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Evaluating the long-term conformation and hoof growth effects of starting hoof trimming at 5 months of age in New Zealand dairy goats

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ABSTRACT

Hoof overgrowth is associated with poor conformation, an altered weight-bearing surface, and a reduction in the hoof's anatomic and functional integrity. As a result of housing systems that promote hoof overgrowth, hoof trimming is considered a priority in dairy goats. However, there are few data on the effects of the timing of first trimming on hoof conformation and growth rate. The aims of this study were (1) to evaluate the long-term effects of 2 different hoof trimming start times and (2) to investigate the pattern of hoof growth across the first 2 yr of life. Eighty 5-mo-old female Saanencross commercially housed dairy goats were allocated randomly to 1 of 2 treatments: (1) early trimmed (trimming beginning at 5 mo old; hooves were trimmed every 4 mo thereafter) and (2) late trimmed (trimming beginning at 13 mo old; hooves were trimmed every 4 mo thereafter). Using a combination of photographs and radiographs, hoof conformation, joint positions, and hoof wall length were assessed before the 13- and 25-mo trimming events. Hoof growth was assessed every 12 wk using caliper measurements. Overall, starting hoof trimming earlier had minor and inconsistent effects. However, detrimental changes in conformation and joint positions occurred between trimming events, particularly in the hind hooves, regardless of trimming treatment. At both assessments, there was a high percentage of overgrown toes and dipped heels, with the hind hooves being more affected compared with the front (overgrown toes at 13 mo, 97.1 vs. 79.1 ± 5.2%; overgrown toes at 25 mo, 91.7 vs. 56.3 ± 6.7%; dipped heels at 13 mo, 98.5 vs. 19.3 ± 5.0%; dipped heels at 25 mo, 88.3 vs. 4.9 ± 4.8%). In addition, at both assessments, the distal interphalangeal joint angle was greater in the hind hooves compared with the front (13 mo, 79.5 vs. 65.2 ± 1.7°; 25 mo, 79.0 vs. 66.7 ± 0.9°), whereas heel angles were less in the hind hooves compared with the front (13 mo, 41.8 vs. 57.1 ± 1.5°; 25 mo, 44.9 vs. 55.9 ± 1.1°). On average, the front hooves grew 4.39 mm/mo and the hind hooves grew 4.20 mm/mo. Early trimming did not have consistent effects on hoof growth rate. Importantly, our results suggest that trimming every 4 mo is not sufficient to prevent hoof overgrowth, the development of poor conformation, and detrimental changes in joint positions, particularly in the hind hooves. Furthermore, the detrimental changes may have masked any long-term treatment effects. Therefore, trimming frequency and age of first trimming should be considered when devising hoof care protocols for dairy goats housed in environments that do not offer opportunities for natural hoof wear.
Key words: hoof wall length, hoof conformation, claw deformation, hoof overgrowth, joint positions

INTRODUCTION

Ruminant hooves are constantly growing; consequently, if the rate of hoof growth exceeds the rate of wear, hooves become overgrown. Hoof growth in cattle ranges from 3.86 to 8.47 mm/mo (Vermunt and Greenough, 1995), with factors such as season (Hahn et al., 1986), age (Prentice, 1973), and nutrition (Manson and Leaver, 1988; Smith et al., 1999) affecting the rate. In farmed ruminants, the rate of hoof wear is mainly affected by flooring substrate [in cows, see Vermunt and Greenough (1996)] and, if the housing environment does not provide an opportunity for natural wear, hoof overgrowth can arise, creating a health and welfare issue [in sheep, see Bokko et al. (2003) and Azizi et al. (2011); cows, Brscic et al. (2015); goats, Zobel et al. (2019) and Sailer et al. (2021)].

Dairy goats are often housed permanently indoors and bedded on substrates such as straw [in the United Kingdom (Anzuino et al., 2010)] or wood shavings [in New Zealand (Solis-Ramirez et al., 2011)], which offer limited opportunities for natural hoof wear. In various countries, the prevalence of hoof overgrowth in com-

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mercially housed dairy goats is high [84 to 100% (Hill et al., 1997), 79% (Anzuino et al., 2010), 66% (Muri et al., 2013), 51% (Hempstead et al., 2021), and 98.2% (Sailer et al., 2021)]. However, no data have been published on hoof growth rates in dairy goats, nor on the prevalence of hoof overgrowth in New Zealand goats.

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., 2002a), 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., 2002a; van Amstel and Shearer, 2006). Similarly, in dairy goats, overgrowth and the resulting claw deformation affect overall hoof conformation negatively (Ajuda et al., 2014). 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). More recently, Chesterton et al. (2022) reported a link between overgrowth, lesions, and lameness in dairy goats.

The trimming process removes hoof overgrowth and aims to improve hoof conformation by restoring the hoof to an anatomically correct shape (Phillips et al., 2000; Bryan et al., 2012) and by promoting symmetry and equal weight bearing between the claws (Bryan et al., 2012). In cows, frequent hoof trimming is important to maintain claw shape and to promote shorter and steeper claws (Manske et al., 2002b). Given the link between hoof overgrowth and claw deformation, Ajuda et al. (2019) suggested trimming should also be considered a priority in dairy goats; however, they do not provide details regarding the frequency of this management practice or the age at which trimming should begin.

Commercially housed dairy goats may need trimming as early as 2 mo of age (Berg et al., 2005); however, this recommendation is not based on primary research. Dairy goat farmers in New Zealand commonly begin hoof trimming between first mating (~8 mo of age) and first kidding (~13 mo of age). Of 16 farms surveyed, 4 delayed trimming until after first kidding (Deeming, 2020). It is unknown whether there are long-term implications of delaying trimming until after first kidding in goats. Some evidence in dairy heifers supports the benefits of hoof trimming before first calving [e.g., lower risk of claw lesions and lameness, improved hoof conformation, better adaptability to postcalving management changes (Phillips et al., 2000; Bell et al., 2009; Gomez et al., 2013; Cook, 2016)]. Unfortunately, with the exception of Bell et al. (2009), these recommendations either lack peer review or are based on postmortem measurements (Phillips et al., 2000). The latter is problematic because accurate assessment of hoof conformation should consider weight bearing and load (Dyson et al., 2011). Thus, although hoof trimming has immediate benefits with improved conformation and joint angles [in horses, see Kummer et al. (2006); in goats, Deeming (2020)], there is a significant literature gap in our understanding of early hoof management in dairy goats and its effect on hoof conformation in the longer term.

The external conformation of the hoof can be assessed using subjective numerical scores or objective measurements on either live animals (subjective scores, sows: de Sevilla et al., 2008, sheep: Kaler et al., 2010; objective measures, cows: Somers et al., 2005) or from photographs (subjective scores and objective measures, goats: Deeming et al., 2019). However, hoof overgrowth, as well as the trimming process itself, can also alter internal joint angles and bone positions (Moleman et al., 2006), and these changes cannot be identified easily using external conformation assessment. Instead, radiographic images are required to determine objectively the positions and angles of joints within the distal limb (Kummer et al., 2006). Radiographic images are a common diagnostic tool to help determine the effect of bone and joint positions on lameness and conformation issues in horses (Colles, 1983). They are used less commonly in dairy animals, likely because of minimal involvement of veterinarians in lameness diagnosis and treatment (Tranter and Morris, 1991; Vermunt, 2004) and the high cost relative to the value of the animal.

Given the dearth of information on hoof trimming in dairy goats, the objectives of our study were 2-fold: (1) evaluate, using photographs and radiographic images, the long-term effects of an early (5-mo) vs. late (13-mo) start to hoof trimming on hoof conformation, joint positions, and hoof wall length; and (2) investigate the pattern of hoof growth across the first 2 yr of life.

MATERIALS AND METHODS

Study Design

A randomized controlled trial was designed to evaluate the long-term effects of 2 different start times for trimming dairy goat hooves, with a focus on hoof growth, hoof conformation, and joint positions. Based on a primary outcome measure [joint angle changes between trimming events in horses (Moleman et al., 2006)], 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, $P = 0.05$). Because of the potential for culling during the study period, this was treated as a minimum; a total of 40 goats

per treatment were enrolled. The study was controlled positively (i.e., no animals were left untrimmed) and was approved by AgResearch Ltd., Ruakura Animal Ethics Committee (no. 13686, approved December 17, 2015). Our study is part of a larger trial investigating the immediate effects of hoof trimming, during which the pre- and posttrimming difference was assessed. The immediate effects of hoof trimming are presented elsewhere (L. Deeming, unpublished data).

Animals and Housing

In December 2015, 80 female goats of approximately 5 mo of age from a commercial dairy goat farm in the Waikato region of New Zealand were enrolled in the study. The 80 goats were selected randomly from a potential of 109 similar-age available animals. This was completed before the researchers visited the farm and had any interaction with the goats. The farm had approximately 700 Saanen-cross milking does. The herd was maintained indoors in 4 separate groups and bedded on wood shavings, with a concrete strip in front of the feed rail. The milking parlor was attached to the housing barn; therefore, when lactating, the goats walked a short distance (<50 m) on a concrete surface twice a day to be milked.

The enrolled goats were assigned randomly to 1 of 2 trimming treatments: early trimming (hooves were trimmed starting at 5 mo of age and then every 4 mo thereafter) and late trimming (hooves were trimmed starting at 13 mo of age and then every 4 mo thereafter). Goats in both treatments were monitored until 25 mo of age. Housing and husbandry management were maintained per the farm's standard protocol. Goats were first mated at approximately 8 mo of age, and first kidded at approximately 13 mo of age, at which point they entered the milking herd. Goats were dried off at approximately 21 mo of age and were approximately 25 mo of age at their second kidding.

Hoof Trimming

A veterinarian experienced in goat hoof trimming completed all trimming. Each hoof was lifted and trimmed according to the technique described by Pugh and Baird (2012).

Any dirt compacted in the toe of the hoof was removed, which allowed the amount of overgrowth to be determined. The hoof wall was trimmed parallel to the coronary band, with the weight-bearing left outer wall slightly longer than the inner wall. If hoof overgrowth was causing the toe to curl upward, the solar surface was trimmed carefully to keep it level, rather than shortening ("dubbing") the toe. The heel was trimmed if it was excessively long. At the 13- and 25-mo assessments, trimming was completed after kidding.

Data Collection

Various measurements were taken every 4 mo for the larger study examining immediate effects of hoof trimming on hoof conformation (5, 9, 13, 17, 21, and 25 mo of age). To address our study's objectives, we present only the radiographs and hoof photographs taken before trimming at 13 and 25 mo of age, and provide measurements of hoof growth, which were acquired at separate time points 12 wk apart (described later). Goats were weighed at each assessment before trimming and before any of the other measurements were undertaken. For practicality and to reduce handling of the goats, only the left front and hind hooves were assessed.

Hoof Conformation

A digital camera (Canon Powershot SX530) was used to take photographs of the hooves immediately before hoof trimming. Hoof photographs were taken while the goats were standing in the milking parlor holding pen on a flat concrete surface, ensuring they were bearing weight evenly on all 4 limbs. Two photographs per hoof were taken: the lateral aspect and the dorsal aspect. The hooves were photographed against a whiteboard that had 2-cm scale markers along the vertical and horizontal edges.

Using the hoof conformation methodology described in Deeming et al. (2019), subjective scores were assigned to each hoof for toe length, heel shape, fetlock shape, claw splay, and claw shape. Each subjective score was based on a 3-point ordinal scale (0 = normal, 1 = moderate conformation issue, and 2 = severe conformation issue), except for fetlock shape, which was scored on a binary scale (0 or 1), with 0 being "normal" in all cases. Two objective measurements were also made: the toe length ratio (the toe length compared with the length of the rest of the hoof) and the claw splay distance (the distance between the axial edge of the distal tip of both claws). All measurements were analyzed using R v3.5.0 statistical software (R Foundation for Statistical Computing). The R code [see Deeming et al. (2019) for code] enabled a distance calibration to be completed using the scale markers, which allowed for distances between selected points on the hooves to be measured and the objective measurements to be calculated.

Two observers scored the photographs. High inter- and intraobserver reliability levels were achieved before scoring of the hoof photos and were confirmed after completion of the sets of photos from each assessment. For the subjectively scored aspects of hoof confor-

mation, weighted kappa (κ_w) statistics were used to measure agreement, ensuring $\kappa_w \geq 0.8$ [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)].

Joint Positions and Hoof Wall Length

Radiographs were taken on a subset of animals (20 goats per treatment, selected randomly at the beginning of the study) by an veterinarian immediately before hoof trimming. A wooden platform was used to ensure goats were in a square standing position, with their head straight and forward. Standardized radiographs of the distal limbs in a lateromedial and dorsopalmar (**DP**) direction, including the proximal phalanx (**P1**), the middle phalanx (**P2**), and the distal phalanx were taken, with the X-ray beam aimed through the fetlock.

The digital radiographs were analyzed using eFilm v3.3.0 software (Merge Healthcare) to determine internal joint positions of the distal part of the lateral claw. For the lateromedial radiographs, the following parameters of the lateral claw were determined: the proximal interphalangeal joint (**PIPJ**) angle, the distal interphalangeal joint (**DIPJ**) angle, the distal interphalangeal joint height (**JH**), and the heel angle (**HA**). These were adapted from methods used previously in the analysis of equine hoof radiographs [for the DIPJ and PIPJ angles, see Kroekenstoel et al. (2006); JH, Kummer et al. (2006); and HA, Drumond et al. (2016)]. First, centers of rotation of the PIPJ and DIPJ were determined. This was achieved by placing a circle on the end of the P1 and P2 bones, ensuring the circle passed through the most palmar and dorsal aspects of the bone (Kroekenstoel et al., 2006). The center of rotation was determined as the central point of the drawn circle (Figure 1A). The parameters were then determined as follows.

PIPJ Angle. A line was drawn through the middle of the P1 bone passing through the center of rotation of the P1 bone (green circle in Figure 1A). A line was drawn linking the center of rotation of the P1 and P2 bones (black circle in Figure 1A). The angle of the intersecting lines was calculated (red arrow in Figure 1A).

DIPJ Angle. A vertical reference line was drawn perpendicular from the horizontal base on which the hoof rested, through the center of rotation of the P2 bone (black circle in Figure 1B). A line was then drawn from the tip of the distal phalanx through the reference line at the center rotation of the P2 bone. The angle of the intersecting lines was calculated (red arrow in Figure 1B).

Heel Angle. A horizontal line was placed at the bottom of the hoof and a line was then drawn following the shape of the heel. The angle of the intersecting lines was calculated (red arrow in Figure 1C).

Joint Height. A horizontal line was placed at the bottom of the hoof and a line was then drawn from the bottom of the hoof to the lowest point on the circle of the P2 bone (dotted red line in Figure 1D).

For the DP view radiographs, the hoof wall length was determined for both the lateral and medial claws. The hoof wall length of either the abaxial (outer) or axial (inner) wall was measured, depending on which was assessed visually to be most overgrown. Measurements were taken from the most distal edge of the distal phalanx on either the abaxial side (Figure 2A) or the axial side (Figure 2B) of the bone.

All radiograph analyses were completed by 1 observer. Intraobserver reliability was assessed before analyses commenced using a random selection of approximately 15% of the radiographs (n = 43), ensuring a CCC of $\geq$0.8 [high level of agreement (Altman, 1990)] was achieved. To ensure ongoing reliability, the CCC was assessed again halfway through the analyses using a random subset of approximately 12% of the radiographs (n = 34).

Hoof Growth

Hoof growth was measured using methods similar to those described by Manson and Leaver (1988). Briefly, at approximately 6 mo of age, a small hacksaw was used to make a mark under the periople. Every 12 wk, another mark was made under the periople, and calipers were used to measure the distance between the new mark and the previous mark. The same veterinarian marked all hooves at each scoring session. To avoid the mark growing out, hoof growth was measured approximately every 12 wk rather than at the quarterly assessments. The measurements were used to calculate hoof growth rate (mm/mo).

Data Handling

The objective measures of hoof conformation (toe length ratio and claw splay distance), as well as the joint positions (PIPJ, DIPJ, JH, and HA) and hoof wall length, were treated as continuous outcome variables. The subjective aspects of hoof conformation were reclassified into binary outcomes with 2 separate analyses completed: the percentage of hooves scored as having a conformation issue compared with those that did

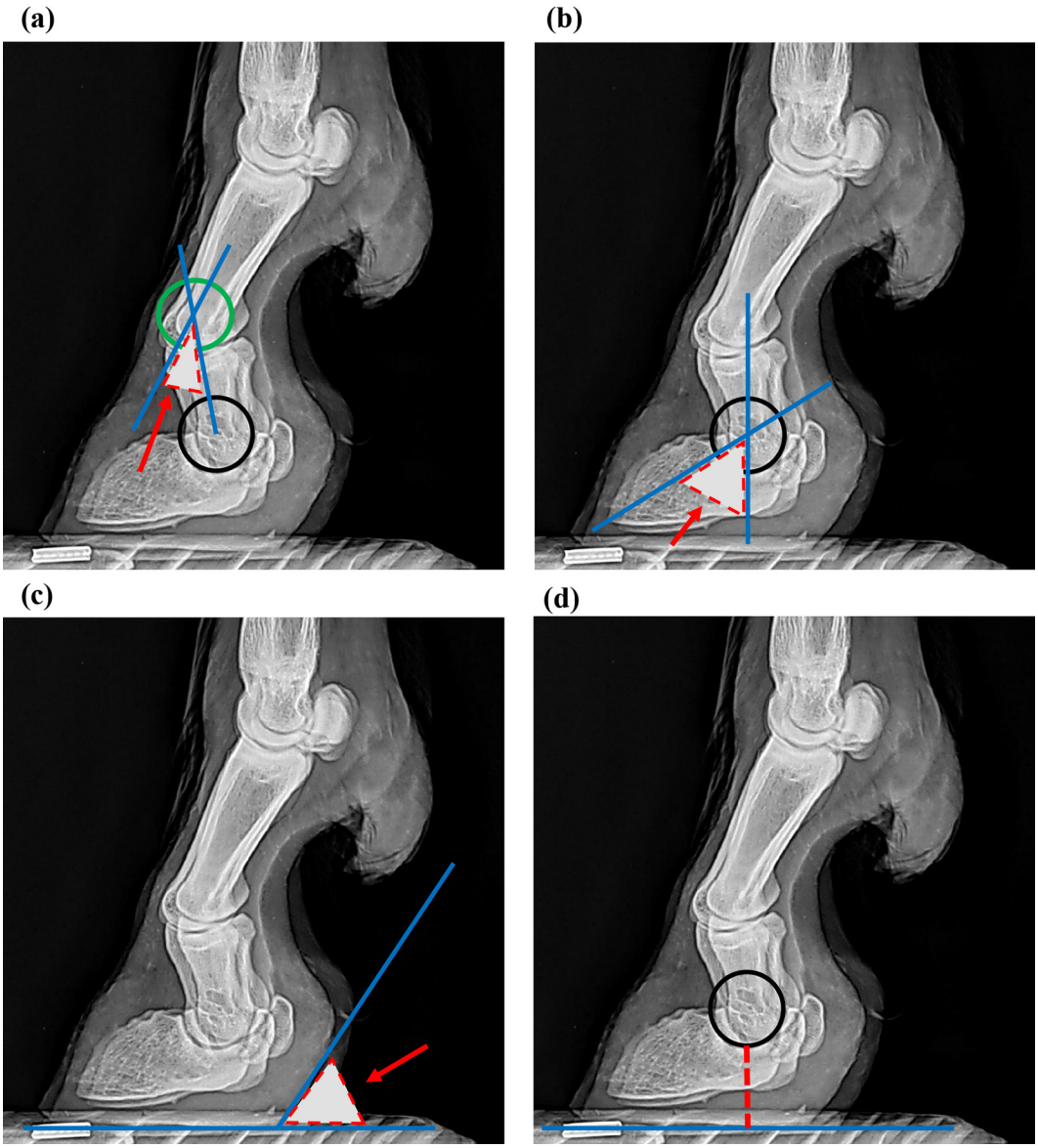

Figure 1. Methods determining (a) the angle of the proximal interphalangeal joint, (b) the angle of the distal interphalangeal joint, (c) the heel angle, and (d) the height of distal interphalangeal joint from radiographs taken in a lateromedial direction. Red arrows, all measured angles; red dotted line, height measurement; green circle, proximal phalanx, central point of circle indicated center of rotation of proximal interphalangeal joint; black circle, middle phalanx, central point of circle indicates center of rotation of distal interphalangeal joint; blue line, lines drawn to form angle or provide reference line for height measurement.

not (scores 1 + 2 vs. score 0, as described earlier) and the percentage of severe conformation issues compared with moderate conformation issues (score 2 vs. score 1, as described earlier). Fetlock shape was not included in the analysis because only 1 dipped fetlock was observed during the 13- and 25-mo assessments. Hoof growth (mm/mo) was treated as a continuous variable. Because goats were removed for health and production reasons by the farmer throughout the course of the study, 67 and 61 goats of the originally enrolled 80, were present at the 13- and 25-mo assessments, respectively.

Data Analysis

All statistical analyses were performed using Genstat v19 (VSN International Ltd.). Trimming treatment was considered a fixed effect and was forced into all models regardless of significance. All biologically relevant interactions were considered, but were removed from the model if not significant ($P < 0.05$ 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.

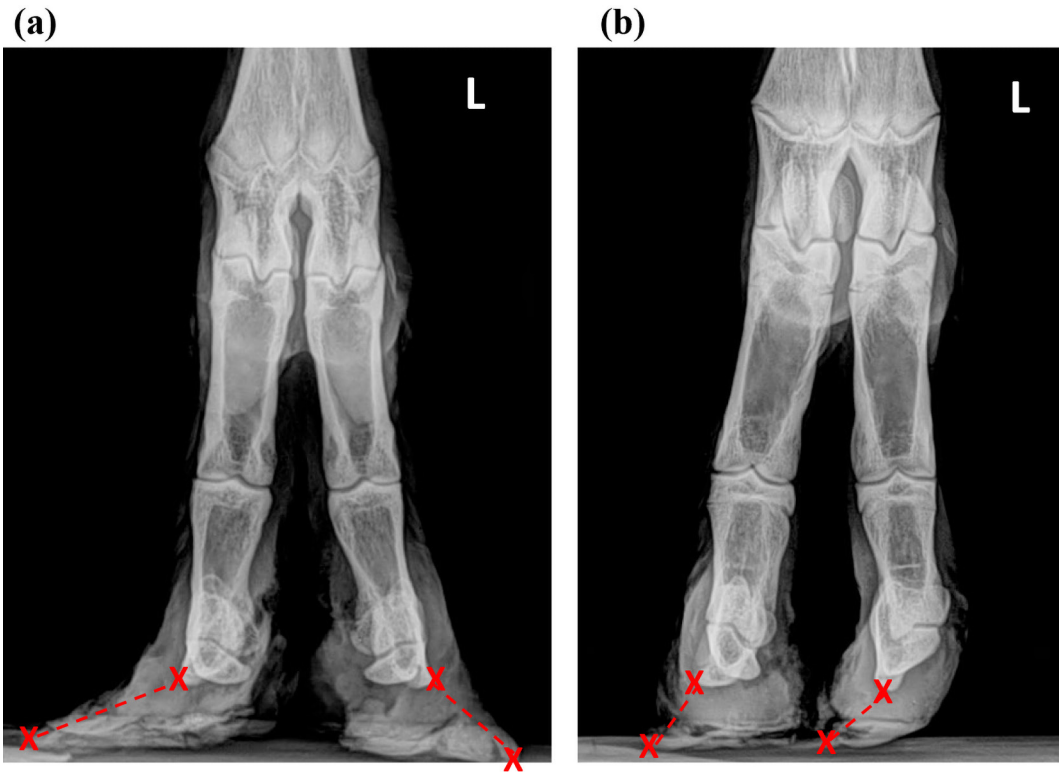

Figure 2. Method to determine hoof wall length from radiographs taken in a dorsopalmar orientation. The distance between the 2 red Xs (the red dotted lines) was measured for (a) the length of overgrowth of the abaxial (outer) hoof wall of the lateral and medial claws, and (b) the length of overgrowth of the axial (inner) hoof wall on the later claw and the abaxial (outer) hoof wall of the medial claw. The axial hoof wall was only measured if it was deemed more overgrown that the abaxial wall.

Age was not included because all goats were the same age. In addition, there was high collinearity between age and assessment. All models were evaluated for assumptions of homoskedasticity and normality of residuals. Homoskedasticity was assessed by examining visually a scatterplot of residuals against predicted values. Normality was assessed using histogram and normal probability plots, as well as by checking the residuals for skewness and kurtosis. A log transformation was applied to improve homoskedasticity and to help normalize the distribution of residuals for the toe length ratio and hoof wall length of REML models; results are presented as back-transformed means with 95% confidence intervals. Results from all other models and graphs (nonoverlapping error bars indicate significance, significant P values are included in the text of the figure caption) are presented as mean ± standard error of the difference. All continuous outcome variables were checked for outliers. Because all data points fell within 3 times the interquartile range away from the first and third quartile, none were considered outliers.

As a result of the generalized linear mixed model (GLMM) method producing unreliable estimates when all observations in one or more factor combinations were zero (i.e., at the 13-mo assessment none of the heels of the hind hooves before trimming were scored as 0, or normal), we used standard REML to analyze all subjectively scored aspects of hoof conformation. First, the percentage of hooves that had a conformation issue (score 0 vs. score 1 + 2) was determined. Second, of those hooves with an issue, the percentage that had a severe conformation issue (score 1 vs. score 2) was determined. We acknowledge that the data are binomial, however, it is the distribution of residuals that is of interest. Residuals were checked for consistency with normal distribution with constant variance.

Long-Term Effects

The pretrimming data from the 13- and 25-mo assessments were used to determine long-term effects, with separate models constructed for each assessment. First, differences by trimming treatment (early vs. late) at 13 mo of age were examined, because this was the assessment predicted to have the greatest differences (n = 67 goats for conformation, n = 37 goats for joint angles and hoof wall length). Differences at the 25-mo assessment were then examined to investigate the long-

term effects of trimming treatment (n = 61 goats for conformation, n = 37 goats for joint angles and hoof wall length).

For continuous variables, linear mixed model analyses using REML were used to test whether there was a difference between trimming treatment for the objectively measured aspects of hoof conformation (toe length ratio and claw splay distance), joint angles (PIPJ, DIPJ, JH, HA), and hoof wall length. Leg (front or hind) was included as a fixed effect.

For the subjectively scored hoof conformation variables, linear mixed model analyses using REML were used to test whether there was a difference between trimming treatment for overgrown toes, dipped heels, misshaped claws, and splayed claws. Leg (front or hind) was included as a fixed effect.

Hoof Growth

Linear mixed models using REML, with splines to account for serial correlation (Welham et al., 2006), were used to model the effects of scoring session (i.e., 6 scoring sessions throughout the study; not at the same time as assessments for other measurements) and trimming treatment on hoof growth (n = 78 goats, because data were included from the 9-mo score session onward). Goat was included as a random effect to account for within-goat correlation. Interactions between scoring session and trimming treatment were tested. Front and hind hooves were analyzed separately to reduce the possibility of complicated interactions masking a treatment effect.

RESULTS

Long-Term Effects of Trimming Treatment

No effects of trimming treatment were observed for the objectively measured hoof conformation variables [toe length ratio at 13-mo ($P = 0.75$) and 25 mo ($P = 0.51$), and claw splay distance at 13 mo ($P = 0.38$) and 25 mo ($P = 0.91$)]; however, various treatment, assessment, and leg effects and interactions were noted.

At both assessment periods, the toe length ratio of the hind hooves was greater than that of the front hooves [13-mo assessment hind leg, 1.03 (95% CI, 0.92 to 1.15); 13-mo assessment front leg, 0.73 (95% CI, 0.65 to 0.82; $F_{1, 65.0} = 36.19$; $P < 0.001$); 25-mo assessment hind leg, 0.86 (95% CI, 0.75 to 0.96); 25-mo assessment front leg, 0.55 (95% CI, 0.49 to 0.62; $F_{1, 58.3} = 51.98$; $P < 0.001$)]. This was consistent with subjectively scored overgrown toes. At the 13-mo assessment, there was a greater percentage of overgrown toes on the hind hooves compared with the front (97.1 vs. 79.1 ± 5.2%, $F_{1, 65} = 11.79$, $P < 0.001$). Of those that were overgrown at the 13-mo assessment, 60.0 ± 7.4% of hind hooves were severely overgrown compared with 15.5 ± 7.4% of front hooves ($F_{1, 56.6} = 36.13$, $P < 0.001$). At the 25-mo assessment, a greater percentage of hind hooves had moderately/severely overgrown toes compared with the front (91.7 vs. 56.3 ± 6.7%, $F_{1, 58.9} = 27.95$, $P < 0.001$).

At the 13-mo assessment, the percentage of dipped heels was greater in the hind hooves than in the front (98.5 vs. 19.3 ± 5.0%, $F_{1, 247.7} = 65.0$, $P < 0.001$). Of those heels that were dipped, 50% of hind hooves had severely dipped heels compared with 14.6% of front hooves ($F_{1, 75.0} = 8.81$, $P < 0.01$). In addition, at the 13-mo assessment, the late-trim treatment tended to have a greater percentage of severely dipped heels compared with the early-trim treatment (40.3 vs. 19.7 ± 14.6%, $F_{1, 75.0} = 3.92$, $P = 0.05$). At the 25-mo assessment, the percentage of dipped heels was greater in the hind hooves than in the front (88.3 vs. 4.9 ± 4.8%, $F_{1, 299.15} = 58.8$, $P < 0.001$).

No treatment effects were noted for joint positions (DIPJ at 13 mo, $P = 0.92$; DIPJ at 25 mo, $P = 0.28$; PIPJ at 13 mo, $P = 0.59$; PIPJ at 25 mo, $P = 0.29$; HA at 13 mo, $P = 0.46$; HA at 25 mo, $P = 0.40$; JH at 13 mo, $P = 0.37$; JH at 25 mo, $P = 0.94$); however, various differences depending on the leg (Table 1) were noted. At both the 13- and 25-mo assessments, the DIPJ angle was greater in the hind hooves than in the front hooves. The same pattern was noted in the PIPJ angle for the 13-mo assessment, and as a tendency at the 25-mo assessment. The front hooves had a greater HA than the hind hooves at the 13- and 25-mo assessments. Likewise, the JH was greater in the front hooves compared with the hind hooves at both assessments. Last, there was a trend for an interaction between leg and treatment. At the 25-mo assessment, hind hooves in the late-trim treatment tended to have a smaller HA than hind hooves in the early-trim treatment (43.0 vs. 46.8 ± 2.0°, $F_{1, 30.7} = 3.93$, $P = 0.06$).

No treatment effect was observed for hoof wall length. Overall, hoof wall length was 2.14 cm (95% CI, 2.02 to 2.27) at the 13-mo assessment and 1.68 cm (95% CI, 1.60 to 1.77) at the 25-mo assessment. At the 13-mo assessment, the hind hooves were longer than the front hooves [hind hooves, 2.43 cm (95% CI, 2.22 to 2.66); front hooves, 1.89 cm (95% CI, 1.73 to 2.07); $F_{1, 94.7} = 25.28$, $P < 0.001$], and the medial claws were longer than the lateral claws [medial claws, 2.26 cm (95% CI, 2.07 to 2.48); lateral claws, 2.03 (95% CI, 1.85 to 2.22); $F_{1, 90.6} = 6.26$, $P < 0.05$]. In addition, there was a claw-by-leg interaction at the 13-mo assessment ($F_{1, 90.75} = 30.70$, $P < 0.001$), with the medial claw of the hind hooves had the greatest hoof wall length (Figure 3A). Similarly, at the 25-mo assessment, the medial claw of the hind hooves

Table 1. Mean ± standard error of the difference for the joint positions of the front and hind legs measured before trimming at the 13-mo (n = 67 goats) and 25-mo (n = 61 goats) assessments

	13-mo assessment				25-mo assessment			
Variable[1]	Front	Hind	*F*-value	*P*-value	Front	Hind	*F*-value	*P*-value
DIPJ (°)	65.2 ± 1.7	79.5 ± 1.7	$F_{1, 33.4} = 72.07$	<0.001	66.7 ± 0.9	79.0 ± 0.9	$F_{1, 31.1} = 175.50$	<0.001
PIPJ (°)	28.1 ± 2.1	39.4 ± 2.1	$F_{1, 33.3} = 28.66$	<0.001	34.3 ± 2.1	38.0 ± 2.1	$F_{1, 32.2} = 3.23$	0.08
HA (°)	57.1 ± 1.5	41.8 ± 1.5	$F_{1, 33.4} = 103.0$	<0.001	55.9 ± 1.1	44.9 ± 1.1	$F_{1, 30.7} = 109.31$	<0.001
JH (cm)	2.3 ± 0.1	1.7 ± 0.1	$F_{1, 33.6} = 68.66$	<0.001	2.2 ± 0.1	1.7 ± 0.1	$F_{1, 31.9} = 70.54$	<0.001

[1]DIPJ = distal interphalangeal joint; PIPJ = proximal interphalangeal joint; HA = heel angle; JH = height of the DIPJ.

was longer than the lateral ($F_{1, 62.3} = 5.56$, $P < 0.05$). There was a leg-by-claw interaction ($F_{1, 62.3} = 33.05$, $P < 0.001$), with the medial claw of the hind hooves having the greatest overgrowth (Figure 3B).

Pattern of Hoof Growth

On average, the front hooves grew 4.39 mm/mo (range, 1.21 to 8.19 mm) and the hind hooves grew 4.20 mm/mo (range, 1.40 to 7.32 mm). There was no treatment effect for the front hooves. Front hoof growth rate increased between 13 and 19 mo of age, decreased from 19 to 22 mo of age, and increased again between 22 and 25 mo of age ($F_{1, 62.9} = 21.06$, $P < 0.001$; Figure 4A). The pattern of hind hoof growth across the measurement sessions differed between treatments (spline, $P < 0.001$; Figure 4B). Hind hoof growth rate increased between 13 and 16 mo of age in the late-trim treatment, but no increase was detected during this time for the early-trim treatment. At all other scoring sessions, there was no treatment difference in hind hoof growth rate.

DISCUSSION

The aims of this study were to determine the long-term effects of starting hoof trimming at either 5 or 13 mo of age on hoof conformation, joint positions, hoof growth, and hoof wall length, and to determine the pattern of hoof growth over the first 2 yr of life in New Zealand dairy goats. In the commercial farm setting of our study, starting hoof trimming earlier in life had only minor and inconsistent effects on hoof conformation and joint positions; similarly, early trimming did not have consistent effects on hoof growth rate. We caution that trimming frequency (3 times per year) resulted in highly overgrown hooves and detrimental changes in hoof conformation and joint positions across both treatment groups that may have masked any treatment effects.

In our study, a high proportion of hooves was scored subjectively as overgrown before hoof trimming at the 13- and 25-mo assessments (range, 74 to 88%). A high proportion of overgrown hooves is a welfare concern because overgrowth compromises the functional and anatomic integrity of the hoof (Phillips et al., 2000; Ajuda et al., 2019). Hoof overgrowth creates a cascade of follow-on effects for overall hoof conformation. In dairy cows, claw shape becomes abnormal (Manske et al., 2002a) and claws become splayed (van Amstel and Shearer, 2006). In dairy goats, overgrowth is one of the main causes of claw deformation (Ajuda et al., 2014), with the hind hooves most affected (Hill et al., 1997; Ajuda et al., 2019). This is in agreement with the results of our study; we found a greater percentage of misshaped claws in the hind hooves compared with the front hooves. As hooves become overgrown, heel depth is reduced (Glicken and Kendrick, 1977; Gitau et al., 1997). This was particularly evident in the hind hooves, with the majority having moderately or severely dipped heels. This corresponds to the X-ray measurements, with a smaller HA in the hind hooves compared with the front, indicating a greater dip in heel shape. In addition, the DIPJ angle was greater in the hind hooves compared with the front, indicating that the dipped heel shape was causing greater deviations of the DIPJ. The deviations in DIPJ are of particular concern because they can result in greater weight bearing through the caudal edge of the distal phalanx, which is a known cause of in sole ulcers in cattle (Blowey, 1992; Lischer et al., 2002; Anees et al., 2022). There are limited reports of sole ulcers in dairy goats (Aguiar et al., 2011; Crosby-Durrani et al., 2016; Sailer et al., 2021), and further work is required to determine whether the etiology is the same as described for sole ulcers in cattle.

When examined on radiographs, the hoof wall of the medial claws of the hind hooves had the greatest length, suggesting that they were most affected by hoof wall overgrowth. Ajuda et al. (2019) reported a greater prevalence of overgrown deformed claws in the hind hooves of goats compared with the front; unfortunately, they measured both the lateral and medial claws, but only reported the overall percentage of deformed claws, preventing comment on whether one claw was more affected than the other. Interestingly, in dairy cows, the

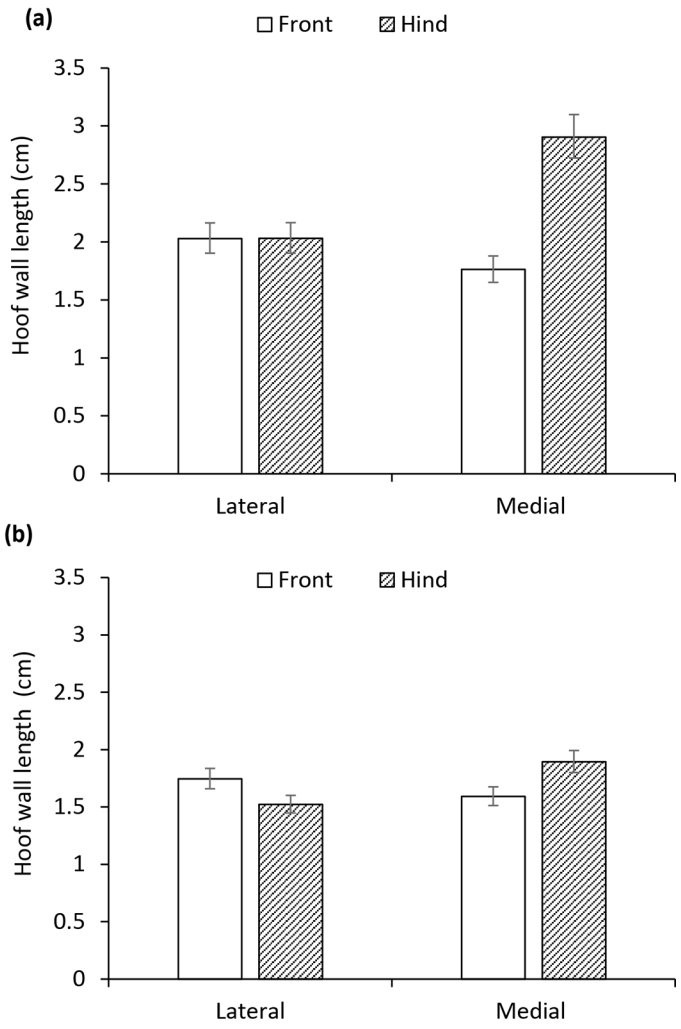

Figure 3. Mean ± standard error of the difference of the pretrimmed hoof wall length of the medial and lateral claws of the front and hind hooves at the (a) 13-mo assessment (lateral, front vs. hind: $P = 0.99$; medial, front vs. hind: $P < 0.001$) and (b) 25-mo assessment (lateral, front vs. hind: $P < 0.001$; medial, front vs. hind: $P < 0.001$). The value of n varied from 67 to 61; numbers declined as a result of goats being removed from the herd for health and production reasons.

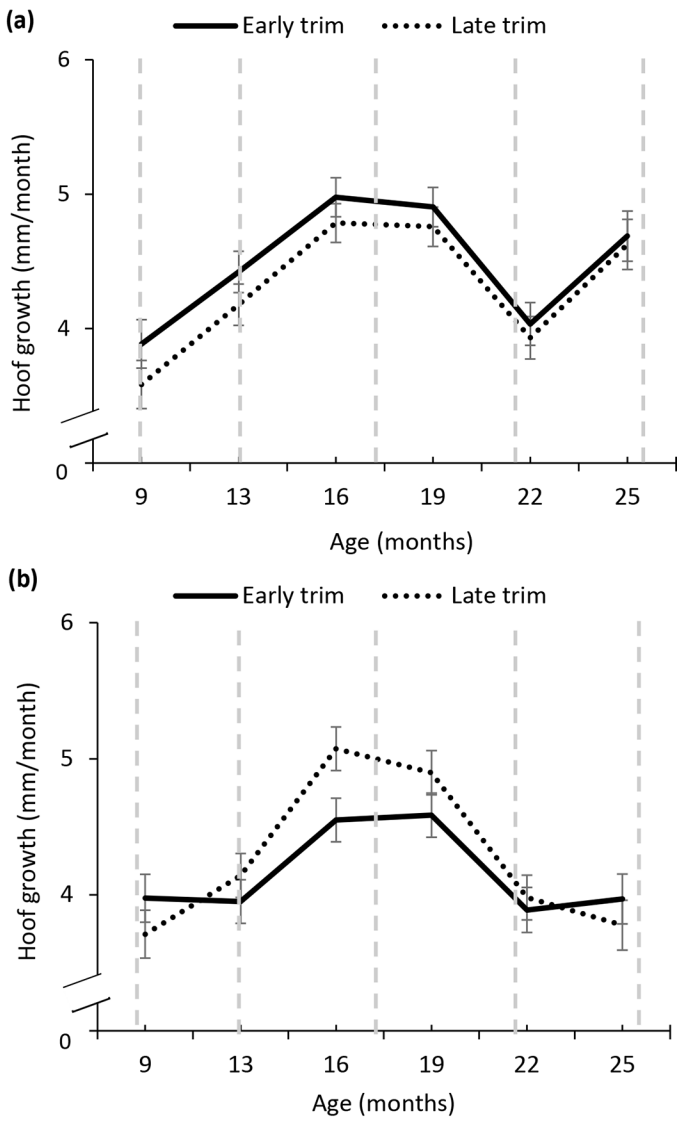

Figure 4. Mean ± standard error of the difference of growth rate of the (a) front hooves and (b) hind hooves at 6 scoring sessions across the goats' first 2 yr of life, starting from 9 mo of age (treatment effect of hind hooves at 16 mo of age, $P < 0.05$). The value n varied from 70 to 61; numbers declined as a result of goats begin removed from the herd for health and production reasons. The light-gray dashed lines signify a hoof trimming event.

hind lateral claw is typically larger (Nuss and Paulus, 2006), bears the greatest weight load (van der Tol et al., 2004; Nuss et al., 2020), and is therefore at greater risk of developing lesions (Murray et al., 1996; Dyer et al., 2007). For instance, overgrown corkscrew claws are typically seen in the hind lateral claw of cows (Ødegård et al., 2013). However, abnormal growth of the medial hind claw has been reported in heifers, resulting in the medial claw being longer than the lateral, causing permanent anatomic changes (Cook et al., 2019). For practicality and to reduce handling of the goats, photographs and radiographs were taken of the lateromedial view of the left front and hind hooves only. Therefore, we did not have corresponding external growth or conformational data for the medial claws. The only measurement taken of the medial claw was the hoof wall length from the DP radiographs. Therefore, comparisons of growth rates and conformation between the claws cannot be made. Future work is required to determine the growth rate, conformation, and weight-bearing pattern of both claws of dairy goats.

Taken together, the findings from our study suggest that hoof trimming every 4 mo (as was standard practice on this farm) was not frequent enough to prevent hoof wall overgrowth and the subsequent detrimental

changes in hoof conformation and joint positions. Starting hoof trimming of goats at 5 mo of age appeared to produce little consistent effect compared with 13 mo of age. Overall, we found only minor treatment effects; there was a tendency at the 13-mo assessment for more of the late-trim goats to have severely dipped heels than goats trimmed early, and overall, goats first trimmed at 13 mo of age had hind hooves with a smaller HA. Although there may be biologically plausible explanations for these findings, we acknowledge that trimming frequency is likely to have had a confounding role, and we caution that the lack of treatment effect may also be a function of sample size.

The lack of literature or preliminary data in this area of research for goats meant that our initial power analysis was conducted based on detecting immediate effects of hoof trimming using data available from the horse literature (Moleman et al., 2006). Given that we have found that the frequency of trimming used (i.e., every 4 mo) was not sufficient to prevent at least moderate hoof overgrowth, it is likely that the longer term effects of early-life trimming were masked, potentially introducing type II errors to our hypotheses [i.e., true effects are not detected (Banerjee et al., 2009)]. Therefore, a larger scale study using our hoof growth rate data in the power analysis should be conducted to reevaluate the effects of early-life hoof trimming in goats.

Hoof growth was similar in the front and hind hooves (4.38 vs. 4.20 mm/mo). Similar findings are reported in sheep, with no difference in the growth rates of front and hind hooves observed (Shelton et al., 2012). Interestingly, in our study, the hind hooves were more overgrown and had a greater proportion of hooves scored as overgrown, suggesting that more hoof wear was occurring in the front hooves. This is in agreement with Prado et al. (2022), who report a difference in sole length of the hind hooves of dairy goats after trimming, but no difference in the front hooves. They attributed this finding to greater hoof wear. Greater body weight is borne by the front hooves than the hind hooves in ruminants [for sheep, see Kim and Breur (2008); cows, Atkins (2009)], which might be expected to encourage greater wear (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). In addition, it is interesting to note that hoof overgrowth was greater in the 13-mo assessment (88% of hooves were overgrown) compared with the 25-mo assessment (74% of hooves were overgrown). We did not compare between assessments within our models; therefore, this represents a numerical difference only. However, we suggest this difference may indicate an effect of hoof wear resulting from management changes that occurred between the assessment periods. For instance, before first kidding (~13 mo of age), the goats will have had little exposure to the milking parlor and concrete surfaces, and therefore may have less opportunity for hoof wear. We acknowledge that it would have been advantageous to measure hoof wear in our study because this variable would have provided more information about changes in hoof length.

Regardless of the timing of first trimming, hoof growth slowed in the front and hind hooves at the 22-mo assessment, when the goats were in late gestation for the second time. Similar results have been reported in dairy cows, with hoof growth decreasing during the second trimester of pregnancy (Dietz and Prietz, 1981). Hoof growth has seasonal variation and is associated with moisture levels and temperature [for sheep, see Smith et al. (2014)], with greater hoof length observed during the winter and spring months. Interestingly, in our study, hoof growth increased in the front and hind hooves between 13 and 19 mo of age. These measurement time points correspond to the winter and spring months in New Zealand, when the housing environment is likely to have had greater moisture levels. Exposure to moisture can cause hooves to soften and swell (Baillie et al., 2000; Gregory et al., 2006), which may explain the greater hoof length during that time. Interestingly, increased moisture content of the hoof is associated with increased hoof wear in dairy cattle, particularly when hooves have prolonged exposure to concrete (Vermunt and Greenough, 1995). In contrast, commercially housed dairy goats are exposed to environments that do no promote hoof wear. Consequently, even when hooves are softer as a result of a greater moisture content, hoof wear may still be less because of the lack of hard surfaces and opportunity for wear.

The hoof growth measurements in our study were taken every 12 wk rather than at the quarterly trimming assessments to avoid the mark growing out. Therefore, the growth measurements were not spaced consistently relative to trimming events. Because hoof growth is reported to increase after trimming [in cows, see Manson and Leaver (1988); sheep, Wheeler et al. (1990)], it is possible that trimming may have had an effect on the hoof growth rates we measured. In addition, as the coronet band has been reported to vary in width between weekly assessments, using the method described by Shelton et al. (2012) in which an X is shaved deep into the hair above the coronary band as an exact point of measurement is advantageous to ensure accurate measurements. Nonetheless, to our knowledge this is the first work to measure hoof growth in dairy goats systematically in a commercial

setting. We recommend that follow-up work evaluate how management such as trimming frequency, bedding maintenance and type, cleaning of the concrete skirt, diet, exercise, and access to the outdoors may all affect hoof growth and wear. This will help inform hoof trimming management regimens specific to a particular farm housing and husbandry practices.

The high proportions of overgrown hooves, dipped heels, misshaped claws, and splayed claws observed across both treatments at both assessment points suggest that neither trimming treatment was successful at preventing poor hoof conformation. The frequency of hoof trimming used in our study has been reported by local and overseas dairy goat farmers (G. Zobel, unpublished data), but our results suggest that more frequent trimming is required. Indeed, veterinary reference texts [e.g., Pugh and Baird (2012)] suggest that as often as every 6 to 8 wk is necessary, depending on the housing environment.

Improving hoof conformation in the short term may be achieved by management factors such as hoof trimming (Manske et al., 2002b). However, genetics may need to be considered for long-term improvement to be achieved. Koluman and Göncü (2016) report breed differences in hoof conformation of Saanen dairy goats compared with meat goats. For instance, Boer goats had larger hoof dimensions, with a greater dorsal wall angle and heel bulb height compared with Saanen goats. Because the goats included in our study were all Saanen cross, there may be a genetic component to the high levels of poor conformation observed. Further studies are needed to investigate the genetic influence and heritability of hoof conformation in dairy goats.

When focusing on immediate management factors to improve hoof conformation, it is likely that adequate trimming schedules need to include consideration of when in life trimming begins, the frequency of subsequent trimming, and the provision of opportunities for goats to wear their hooves naturally. The latter is important because an environment that promotes natural hoof wear will encourage self-maintenance of the hooves (Florence and McDonnell, 2006). For example, dairy cow exposure to an abrasive concrete surface resulted in 35% more hoof wear than cows exposed to a dirt surface (Hahn et al., 1986). Although prolonged standing on concrete promoted lameness in cows (Somers et al., 2003), goats in their natural environment populate hilly and rugged environments, often resting directly on rocks in steep terrain (Zobel et al., 2019), and may travel long distances [e.g., 3 km in a 24-h period (Zobel et al., 2018)]. In such circumstances, overgrown hooves may not be an issue, despite a lack of hoof trimming (Zobel et al., 2019).

CONCLUSIONS

Trimming goats early in life had only minor effects on hoof growth. Hoof growth rate was similar in front and hind hooves, and slowed when the goats were pregnant, suggesting an effect of stage of life and gestation. There were no meaningful long-term effects of starting trimming before kidding on hoof conformation; however, we caution that our study may not have had enough power to assess this, and trimming frequency likely masked any treatment effects that did exist. Indeed, we suggest that the high prevalence of poor conformation and deviations in joint positions recorded before trimming provide evidence that trimming every 4 mo (3 trims/y) is not frequent enough to prevent hoof overgrowth, poor conformation, and detrimental changes in joint positions. Further research is needed to inform the development of trimming protocols to account for the age at which trimming should start and trimming frequency to produce long-term improvements to goat hoof health.

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