one commercial farm (Chapter 5) ranged from 55-97% at four assessments over the first two years of life. Additionally, high prevalence of poor hoof conformation was observed prior to trimming on this farm, particularly in the hind hooves. For instance, the prevalence of dipped heels ranged from 85-98%, and misshaped claws ranged from 38-67%. The proportions of dipped heels and misshaped claws decreased following hoof trimming, (range: 42-68%, and 17-33% respectively) suggesting an association between hoof overgrowth and poor conformation.

Hoof overgrowth in dairy goats is not unique to New Zealand, but is a common issue in all commercially indoor housed goats (UK: Anzuino et al., 2010; Italy: Battini et al., 2016; Portugal: Ajuda et al., 2019). Overgrown hooves are caused by lack of opportunity to naturally wear hooves and inadequate trimming practices (AWIN, 2015). As reported in Chapter 5, dairy goats' hooves grow at approximately 4mm a month. If only trimmed every 4 months as is common practice, (Chapter 5) this can amount to a considerable amount of growth. Without opportunities for goats to wear their hooves, more frequent hoof trimming would be required to prevent hoof overgrowth.

6.1.3. Hoof trimming

Through the validation of both scoring methods in the first two experimental chapters, I was able to apply these methods to improve my understanding of the anatomical and behavioural effects of hoof trimming. This included the immediate effects of hoof trimming, and the impacts of early life trimming and subsequent trimming frequency.

In this thesis, the term ‘early life trimming’ is used to describe whether goats were trimmed before first kidding; when cow literature is discussed, it refers to trimming heifers prior to first calving.

6.1.3.1. Immediate effects of hoof trimming

The aim of hoof trimming is to improve conformation by removing hoof overgrowth (Bryan et al., 2012). In an experimental study on one farm (Chapter 5), trimming was completed by a trained veterinarian and was successful in reducing overgrowth. Furthermore, trimming consistently resulted in a toe length ratio of <0.5 in the front and hind hooves, which indicates that trimming was done appropriately. Interestingly, a similar toe length has been observed in goats kept in an alpine environment that had not been trimmed for a number of months (Zobel et al., 2019). In that study, the goats travelled upward of 3km in a 24 hour period and had therefore naturally worn their hooves (Zobel et al., 2018), reducing the need for frequent trimming.

Hoof trimming immediately improved other aspects of hoof conformation, notably the prevalence of dipped heels and misshaped claws were reduced in the hind hooves following trimming (Chapter 5). Additionally, hoof trimming reduced the deviation of the joint positions in the distal limb. The deviation of the DIPJ signifies rotation of the distal phalanx, and therefore restoring this to an anatomically correct position is beneficial to reduce the risk of sole ulcers (cows: Blowey, 1992).

While there were immediate benefits of hoof trimming (Chapter 5), the process of trimming may be both stressful and painful and the impacts of this on the animal should be considered (cows: Pesenhofer et al., 2006). An increase in lying time and gait score indicative of lameness has been reported in dairy cows following hoof trimming and may be interpreted as a pain response (Chapinal et al., 2010; Van Hertem et al., 2014). The increased time spent lying (increased lying time range: 2-4 hours) observed on the day following trimming (at 3 of the 4 assessments; Chapter 5) suggests trimming impacts this behaviour. However, due to high variability in lying behaviour even prior to trimming the data should be interpreted with caution. Completing gait scores post trimming would provide information about the lameness status of the animal and thus provide some evidence as to whether the goats are indeed in pain following trimming.

6.1.3.2. Effects of early life trimming and subsequent trim frequency

While hoof trimming is known to be important for dairy animals, my work is the first to evaluate the effects of early life trimming on aspects of hoof health in dairy goats.

In the observational study across 16 dairy goat farms (Chapter 4), goats that had not been trimmed prior to first mating (8.0 ± 0.70 months) had greater odds of poor hind hoof conformation (overgrown hooves, dipped heels and misshaped claws) at that time than compared with goats on farms that had already trimmed. In the longer term, goats on farms that had not trimmed before first kidding (14.8 ± 0.86 months) had greater odds of having dipped heels on the hind hooves at the end of second lactation (34.1 ± 0.90 months).

In contrast in the experimental study on one commercial farm, there were only minor long-term effects of trimming before first kidding (trimmed at 5 and 9 months) on hoof conformation and joint positions and these were not consistent at assessments at the end of the first (13 months) and second (25 months) lactations. However, neither treatment (either trimmed twice in early life or not trimmed until after first kidding) prevented hoof overgrowth and poor conformation, suggesting that time of first trimming as well as the frequency of subsequent trimming may be important

In terms of subsequent trimming frequency, the results from the observational and experimental study indicate that the trimming frequencies included in these studies were not appropriate to prevent poor hoof conformation. On one commercial farm (Chapter 5) following the initial early life trimming all goats were trimmed every 4 months. As high prevalence of poor conformation was observed in both the early and late trimmed treatments it suggests that the subsequent hoof trimming was not frequent enough to prevent overgrowth. Across 16 farms, two of the regimes both trimmed before first kidding, with one trimming ≥ 4 times per year thereafter, and the other trimming 2-3 times per year thereafter. There were no differences in the risk of hoof overgrowth and poor conformation between those two trimming frequencies (Chapter 4), high proportions of poor conformation were observed in both. However, the time since last trim was not taken into consideration. Therefore, this will have impacted the amount of overgrowth and consequently the hoof conformation observed, given the observed effects immediately after trimming on hoof overgrowth, conformation and joint positions (Chapter 5).

In dairy heifers it is suggested that early life hoof management is important to reduce the future risk of poor conformation and lameness (Offer et al., 2000; Bell et al., 2009). Early life trimming is particularly important for heifers managed indoors because they have little opportunity to wear their hooves, and may be required as early as six months of age (Amstutz, 1985). As dairy goat kids are typically reared indoors on soft bedding materials such as straw or shavings, early life trimming is likely to be equally important. In the observational study across 16 farms there were high proportions of poor conformation observed (Chapter 4) at the assessment at first mating. This suggests that trimming at an even younger age than first mating may be required to prevent these poor conformation traits.

At the end of the second lactation the mean proportions across 16 farms were above 50% for dipped heels, misshaped claws, and splayed claws in the hind hooves. Interestingly, at the end of the second lactation (Chapter 4) the proportion of hoof overgrowth (range: 11-30%) was lower than the other aspects of poor conformation. This suggests that the hoof trimming regimes were successful in reducing overgrowth but not successful at correcting other aspects of conformation in the longer term.

It was not within the scope of the study reported in Chapter 4 to investigate whether the high levels of poor conformation increased the risk of lameness. High proportions of poor conformation (overgrown toes, dipped heels, misshaped claws and splayed claws) were observed before trimming at each of the four assessments on one commercial farm (Chapter 5). However, although many goats were assessed as having an uneven gait (range: 12.1-42.6%, across 5 assessments) few goats were reported as clinically lame (0-9%, across 5 assessments) during the study period. Dipped heel conformation and misshaped claws are associated with claw lesions and lameness in dairy goats (Hill et al., 1997; Ajuda et al., 2014), therefore, it would be valuable to further investigate the associations between an uneven gait, a lame gait, and poor conformation. This will be discussed further below.

6.1.4. Other reasons for poor conformation

Factors other than the start and frequency of trimming may impact hoof conformation. For example, hoof shape in dairy cows is in part dependent on the trimming technique used (Vermunt and Greenough, 1995), therefore poor trimming technique may cause poor conformation (Clarkson et al., 1993). It is possible that this may be responsible for some of the poor conformation observed across the 16 farms (Chapter 4). For instance, over 50% of the hind hooves of goats were misshaped at the assessment at the end of the second lactation.

However, there are also several environmental factors that impact upon hoof conformation, such as flooring substrate (cows: Telezhenko et al., 2009). In Chapter 4, over 70% of the front and hind hooves of the goats were splayed, while in the experimental study on one farm (Chapter 5), over 60% of the front hooves of the goats were splayed at the end of the second lactation. All trimming in the experimental study was completed by the same trained veterinarian using the trimming approach used by Pugh and Baird (2002) and yet high proportions of splayed claws were observed. This suggests there is a commonality among the farms included in Chapters 4 and 5 that may be resulting in splayed claws. For instance, dairy goats in New Zealand are typically bedded on wood shavings.

Indeed, it is suggested that claw splay is due to hooves adapting to softer flooring substrates (Zuba, 2012). Therefore, the environment may be having a greater impact on claw splay than hoof trimming.

Further, there may be a genetic component to the poor conformation observed (cows: Bergsten, 2001). It is suggested that dairy heifers be closely examined for conformational hoof traits prior to mating (Anderson and Rogers, 2001). If an animal has poor conformation it should be not be considered as a viable replacement (Anderson and Rogers, 2001) or included in breeding programmes (Baggott, 1982). In dairy cattle, an improvement in foot and leg conformation traits is possible by considering the claw measurements of future bulls (Boelling et al., 2001). No information to evaluate a genetic component to poor conformation was gathered in my studies, but I suggest that this is an area that may need considering in dairy goats. However, methods of evaluating hoof conformation need to be standardised in order to assess genetic associations and heritability. To be useful for this purpose, the subjective aspects of the hoof conformation assessment developed (Chapter 2) need testing in an on-farm setting. If reliable they could be used to determine those goats with poor conformation and therefore indicate animals that may not be suitable to breed from.

6.2. Management and animal welfare implications

Good hoof trimming protocols should include consideration for when trimming begins and the frequency of subsequent trimming. Additionally, other factors need to be considered when deciding on appropriate hoof care, such as, the provision of opportunities for goats to naturally wear their hooves. This may aid in reducing hoof overgrowth and the associated risk of poor conformation, thus decreasing the need for frequent hoof trimming. I propose that hoof management in dairy goats needs to be reviewed and protocols updated, with timing of first trimming, trimming frequency and housing environments examined.

Hoof and leg disorders become more prevalent with more confined management systems, as environmental conditions such as flooring substrate and poor hygiene can influence hoof conformation (Bergsten, 2001). The results reported on one commercial farm (Chapter 5) highlight that trimming more frequently than every 4 months is required to prevent hoof overgrowth and poor conformation when goats are housed in an environment that does not promote hoof wear. In their natural environment, goats populate hilly rugged environments (Zobel et al., 2019) and indeed, when dairy goats are given the choice they prefer to be on harder flooring substrates rather than shavings (Sutherland et al., 2017). Therefore, including hard surfaces in the environment of commercially housed goats may be advantageous for better meeting their preferences as well as promoting hoof wear, thus reducing the need for such frequent trimming.

Similarly, to dairy goats, overgrown hooves are also an issue in captive zoo ungulates due to decreased activity levels and reduced opportunity for hoof wear compared to their wild counterparts (Huffman, 2013). Indeed, the Association of Zoos and Aquariums (AZA) recommends providing abrasive flooring substrates such as textured cement or crushed gravels in walkways and high traffic areas to promote hoof wear (zebra: Fischer and Shurter, 2001, giraffe: Jolly, 2003). I suggest that modifications to dairy goat housing to include abrasive surfaces may help with hoof health issues, such as overgrowth and lameness. For instance, an outdoor environment promotes more activity in dairy goats (Freeman et al., 2018). If the outdoor environment is equipped with abrasive flooring substrates and/or climbing opportunities this may encourage hoof wear and promote hoof health. Additionally, enriched environments promote more activity in dairy goats and decrease abnormal behaviours (Gomes et al., 2018), by encouraging more species specific behaviour (van de Weerd and Day, 2009). This may improve animal welfare by promoting positive affective states, promoting the performance of natural behaviours and improving biological functioning.

The higher prevalence of lameness observed following kidding on one farm (Chapter 5) may be a result of several factors. However, reducing extreme changes in management around this time is likely to reduce lameness risk. For instance, farmers could move the goats through the milking parlour during the dry period to increase activity levels and to ensure the goats' hooves are exposed to concrete during this time. Exposure to the milking parlour and the concrete walkways may be particularly important for primiparous goats as they will have had minimal prior contact with concrete. Furthermore, keeping groups of goats as stable as possible during the dry period and transition period may reduce the stress on the goats (Patt et al., 2012), thus reducing the risk of antagonistic interactions and reducing lameness risk (cows: Mahendran and Bell, 2015).

6.3. Limitations

A key limitation of the work completed for this thesis is that the developed hoof conformation assessment and 5-point gait scoring system have not been tested in an on-farm setting. In addition, the hoof conformation assessment required considerable training prior to starting scoring of the photos, while some aspects required intermittent training throughout the course of the study to ensure ongoing reliability. The subjective scores would be most applicable to an on-farm setting.

Therefore, as the toe length and heel scores were reliably scored throughout, I propose that these could be more readily trialled on farm.

The gait scoring system was developed using live observations of goats; however this was in a controlled setting at the AgResearch Goat Research Facility, with the goats released one at a time from the milking parlour. This would not be feasible if trying to score a whole herd on farm. The 5-point system was used reliably in Chapter 5; however, the scoring was completed from videos, allowing the observers to watch and re-watch the video before allocating a score. Further testing is required to determine if an uneven gait can be identified in an on-farm setting. If this is not feasible, other methods of detecting an uneven gait will need to be explored (e.g., pressure plates); this will be discussed in more detail below.

Several other factors apart from the timing of first hoof trimming and the frequency of subsequent trimming may influence hoof conformation. For example, farm management factors will have a large impact (cows: Mahendran et al., 2017). In the 16-farm observational study (Chapter 4), farm management factors (e.g. stocking density, distance walked to parlour, diet) were not considered, making it difficult to make definitive conclusions about the effects of the observed hoof trimming regimes. In addition, time since last trimming needs to be taken into consideration as the amount of overgrowth will influence the other aspects of hoof conformation. Nonetheless the study provides preliminary evidence that first trimming prior to first mating is beneficial to hoof conformation. It also highlights the high proportions of poor hoof conformation in New Zealand dairy goats, suggesting further work is needed in this area.

A key limitation to the experimental study (Chapter 5) was the sample size. A power analysis was conducted for one of the main variables of interest (hoof growth between trimming intervals), however this was conducted using data from a study of horses due to the lack of data for either dairy cows or dairy goats in this area. The small sample size is likely to have introduced type II errors, whereby failure to reject a null hypothesis which is actually false occurs (i.e. true effects are not detected). Indeed, retrospective power analysis suggested over 400 animals per treatment group would have been required to observe a difference in gait scores between trimming treatments.

Another limitation of the experimental study (Chapter 5) was the lying behaviour data. There was high variability in daily lying time even prior to hoof trimming. Nevertheless, an increase in lying time the day following hoof trimming was determined at 3 of the 4 assessments. The results provide evidence that there is a behavioural response to hoof trimming, however due to the variability the data should be interpreted with caution. It is possible that unknown farm management factors were having a greater impact on lying than the trimming process itself. The reason for the increase in lying time following hoof trimming needs investigating in a more controlled environment.

Hoof growth was measured in 80 goats on one farm (Chapter 5), however it would also have been advantageous to measure hoof wear, as it would have provided more information about changes in hoof length. Hoof wear could be measured using a similar method to hoof growth in dairy cows (Tranter and Morris, 1992). Therefore, the same mark that was made below the periople for hoof growth could have been utilised to determine hoof wear, by measuring the distance from the mark down to the weight bearing surface of the claw (Tranter and Morris, 1992). It may be possible that once the hoof gets to a certain length it reaches a homeostasis where hoof growth equals hoof wear. For instance, a longer toe may promote greater wear, therefore hooves may be growing at similar rates, but wearing at different rates depending on how overgrown they are.

6.4. Future work

The research outlined in this thesis provides a fundamental starting point and offers a platform for much needed future work into the area of hoof health in dairy goats. The key area that warrants further work is to firstly determine lameness prevalence on New Zealand dairy goat farms. Secondly, causes of lameness in New Zealand dairy goats need to be determined. Thirdly, more research is needed to investigate the role of hoof trimming and alternative ways to promote good hoof health. Finally, I believe there is a common goal among researchers and farmers to minimise lameness. However, I suggest there needs to be awareness raised among farmers around the impacts of lameness, poor conformation and the importance of early detection.

6.4.1. Methods to estimate lameness prevalence

The 5-point scoring system presented in Chapter 3 may allow for trained observers to determine a more accurate lameness prevalence in New Zealand dairy goats. As seen in the results presented in the experimental study, lameness prevalence can change depending on the stage of lactation/gestation. Therefore, a snapshot prevalence would not accurately represent the lameness status of the industry, nor provide information regarding potential causes of lameness or allow identification of high-risk periods. I suggest that at least two gait scores on each farm would be required, one following kidding (at the start of lactation) and one towards the end of lactation.

Large herd sizes mean that gait scoring all animals may not be feasible. To reduce the time costs, sampling strategies for monitoring lameness prevalence in dairy cows have been investigated. For example, Main et al. (2010) developed a sampling strategy based on the order that cows exited the milking parlour, allowing for a calculated sample size of cows to provide an estimate of lameness prevalence within 5% of the true prevalence. The herd size of dairy goat farms in New Zealand range from 210 to 1800 goats (average 650 goats) (Stafford and Prosser, 2016), therefore, sampling strategies may need to be considered rather than gait scoring every animal. However, dairy goats are known to be difficult to gait score in an on-farm setting. The first step in determining an industry wide lameness prevalence should be to establish whether an uneven gait can be identified on farm. If standardised protocols cannot be developed to identify an uneven gait and thus use the 5-point system, other methods to detect potential precursors of clinical lameness on farm should be investigated.

Pressure plates have been used to monitor ground reaction forces exerted on each claw at the claw-floor interface at standing and in walk in dairy cows (Van der Tol et al., 2002). As a lame animal will try to reduce the weight on the affected limb, this is a successful automated method of lameness detection, with minimal human intervention (cows: Maertens et al., 2011). Gait analysis has also been completed in sheep using pressure plates (Agostinho et al., 2012), and in goats trained to walk over a pressure-sensing walkway (Rifkin et al., 2019), therefore demonstrating that this method can be used in smaller ruminants. However, it is essential the animal walks at a steady pace for accurate assessments of the weight bearing on each limb

(Maertens et al., 2011). Due to dairy goats often moving faster than a walk, I suggest that using pressure plates while standing may be more appropriate, with the potential for this to be completed while they stand in the milking parlour.

Monitoring behaviour by attaching wearable sensors to the animal is becoming increasingly used in farm management of dairy cows (Berckmans, 2006). However, there are few data investigating the use of sensors in dairy goat management. Accelerometers are non-invasive devices that are commonly attached to the animal's leg in order to monitor lying behaviour (Blackie et al., 2011). As lame animals lie longer than non-lame animals (Ito et al., 2010), accelerometers can be used to detect lameness. Leg mounted acccelerometers have been validated for use in dairy goats (Zobel et al., 2015), however, there are currently no data from them evaluating if lying beahviour is associated with lameness. Accelerometers attached to the leg require restraint of the animal and can result in an adjustment period of two days in dairy cows (MacKay et al., 2012). I therefore suggest alternative wearable devices should be investigated in dairy goats. Ear tags have been successfully used to detect lameness in sheep (Barwick et al., 2018) and pigs (Scheel et al., 2017), while a neck collar sensor has been used in cows (Van Hertem et al., 2013), this could therefore be an area of future research in dairy goats.

Infrared thermography (IRT) is a non-invasive, remote method of measuring an animal's surface temperature (Cook and Schaefer, 2013) and IRT has been used to detect lameness in dairy cows (Alsaaod et al., 2015) and sheep (Byrne et al., 2018). The body surface temperature is a function of blood flow and metabolism rate of the underlying tissues (Turner, 1991). Injured or diseased tissue have an altered circulation, therefore, measuring changes in surface temperature of the hoof can detect increased heat which may relate to inflammation and lameness (horses: Eddy et al., 2001), as claw lesions cause an increase in inflammation and therefore an increase in temperature of the affected limb (cows: Alsaaod and Büscher, 2012). The use of IRT to detect lameness in dairy goats should be investigated, however I question its on-farm applicability due to a controlled environment being required (Alsaaod et al., 2014).

6.4.2. Causes of lameness

Lameness is condition indicative of pain (Anil et al., 2002; Whay et al., 1997), with hoof lesions associated with approximately 90% of lameness in cattle (Murray et al., 1996). However, it is important to note that lesions do not always cause lameness (Logue et al., 1994). Indeed, Manske et al., (2002) found no association between the most prevalent hoof lesions (e.g. heel erosion, sole haemorrhage and dermatitis) and lameness on 101 Swedish dairy cows farms. However, the authors highlight that the environment in which gait was assessed was often suboptimal and the estimate of lameness prevalence may have been underestimated. Furthermore, pain is a complex and individualistic experience (Viñuela-Fernández et al., 2007) and therefore not all animals will react in the same way. There is research from the UK suggesting that bacterial claw lesions are a major risk factor of lameness in dairy goats (Groenevelt et al., 2015; Groenevelt, 2017), However, the aetiology of these lesions was not clear and the authors suggested lesions may have first developed as a white line lesion or sole ulcer, with the treponeme infections being secondary (Groenevelt et al., 2015). The major causes of lameness in New Zealand dairy goats need investigating. Future work should focus on the categorisation and aetiology of claw lesions in dairy goats, and the impact this has on the gait of the animal.

Poor conformation traits such as overgrown hooves and dipped heels increase the risk of claw lesions and lameness in dairy cows (Blowey, 1992) and goats (Ajuda et al., 2014, Ajuda et al., 2019). However, it should be noted that primary research to support this claim is lacking. The work in this thesis was based around the assumption that poor conformation would cause lameness in New Zealand dairy goats. However, in the experimental study (Chapter 5) high proportions of poor hoof conformation were reported, but low levels of clinical lameness (gait score ≥ 3) were observed. It is possible that the goats were able to adapt to some deviation from anatomically correct conformation without gait being acutely impacted. However, I caution that these data were collected on one commercial farm and are therefore not representative of the wider population of New Zealand dairy goat farms. Furthermore, although clinical lameness was lower than expected there were many goats scored as having an uneven gait (Chapters 3 and 5). Some of the possible reasons for this have been discussed previously in this chapter (e.g. hoof overgrowth, udder fill, early development of a claw lesion). Further work needs to be completed to determine the cause for the uneven gait and whether it develops into clinical lameness. Additionally, I suggest that the goats in the experimental study (Chapter 5) needed following past their second lactation to determine if chronic, long term poor conformation results in lameness as the goats get older. Indeed, Ajuda et al (2019) report an association between hoof overgrowth, poor conformation and lameness in dairy goats aged 2-5 years of age. Determining if lameness risk increases with age and prolonged poor conformation may help to establish trimming management and treatment protocols. The increase of lameness around kidding should also be considered, to determine if there are management practices that could be put in place during this potentially critical period.

6.4.3. Hoof trimming

Given the failure of common trimming practices to prevent poor hoof conformation in my studies, an investigation into how the provision of alternative flooring substrates promotes hoof wear in dairy goats is required. Less frequent trimming would reduce the potential negative impacts on the goat, and also reduce the economic costs to the farmers in terms of paying contractors and mitigating any drop in milk yield following trimming (cows: Pesenhofer et al., 2006).

To my knowledge there are no data investigating hoof trimming techniques in dairy goats. The main source of trimming information regarding hoof trimming in goats is from veterinary text books (e.g. Sheep and Goat Medicine: Pugh and Baird, 2002). However, it is unlikely that contractors and farm workers/managers will be exposed to this information. Indeed, in a recent survey of dairy cattle in the US, there was a lot of variation in the training contract trimmers were exposed to, with most (65%) stating they learnt from an apprenticeship, and 30% stating they learnt primarily through experience (Kleinhenz et al., 2014).

I suggest that standardisation of information is important in the hoof trimming of dairy goats. However, the appropriate standard can only be recommended once the efficacy of trimming techniques in dairy goats has been evaluated. This needs to include establishing an appropriate trimming frequency and determining the effectiveness of techniques used in terms of promoting good conformation and reducing lameness. In the experimental study completed on one farm (Chapter 5) trimming every 4 months was not frequent enough to prevent hoof overgrowth and poor conformation. Dairy goats hooves may need trimming as often as every 6-8 weeks depending on the housing environment (Pugh and Baird, 2002). I think it is also important to note that as bacterial lesions are prevalent in the UK, trimmers in New Zealand need to ensure equipment is disinfected between animals as a precaution of spreading bacterial disease (Sullivan et al., 2014).

6.4.4. Raising awareness

Finally, I believe a complimentary approach to reducing lameness in the dairy goat industry will be through increasing awareness among farmers. Farmers commonly underestimate lameness (cows: Whay et al., 2002; Espejo et al., 2006). While this may be due to difficulties in detecting subtle signs of lameness (Mill and Ward, 1994), it may also be due to a lack of understanding of the impact of lameness and the importance of identifying lameness as early as possible (Whay et al., 2002).

One way of increasing awareness among farmers is through workshops. Following a farmer workshop in Ontario Canada, 73% (n=19) of participants stated that the information provided had altered their views on lameness (Deeming et al., 2016). Whether this translates into altered practice remains to be evaluated.

Another way of promoting behaviour change among farmers is through benchmarking. This process measures aspects of farm performance, thus allowing producers to evaluate their current performance relative to others (von Keyserlingk et al., 2012) and can encourage farmers to make changes to management in an effort to improve performance (Atkinson et al., 2017; Sumner et al., 2018). Benchmarking could provide an opportunity to increase awareness and motivate change (if required) on New Zealand dairy goat farms.

6.5. Final conclusions

As lameness is one of the major welfare issues in the dairy industry, efforts need to be made to minimise its occurrence and to understand the factors contributing to it. The studies presented in this thesis have provided insights into the hoof conformation and gait of dairy goats and how these factors are impacted by hoof trimming. Hoof trimming was shown to have some short-term beneficial impacts on hoof conformation and joint positions. However, the trimming practices evaluated in these studies did not appear adequate to avoid poor conformation. Overall, the results of my thesis suggest that a multifaceted approach is required when considering hoof conformation and lameness in dairy goats. Hoof management strategies should consider the timing of first hoof trimming and subsequent trimming frequency, the trimming techniques used, as well as providing an environment that promotes hoof wear, good conformation and hoof health. The results of my research provide an essential starting point; however, there is still significant work required in the area of hoof conformation and lameness in dairy goats.

6.6. References

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Appendix One

R code used in the development of the hoof conformation assessment (Chapter 2)

```
# This is the user-interface definition of a Shiny web application. You can run the application
by clicking 'Run App' above.
# Find out more about building applications with Shiny here:
#     http://shiny.rstudio.com/
#library(shiny)

# Define UI for application that draws a histogram
shinyUI(fluidPage(

  # Application title
  titlePanel("Measuring photos"),

  # Sidebar with a slider input for number of bins
  sidebarLayout(
    sidebarPanel(
      # this will allow the tool to be increased to other applications. At the moment only goat
hoof is functional.
      radioButtons("type", "What type of measurements would you like to make?",
                   c("Animal hoofs" = "hoof",
                    # "Meat Curvature" = "curve",
                    # "Drone images" = "drone",
                     "Other" = "other"  )  ),

      # we then have a bow to allow the user to upload as many images as they would like.
      h3("Upload the photos you would like to measure"),
      fileInput('Photolist', 'Choose Photo Files',
                accept= "image/*", multiple = TRUE),

# The following is for measurement type = hoof.
      conditionalPanel(
        condition = "input.type == 'hoof'",
        uiOutput("radio"),
        # entering the meta data
        h4("Enter the meta data for the selected photo"),

        uiOutput('resetable_input'),
        tags$hr(),

        # enter the measurements
        uiOutput('resetable_input_side'),

        # save and download buttons
        actionButton("save", "Save data"),
        downloadButton("downloadData", "Download")  )   ),

    # Show a plot and the table of data.
    mainPanel(
      plotOutput('Plot',
                 click = "plot_click"),
      dataTableOutput("points"),
```

```
    textOutput("distance"),
    textOutput("ratio"),
    tableOutput("table")
    )
  )
))



# This is the server logic of a Shiny web application. You can run the application by clicking
'Run App' above.
# Find out more about building applications with Shiny here:
#    http://shiny.rstudio.com/

library(shiny)
library(tcltk2)
library(jpeg)
library(zoo)

# Define server logic required to draw a histogram
shinyServer(function(input, output) {

  # setting up the name of the file you selected
  file_name <- reactive({
    inFile <- input$Photolist
    if (is.null(inFile))
      return(NULL)

    return (stringi::stri_extract_first(str = inFile$name, regex = ".*(?=\\.)"))
  })

  #Providing the file path
  file_location <- reactive({
    inFile <- input$Photolist
    if (is.null(inFile))
      return(NULL)
    return (inFile$datapath )
  })

  # a button that can be used to select the photo you want to measure. all files uploaded will
appear in the list.
  output$radio <- reactiveUI(function() {

    radioButtons("This_File", "Choose a photo to measure",
                 choiceNames = c("None", file_name()),
                 choiceValues = c("NA", file_location()))
  })

  output$myFilePath <- renderText({ input$This_File })
```

```
 # show the photo in the plot plane.
 output$Plot <- renderPlot({
  img <- readJPEG(input$This_File)
  op <- par(mar=c(0,0,0,0))
  on.exit(par(op))
  plot.new()
  plot <- rasterImage(img,0,0,1,1)
  return(plot)
  #}
 })

 #entering meta data on your photo, such as photo id, front or hind legs and view from front
or side.
 output$resetable_input <- renderUI({
  times <- input$save
  div(id=letters[(times %% length(letters)) + 1],
  textInput("ID", "Photo ID"),
  textInput("leg", "Leg information",placeholder = "e.g. hind, front, left, right"),
   radioButtons("view", "View",
         c("Front" = "front",
          "Side" = "side",
          "Other" = "other"))
  )
 })
# set up input values for hoof
  output$resetable_input_side <- renderUI({
   times <- input$save
   # setting up the scale calibration
    div(id=letters[(times %% length(letters)) + 1],
    numericInput('width', 'Enter width of the scale bar',0),
    numericInput('hight', 'Enter height of the scale bar',0),
    actionButton("plotpoints", label = "Click on horizontal and vertical scale bars and then
click here once complete"),

    # setting up the field to enter the scores for the side view.
    if(input$view == 'side') {
     list(
      textInput('growth', 'Growth Score', placeholder = "0,1,2,unknown (u)"),
      textInput('heel', 'Heel Score', placeholder = "0,1,2,unknown (u)" ),
      textInput('Fetlock', 'Fetlock integrity', placeholder = '0,1,unknown (u)'),
      textAreaInput('comments',  'Comments', rows = 2, cols = 80),
      actionButton("measureratio", "Click three points you wich to measure the ratio of two
distance on plot then click here once complete")
     )
    },

    # setting up the field to enter the scores for the front view
    if(input$view == 'front'){
     list(
```

```
        textInput('shape', 'Shape Score (measure distance of splay only if shape = 0)',
placeholder = "0,1,2,unknown (u)"),
        textInput('splay', 'Visual score of splay', placeholder = "0,1,2,unknown (u)" ),
        textAreaInput('comments', 'Comments', rows = 2, cols = 80),
        actionButton("measuredist", "Click splay distance on plot then click here once
complete")
      )
    }
  )
})

## start recording clicks
xy_new <- reactiveValues(x= numeric(0), y = numeric(0), line=numeric(0)) # add new points

 # Listen for clicks and store values
 observe({
  if (is.null(input$plot_click)){
   return()
  }

  isolate({
   xy_new$x <- c(xy_new$x, input$plot_click$x)
   xy_new$y <- c(xy_new$y, input$plot_click$y)
  })
 })

 pointsforplot <- eventReactive(input$plotpoints, ignoreNULL = F, {
  data.points = as.data.frame(xy_str(xy_new))
  x = xy_new$x
  y = xy_new$y
  data.points = data.frame(x,y)
  #as.data.frame(x = xy_new$x, y = xy_new$y)
 })

 output$points <- renderDataTable({ pointsforplot() })

  # preforming the calibration and measuring the distance between the two clicks when on
the front view.
 distanceSpray <- eventReactive(input$measuredist, ignoreNULL = T, {
  cal = pointsforplot()
  nrows = dim(pointsforplot())[1]
  x = xy_new$x
  y = xy_new$y
  data.distance = data.frame(x,y)
  yrows = dim(data.distance)[1]
  data.points = data.distance[(nrows+1):yrows,]
  x1   <- 0
  x2   <- 0 + input$width
  y1   <- 0
  y2   <- 0 + input$hight
```

```
    x     <- cal$x[c(1,2)]
    y     <- cal$y[c(3,4)]
    cx <- lm(formula = c(x1,x2) ~ c(x))$coeff
    cy <- lm(formula = c(y1,y2) ~ c(y))$coeff

    data.points$x <- data.points$x*cx[2]+cx[1]
    data.points$y <- data.points$y*cy[2]+cy[1]

    data.points <- data.points[order(data.points$x),]
    nrow(data.points)
    if(nrow(data.points) == 2){
      distance = sqrt((data.points$x[2]- data.points$x[1])^2 +
                     (data.points$y[2]- data.points$y[1])^2)
    }else distance = NA

    distance
  })

  output$distance <- renderText({ distanceSpray() })

# preforming the calibration and measuring the ratio of splay when side view.
  ratioSpray <- eventReactive(input$measureratio, ignoreNULL = T, {
    cal = pointsforplot()
    nrows = dim(pointsforplot())[1]
    x = xy_new$x
    y = xy_new$y
    data.distance = data.frame(x,y)
    yrows = dim(data.distance)[1]
    data.points = data.distance[(nrows+1):yrows,]
    x1    <- 0
    x2    <- 0 + input$width
    y1    <- 0
    y2    <- 0 + input$hight
    x     <- cal$x[c(1,2)]
    y     <- cal$y[c(3,4)]
    cx <- lm(formula = c(x1,x2) ~ c(x))$coeff
    cy <- lm(formula = c(y1,y2) ~ c(y))$coeff

    data.points$x <- data.points$x*cx[2]+cx[1]
    data.points$y <- data.points$y*cy[2]+cy[1]

    data.points <- data.points[order(data.points$x),]
    n <- nrow(data.points)
    if(n == 3){
      ratio = sqrt((data.points$x[2]- data.points$x[1])^2 + (data.points$y[2]-
data.points$y[1])^2)/
        sqrt((data.points$x[2]- data.points$x[3])^2 + (data.points$y[2]- data.points$y[3])^2)
    }else ratio = NA

    ratio
```

```
})

output$ratio <- renderText({ ratioSpray() })

 # creating a vector with all the information
resultsData <- data.frame(
  PhotoName = NA,
  PhotoID = NA,
  LegInfo = NA,
  Veiw = NA,
  Width = NA,
  Height = NA,
  Shape = NA,
  Splay = NA,
  distance = NA,
  Growth = NA,
  Heel = NA,
  Fetlock.integrity = NA,
  ratio = NA,
  Comments=NA)

# saving the data into a data frame
savedata <- reactive({
  results <- data.frame(
    PhotoName = NA,
    PhotoID = NA,
    LegInfo = NA,
    Veiw = NA,
    Width = NA,
    Height = NA,
    Shape = NA,
    Splay = NA,
    distance = NA,
    Growth = NA,
    Heel = NA,
    Fetlock.integrity = NA,
    ratio = NA,
    Comments=NA)
  if(input$view == 'front'){
  results <- data.frame(
    PhotoName = input$This_File,
    PhotoID = input$ID,
    LegInfo = input$leg,
    Veiw = input$view,
    Width = input$width,
    Height = input$hight,
    Shape = input$shape,
    Splay = input$splay,
    distance = distanceSpray(),
    Growth = NA,
```

```
      Heel = NA,
      Fetlock.integrity = NA,
      ratio = NA,
      Comments=input$comments)
    }
    if(input$view == 'side'){
      results <- data.frame(
        PhotoName = input$This_File,
        PhotoID = input$ID,
        LegInfo = input$leg,
        Veiw = input$view,
        Width = input$width,
        Height = input$hight,
        Shape = NA,
        Splay = NA,
        distance = NA,
        Growth = input$growth,
        Heel = input$heel,
        Fetlock.integrity = input$Fetlock,
        ratio = ratioSpray(),
        Comments=input$comments)
    }
    results
  })

  # a button to save the inputs, before moving onto the next photo
    observeEvent(input$save, {
      resultsData <<- rbind(resultsData, savedata())
      output$table <- renderTable(resultsData)
      xy_new$x <- NULL
      xy_new$y <- NULL
      })

    # downloading the data into an .csv file.
    output$downloadData <- downloadHandler(

      # Create the download file name
      filename = function() {
        paste("data-", Sys.Date(), ".csv", sep="")
      },
      content = function(file) {
        write.csv(resultsData, file)                    # put Data() into the download file
      })
       })

### Functions
xy_str <- function(e) {
  if(is.null(e)) return("NULL\n")
  paste0("x=", round(e$x, 2), " y=", round(e$y, 2), "\n")
}
```

Appendix Two

Conference abstracts

The effect of earlier and more frequent hoof trimming on hoof conformation of dairy goats

Deeming LE, Beausoleil NJ, Stafford KJ, Webster JR, Zobel G

Presented at Universities Federation of Animal Welfare. Hong Kong. 25th-26th October 2018.

Regular hoof trimming is important for hoof health and conformation in dairy ruminants. Hoof growth due to a lack of trimming may adversely impact hoof conformation. Nonetheless, it is common farm practice on New Zealand dairy goat farms to start hoof trimming after first kidding (12-13 months of age) which may be too late to prevent detrimental changes to hoof conformation. Therefore, the aims of this trial were to determine: 1) if earlier and more frequent trimming impacts hoof conformation 2) if hoof conformation is altered by the trimming process. Sixteen Saanen X goat kids were enrolled after weaning (5-6 months of age) on a commercial farm. They were randomly assigned to one of two hoof trimming regimes: A) first trimming at 5 months of age, then trimmed at 9 and 13 months, B) first trimming at 13 months of age. Each of the goats had radiographs taken immediately before and one day after trimming at 13 months of age. Radiographs were taken of the left front and left hind distal limb in a lateromedial direction and analysed using eFilm 3.3.0 software. The following parameters were determined: 1) the angle of deviation of the third phalanx (P3) from a vertical 180^o reference point, 2) the height (cm) of P2/P3 joint (JH3). There was no difference between the two trimming regimes in P3 angle or JH3 height evaluated at 13 months of age, however these parameters were altered by the process of trimming. In both groups the angle of P3 decreased after trimming for the front ($F_{1,14} = 87.88$, $P < 0.001$) and hind hooves ($F_{1,14} = 63.92$, $P < 0.001$). Similarly, the height of JH3 decreased after trimming for the front ($F_{1,14} = 6.50$, $P < 0.05$) and hind hooves ($F_{1,14} = 24.02$, $P< 0.001$). No effects of the earlier, more frequent trimming regime were found compared to common farm practice. The effects of trimming on hoof conformation found in this study, highlight the importance of hoof trimming. The removal of overgrown horn decreased the deviation of P3 and the height of JH3, which may decrease the risk of injury and lameness. The data presented are a subset of goats

from an ongoing trial, this study will continue in order to determine the longer-term impacts of delayed trimming in dairy goats.

Can a workshop alter dairy goat farmers' views on lameness?

Laura Deeming, Ngaio Beausoleil, Kevin Stafford, Jim Webster, Gosia Zobel

Presented at International Society for Applied Ethology Regional Conference. Auckland. October 27th 2016.

Lameness, a painful condition that impedes normal walking, is one of the most serious welfare issues faced by dairy animals. In dairy goats, knowledge about risk factors and identification of lameness is particularly limited, and therefore farmers may underestimate lameness prevalence on their farms. The aim of this study was to determine if farmer views towards lameness in dairy goats changed following a workshop. The workshop involved participants (n=26, Ontario, Canada dairy goat farmers) completing a questionnaire prior to a presentation and facilitated discussion about the impacts of lameness on welfare and production. Questions included whether they perceived lameness to be an issue on their farm, their hoof trimming regime and their opinion on the main cause of lameness. Following the facilitated discussion participants were asked to share ideas and allocate them to one of four themes: 1) not an issue (do nothing), 2) not an issue (educate the public), 3) issue (educate farmers), or 4) issue (do more research). Finally, farmers were asked to reflect upon how their opinion regarding lameness had changed. Prior to the workshop, 50% of the farmers (n=13) indicated that lameness was not an issue on their farm, while 46% (n=12) responded that there were mild or occasional lameness issues. The primary cause of lameness was thought to be infrequent hoof trimming. Following the workshop 73% (n=19) of participants stated that the information provided had altered their views on lameness, 15% (n=4) stated that their opinion had not changed, the remaining 12% (n=3) did not respond. Most farmers thought more research was needed regarding trimming regimes and hoof care, and more farmer education is required. These results suggest that workshops can be successful in educating farmers about the impacts of lameness and in turn can alter farmer views on this serious welfare issue.

Appendix Three

Survival of replacement kids from birth to mating on commercial dairy goat farms in New Zealand

Authors note: Appendix three is a publication completed in parallel with the research work in this thesis. It is presented in the style of the Journal of Dairy Science where it has been published.

Todd CG, Bruce B, **Deeming LE**, Zobel, G. 2019. Short communication: Survival of replacement kids from birth to mating on commercial dairy goat farms in New Zealand. Journal of Dairy Science 10, 9382-9388.

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Short communication: Survival of replacement kids from birth to mating on commercial dairy goat farms in New Zealand

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ABSTRACT

Commercial dairy goat systems rely on the successful rearing of kids for herd replacement. The objectives of this study were to (1) determine survival from birth until mating for a large cohort of commercial dairy goat kids; (2) descriptively summarize the causes of mortality and removal from the herd during this period; and (3) compare actual (determined by postmortem examination) and suspected (farmer-reported) causes of mortality. A total of 1,262 female kids were enrolled at birth on 16 commercial dairy goat farms in New Zealand. Median ages at weaning and mating were 86 d [minimum = 54, quartile (Q)1 = 78, Q3 = 97, maximum = 144] and 223 d (minimum = 183, Q1 = 208, Q3 = 237, maximum = 310), respectively. Overall, 87.1% (1,099/1,262) of kids remained on farm at mating, 10.4% (131/1,262) died or were euthanized, and 2.5% (32/1,262) were lost to follow-up or sold. Mortality risk was greatest in early life, with more than 90% of deaths occurring before weaning. Mortality from enrollment to mating varied between farms (minimum = 0%, Q1 = 5.9%, median = 8.9%, Q3 = 15.8%, maximum = 20.5%). The leading cause of death was gastrointestinal disorders (33.6%, 36/107), followed by disbudding-related injury (15.9%, 17/107), and septicemia (12.1%, 13/107). Farmers correctly identified approximately half of the deaths attributed to gastrointestinal disorders (56.0%, 14/25) and disbudding-related injury (44.4%, 4/9), but were less successful at diagnosing septicemia (0%, 0/5), starvation or dehydration (0%, 0/4), and suffocation (18.8% 3/16). This is the largest cohort of dairy goat kids to be systematically followed over time to confirm survival until mating and to determine causes of death by postmortem examination. We found that kid mortality was highest during the preweaning period and there was often a discrepancy between farmer-perceived and actual cause of death. Postmortem examinations should be more widely used to establish causes of death and inform on-farm strategies to reduce kid mortality.

Key words: caprine, mortality, gastrointestinal disorders, disbudding, septicemia

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Short Communication

Replacement kids that die or are removed from the herd before they begin lactating represent an economic loss to the farm and industry. Mortality is also an important farm-level indicator of animal welfare (Ortiz-Pelaez et al., 2008; de Vries et al., 2011). Dairy goat farmers in the United States estimated that 13.3% of all kids born during 2015 died during the same calendar year (USDA, 2017); these data do not distinguish between stillbirth and mortality in kids born alive. In New Zealand, more than half of goat carcasses submitted to an animal health laboratory for postmortem examination were of animals younger than 6 mo of age (Buddle et al., 1988). Gautam (2012) summarized removal records from 38 commercial dairy goat farms in New Zealand and reported that within the first year of life, on any given day, more than 6 goats were removed because of death, culling, or sale.

Causes of mortality and other reasons for removal from the herd have not been well documented in dairy goat kids. Miscellaneous disorders, such as bloat, gastrointestinal issues, cancer, and other non-infectious causes, were cited by dairy goat farmers in New Zealand as the main removal reasons, but these data were not stratified by age category, so kid and adult removals were summarized together (Gautam, 2012). Goat farmers in the United States identified internal parasites and weather-related problems as the leading causes of kid mortality, yet they were unable to determine a suspected cause of death in almost 30% of cases (USDA, 2017). That survey did not stratify by use type and thus included causes of mortality from all farm systems (i.e., milk, meat, and fiber production).

Postmortem examination is an important diagnostic tool for establishing cause of death or resolving unclear cases (McConnel et al., 2009; Thomsen et al., 2012; Wäsle et al., 2017). In extensively managed goat herds, postmortem examinations have indicated that mis-mothering, hypothermia, white muscle disease, and enteritis are key causes of kid death (Buddle et al., 1988; Ramírez-Bribiesca et al., 2001). Although those authors did not compare their findings with farmer reports, research in other species has demonstrated potential discrepancies between postmortem diagnoses and farmer-suspected causes of death (McConnel et al., 2009; Thomsen et al., 2012). The objectives of this study were to (1) determine survival from birth until mating for a large cohort of commercial dairy goat kids, (2) descriptively summarize the causes of mortality and removal from the herd during this period, and (3) compare actual (determined by postmortem examination) and suspected (farmer-reported) causes of mortality.

All study procedures were approved by the AgResearch Limited Human (#6/2015) and Animal Ethics Committees (#13478). Sixteen commercial dairy goat farmers from the Waikato region of New Zealand volunteered to participate. Selection was based on farmer willingness to participate, and no prescreening of farm management occurred. The Waikato region contains 72% of New Zealand's dairy goat farms (Scholtens et al., 2017); these farms are predominantly members of the Dairy Goat Cooperative. The enrolled farms represented 22% of all Cooperative farms. Lactating herd size [minimum = 343; quartile (Q)1 = 572, median = 636, Q3 = 849, maximum = 1,539] and mean milk production (test-day total milk, kg/doe: minimum = 2.9, Q1 = 3.3, median = 3.6, Q3 = 3.9, maximum = 4.5; milk fat, %: minimum = 3.2, Q1 = 3.5, median = 3.6, Q3 = 3.7, maximum = 4.0; protein, %: minimum = 2.9, Q1 = 3.0, median = 3.1, Q3 = 3.2, maximum = 3.3) for each enrolled farm were estimated using 2017 herd test data (Livestock Improvement Corporation, Hamilton, New Zealand). Herd test data were not available for 3 farms. Farmers reported that they intended to rear between 90 and 500 replacement kids (Q1 = 175, median = 250, Q3 = 300) during 2015. To minimize the likelihood of selection bias (e.g., farmers enrolling only their healthiest animals), kids were enrolled immediately after birth. A total of 1,262 female kids were enrolled between May 26 and September 5, 2015, which coincided with the typical winter kidding season in New Zealand (Scholtens et al., 2017). The majority of kids were born in July (63.5%, 802/1,262), followed by June (21.9%, 276/1,262), August (7.8%, 99/1,262), May (6.2%, 78/1,262), and September (0.6%, 7/1,262). The median number of enrolled kids per farm was 80 (minimum = 70, Q1 = 79, Q3 = 80, maximum = 83), and median age at enrollment was 1 d of age (minimum = 1, Q1 = 1, Q3 = 2, maximum = 8). Two additional kids were enrolled and subsequently excluded from all analyses when confirmed to be male. To track individual kids over time, the farm identifier for each kid was printed on a yellow cow ear tag (Maxi Tag, Allflex NZ Ltd., Palmerston North, New Zealand) and attached to their orange collar. All kids were also assigned with a unique identification number for the study.

Kids were cared for according to standard farm protocols; no experimental treatments or interventions were applied by the research team. After removal from the dam (immediately on 4 farms, up to 24 h on 11 farms, after 24 h on 1 farm), colostrum was fed (heat-treated goat colostrum on 2 farms, untreated goat colostrum on 5 farms, untreated cow colostrum on 5 farms, bovine-based replacer on 2 farms, and no additional colostrum on 2 farms where kids remained with the dam for 24 h or longer). Kids were housed in all-female group pens (enrolled kids mixed with nonenrolled kids) and had access to ad libitum whole cow milk (on 2 farms) or milk powder (whole milk on 8 farms; whey-based on 6 farms) for at least part of the preweaning period. Kids were disbudded within the first few weeks of life, using cautery methods (15 farms) or caustic paste (1 farm). A nonsteroidal anti-inflammatory drug (NSAID) was administered following cautery disbudding on 1 farm. Decision criteria for weaning were BW (11 farms), age (2 farms), or a combination of BW and age (3 farms). Minimum target age for weaning varied from 8 to 10 wk. Farmers favoring BW for weaning decisions reported a minimum weight of 15 kg; however, only 2 farmers routinely weighed their kids. All farms used natural mating and farmers aimed to introduce bucks between 7 and 8 mo. of age.

Farmers were responsible for daily kid care, detecting and administering treatment for illness, and documenting dates and reasons for removal from the herd. Removal reasons included death, euthanasia, lost to follow-up (e.g., due to an identification issue, movement off-site, or inability to determine whereabouts of kid), or sold. If the farmer did not provide a removal date for a kid that was no longer in the herd, removal date was assigned as 1 d after the last confirmed presence on the farm. Confirmation was based on health treatment records or weighing records collected by the research team during routine farm visits. Farmers were asked to submit dead kids for postmortem examination; when possible, the farmer also provided a clinical history and the suspected cause of death. If the postmortem examination could be performed within 2 d of death, the carcass was refrigerated at 4°C; otherwise, it was frozen at −20°C and thawed for 1 d before the examination. A systematic inspection of all thoracic and abdominal organs, tissues, joints, umbilicus, skull, and brain was completed by a veterinarian. Cause of death was determined based on any gross pathological lesions or abnormal findings observed. Histopathology was not performed. Sudden death and no obvious cause of death on gross examination were classified as suspected Clostridial infection; diagnostic laboratory testing was not completed to confirm the diagnosis.

Data were analyzed using SAS 9.4 (SAS Institute Inc., Cary, NC), with goat kid as the unit of interest. A Kaplan-Meier curve was constructed to display cumulative survival to mating (PROC LIFETEST). Kids that were removed from the herd before mating because of death, euthanasia, or other reason (e.g., lost to follow-up or sold) were treated as censored observations. Descriptive statistics were generated for age at enrollment, censoring, weaning, and mating (PROC UNIVARIATE). Survival, causes of death and reasons for removal from the herd were summarized across 3 periods: (1) enrollment to 14 d of age, (2) 15 d to weaning, and (3) weaning to mating (PROC FREQ). Survival and removals from the herd were summarized by farm. A contingency table (PROC FREQ) was used to compare postmortem-determined and suspected causes of death.

This study followed a large cohort of dairy goat kids under commercial conditions, across multiple farms, to establish survival until mating (Figure 1). A total of 163 kids were removed from their respective herds by mating. Median age at censoring was 30 d (minimum = 2, Q1 = 7, Q3 = 55, maximum = 198). At 14 d of age, 95.1% (1,200/1,262) of the enrolled kids remained on farm; of the 62 kids that were removed, 40 died, 12 were euthanized, 6 were lost to follow-up, and 4 were sold. At weaning, 89.2% (1,126/1,262) of the enrolled kids remained on farm. Of the additional 74 kids removed after 14 d of age, 50 died, 17 were euthanized, and 7 were lost to follow-up. Median age at weaning (n = 1,019 kids) was 86 d (minimum = 54, Q1 = 78, Q3 = 97, maximum = 144). Farmers did not provide weaning dates for 107 kids; however, these kids were confirmed alive at a follow-up visit by the research team. At mating, 87.1% (1,099/1,262) enrolled goats remained on farm. Of the 27 goats removed between weaning and mating, 12 died and 15 were lost to follow-up. Median age (n = 1,071) at mating was 223 d (minimum = 183, Q1 = 208, Q3 = 237, maximum = 310). Farmers did not provide mating dates for 28 goats but these goats were confirmed alive at a follow-up visit.

Overall, 10.4% (131/1,262) of the enrolled kids died or were euthanized between enrollment and mating. All kids had to be alive at enrollment so this estimate does not include stillbirths. Mortality risk in this cohort of dairy goat kids was greatest during the preweaning period (i.e., greater than 90% of deaths), which confirms that this is a high-risk period for mortality in goat

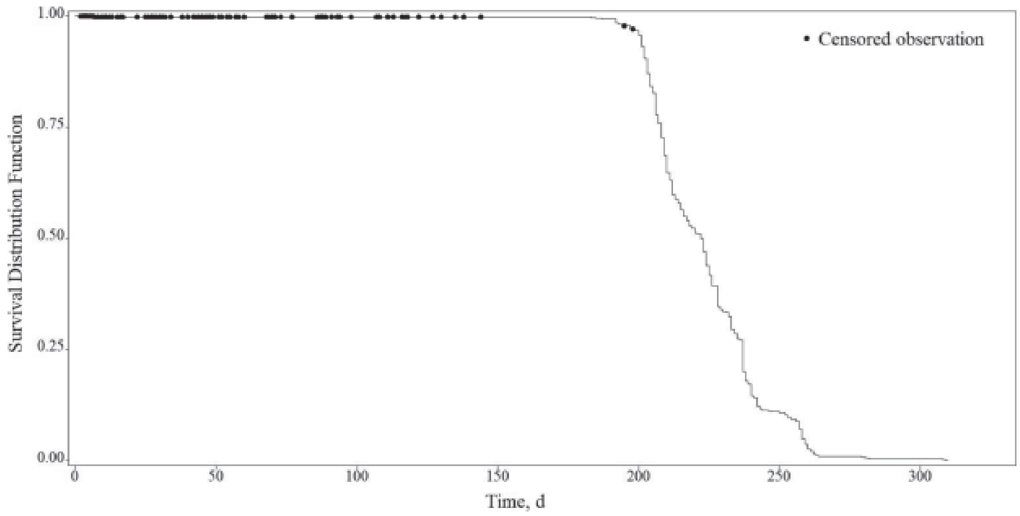

Figure 1. Kaplan-Meier curve for survival from enrollment to mating for 1,262 dairy goat kids on 16 commercial farms. The survival function begins at 1.0, decreases with every kid that was mated, and ultimately reaches 0.0 after all kids had been mated or censored. Censored observations include any kid that died, was euthanized, or was removed from the herd for another reason (e.g., lost to follow-up or sold). Median age at weaning was 86 d [minimum = 54, quartile (Q)1 = 78, Q3 = 97, maximum = 144]. Median age at mating was 223 d (minimum = 183, Q1 = 208, Q3 = 237, maximum = 310). Median age at censoring was 30 d (minimum = 2, Q1 = 7, Q3 = 55, maximum = 198).

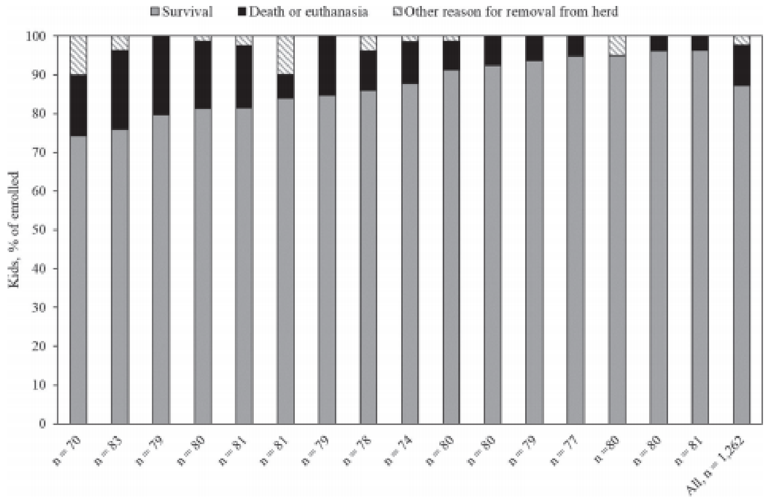

Figure 2. Farm-level distribution of survival, mortality (death or euthanasia), and other reasons for removal from herd (e.g., lost to follow-up or sold) from enrollment to mating, for 1,262 dairy goat kids on 16 commercial farms, with farms ordered from lowest to highest survival.

kids (Perez-Razo et al., 1998; Turkson, 2003; Snyman, 2010). Goat kid mortality can exceed 40% in tropical and subtropical areas, where kids are mainly reared under extensive or semi-extensive conditions (Husain et al., 1995; Awemu et al., 1999; Ameh et al., 2000; Snyman, 2010). Farmers in the United States estimated that 10% of kids born alive on milk-producing farms died before weaning (USDA, 2010). Kids enrolled in the present study were generally from larger herds than those in North America, but management would be relatively similar (e.g., born indoors, reared separately from the dam, fed whole milk or milk replacer; USDA, 2010; Bauman et al., 2016).

Mortality varied by farm (minimum = 0%, Q1 = 5.9%, median = 8.9%, Q3 = 15.8%, maximum = 20.5%). More than 20% of enrolled kids on 2 farms died or were euthanized between enrollment and mating, whereas no deaths were recorded on another farm (Figure 2). Large between-farm variation in mortality has also been reported in Angora goat kids (Snyman, 2010). Specific animal, environmental, and management factors (e.g., birth weight, colostrum ingestion, sex, twin/triplet status, time spent with the dam, housing, preventive health treatments, or season) can influence kid mortality risk (e.g., Gebrelul et al., 1994; Husain et al., 1995; Awemu et al., 1999; Massimini et al., 2007). Further research should investigate associations between management practices, environmental factors, and farm-level mortality. Future research to evaluate risk factors for mortality is planned.

Of the 131 kids that died or were euthanized, 107 were submitted for postmortem examination (Table 1). Overall, the leading causes of mortality were gastrointestinal disorders (33.6%, 36/107), including bloat, ruptured abomasum, intestinal torsion, and enteritis, followed by disbudding-related injury (15.9%, 17/107) and septicemia (12.1%, 13/107). Of the deaths that occurred during the first 14 d of life, 18.6% (8/43) and 14.0% (6/43) were due to septicemia and starvation or dehydration, respectively. Of the deaths that occurred after 14 d of age, 42.2% (27/64) and 18.8% (12/64) were attributed to gastrointestinal disorders and disbudding-related injury, respectively.

Although gastrointestinal disorders are a significant cause of mortality in young ruminants (e.g., Vatn et al., 2000; Urie et al., 2018), we had not expected that abomasal rupture or intestinal torsion would result in 1 of every 4 deaths (26.2%, 28/107). The exact pathogeneses of these conditions are not fully understood (Marshall, 2009; Pugh and Baird, 2012; Burgstaller et al., 2017), but associations with farm-specific feeding management are likely. Deaths due to abomasal rupture were generally the result of bloat; only 1 case of perforated abomasal ulcer was recorded. More than two-thirds of the farms (68.8%, 11/16) had at least one gastrointestinal disorder death. Interestingly, half of all deaths due

Table 1. Causes of mortality as determined by postmortem examination for 107 dairy goat kids that died or were euthanized between enrollment and mating on 16 commercial farms

Primary cause[1]	Birth to 14 d, no.	15 d to weaning,[2] no.	Weaning to mating,[3] no.	Total, no.
Ruptured abomasum	3	14	1	18
Disbudding-related injury	5	12	—	17
Septicemia	8	5	—	13
Intestinal torsion	2	7	1	10
Pneumonia	2	5	2	9
Suspected *Clostridia* infection	1	6	1	8
Starvation or dehydration	6	—	—	6
Suffocation[4]	5	—	—	5
Enteritis	2	3	—	5
Bloat	2	—	1	3
Joint ill	1	1	—	2
Brain hemorrhage	2	—	—	2
Congenital deformity	1	1	—	2
Injury	—	1	—	1
Unknown[5]	3	3	—	6
Total[6]	43	58	6	107

[1]Causes of mortality are reported in order of total frequency, with ruptured abomasum being the most frequent and injury being the least frequent.

[2]Median age at weaning was 86 d (minimum = 54, quartile 1 = 78, quartile 3 = 97, maximum = 144).

[3]Median age at mating was 223 d (minimum = 183, quartile 1 = 208, quartile 3 = 237, maximum = 310).

[4]Referred to as "smothered" by farmers.

[5]No cause of death was determined during postmortem examination.

[6]A total of 131 kids died; however, 24 kids were not submitted for postmortem examination.

to gastrointestinal disorder occurred on just 2 farms. Of those kids that died of gastrointestinal disorders, 66.7% (24/36) were fed using automated milk feeders and 33.3% (12/36) were fed from large drums with multiple teats. Overall, 55.7% (703/1,262) and 44.3% (559/1,262) of enrolled kids were reared on automated and drum-based feeders, respectively. Whole milk powder was fed to 72.2% (26/36) of kids that died of gastrointestinal disorders, whereas whey-based powder (19.4%, 7/36) or whole cow milk (8.3%, 3/36) was fed to the other kids. Overall, whole milk powder, whey-based powder, and whole cow milk were fed to 50.2% (634/1,262), 37.0% (467/1,262), and 12.8% (161/1,262) of enrolled kids, respectively. We encourage future work to focus on farm-specific feeding practices (e.g., milk preparation routine, cleaning procedures, feeder competition, individual intake), paired with laboratory testing for pathogen identification (Vaatstra, 2018).

Disbudding causes considerable tissue damage and inflammation (Thompson et al., 2005; Hempstead et al., 2018b), and wounds can take months to heal and re-epithelialize (Adcock and Tucker, 2018; Hempstead et al., 2018a). Cautery disbudding in goat kids, when performed incorrectly, can cause thermal injury to the skull and brain (Sanford, 1989; Thompson et al., 2005; Dennler et al., 2014; Hempstead et al., 2018b). Compared with calves, goat kids are at increased risk of thermal injury because their frontal bone is relatively thin, horn buds are larger, and the frontal sinus is undeveloped (Thompson et al., 2005; Molaei et al., 2015). Postmortem examination identified several lesions consistent with disbudding injury, including inflammation and purulent discharge beneath the horn bud site, discoloration on the inner surface of the skull, reddened meninges, and meningitis. Age at death for kids that died of disbudding-related injury ranged from 2 to 57 d (Q1 = 13, median = 28, Q3 = 38). Six kids showed signs of other conditions (e.g., pneumonia, scouring) at postmortem examination; however, presence of meningitis, infection below the horn buds, burns on the underside of the skull, or brain discoloration was determined to be primary cause of death. More than half of the participating farms (56.3%, 9/16) had at least one death attributed to disbudding-related injury. Of the kids that died of disbudding-related injury, 47.1%, (8/17) were on farms where disbudding was performed by farm staff; the other kids were disbudded by the herd veterinarian (29.4%, 5/17) or a contractor (23.5%, 4/17). Collectively, this demonstrates that, regardless of operator experience, implementation of appropriate care and correct disbudding procedure is vital.

Farmers provided a suspected cause of death for 54 of the submitted carcasses (Figure 3). Suspected causes suggested that the majority of the kids died of gastrointestinal disorders (31.5%, 17/54), suffocation by smothering (29.6%, 16/54), pneumonia (11.1%, 6/54), or disbudding-related injury (9.3%, 5/54). Overall, there was a lack of agreement between actual and sus-

Farmer suspected \ Postmortem examination	Gastrointestinal disorder	Disbudding-related injury	Septicemia	Pneumonia	Starvation or dehydration	Suffocation	Other
Gastrointestinal disorder	**14**	1	2	-	-	-	-
Disbudding-related injury	1	**4**	-	-	-	-	-
Septicemia	-	-	**-**	-	-	-	-
Pneumonia	-	1	1	**4**	-	-	-
Starvation or dehydration	-	-	-	-	**-**	-	2
Suffocation	7	-	1	-	4	**3**	1
Other	3	3	1	-	-	-	**1**

Figure 3. Causes of mortality for 54 dairy goat kids that died or were euthanized between enrollment and mating presented as a comparison between postmortem examination–determined causes and farmer-suspected causes. Shaded cells display the number of suspected causes of death provided by farmers that were subsequently confirmed by postmortem examination. "Gastrointestinal disorder" includes deaths due to bloat, ruptured abomasum, intestinal torsion, and enteritis. "Other" includes deaths due to suspected *Clostridia* infection, brain hemorrhage, congenital deformity, injury, lameness, mineral deficiency, neurological problem, and unknown causes.

pected causes of mortality, with 48.1% (26/54) of the farmer-suspected causes being confirmed by postmortem examination. None of the deaths due to septicemia (0%, 0/5) or starvation or dehydration (0%, 0/4) were correctly identified by farmers. Approximately half of the deaths that were attributed to gastrointestinal disorders (56.0%, 14/25) and disbudding-related injury (44.4%, 4/9) were successfully identified by farmers. In addition, farmers indicated that 16 kids died from suffocation; however, postmortem examination confirmed that only 18.8% (3/16) of these kids suffocated, whereas the others died of underlying issues, such as gastrointestinal disorders, septicemia, and starvation or dehydration. This highlights the benefit of submitting dead kids for postmortem examination; accurately determining cause of death will allow for appropriate intervention strategies to be initiated to reduce kid mortality.

Previous research on mortality in goat kids has focused on the collection of surveillance or cross-sectional data. Although these approaches are useful, they rely on voluntary submissions of carcasses for postmortem examination or the results reflect mortality at a point in time. One of the main strengths of the current study is that a longitudinal study design was implemented. Thus, a large, defined cohort of kids, across multiple commercial dairy goat farms, was monitored from birth for survival over time, and causes of death were confirmed by postmortem examination. Overall, mortality varied between farms, with 1 farm recording no deaths, and 2 farms losing more than 20% of their enrolled kids. More than 90% of kid deaths occurred before weaning, which suggests that interventions need to be targeted to the preweaning period.

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Appendix Four

Conference proceedings

Authors note: Appendix four consists of two peer reviewed conference proceedings that were completed in parallel with the research work in this thesis.

Appendix Five

Statements of contribution

Authors note: A statement of contribution has been completed for each published chapter (Chapter 2 and 3).

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STATEMENT OF CONTRIBUTION
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We, the candidate and the candidate's Primary Supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the candidate's contribution as indicated below in the *Statement of Originality*.

Name of candidate:	Laura Elizabeth Deeming
Name/title of Primary Supervisor:	Assoc. Prof. Ngaio Beausoleil
Name of Research Output and full reference:	
Deeming LE, Beausoleil NJ, Stafford KJ, Webster J, Zobel G. 2019. The development of a hoof conformation assessment for use in dairy goats. Animals. In Press	
In which Chapter is the Manuscript /Published work:	2
Please indicate:	
• The percentage of the manuscript/Published Work that was contributed by the candidate:	80
and	
• Describe the contribution that the candidate has made to the Manuscript/Published Work:	
Laura was involved in the conceptualisation of the study, and with data collection. She had a primary role in statistical analysis, interpretation and writing of the paper, with guidance from supervisors.	
For manuscripts intended for publication please indicate target journal:	
This chapter has been accepted for publication in Animals.	
Candidate's Signature:	[signature]
Date:	18/11/19
Primary Supervisor's Signature:	Ngaio Beausoleil Digitally signed by Ngaio Beausoleil Date: 2019.11.18 10:48:39 +13'00'
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Name of candidate:	Laura Elizabeth Deeming
Name/title of Primary Supervisor:	Assoc. Prof. Ngaio Beausoleil
Name of Research Output and full reference:	
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In which Chapter is the Manuscript /Published work:	3
Please indicate:	
• The percentage of the manuscript/Published Work that was contributed by the candidate:	85
and	
• Describe the contribution that the candidate has made to the Manuscript/Published Work:	
Laura had a primary role in study design, data collection, statistical analysis, interpretation and writing of the paper, with guidance from supervisors	
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Chapter 3: Deeming, LE., Beausoleil, NJ., Stafford, KJ., Webster, JR., Zobel, G. 2018. Technical note: The development of a reliable 5-point gait scoring system for use in dairy goats. Journal of Dairy Science 101, 4491-4497.