

Effect of exercise and environmental terrain on development of the digital cushion and bony structures of the bovine foot

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OBJECTIVE

To determine whether exercise on alternative terrain affects the development of the digital cushion and bony structures of the bovine foot.

ANIMALS

20 weaned bull calves.

PROCEDURES

Two-month-old calves were randomly allocated to an exercise or control group. For 4 months, the control group was maintained in grass paddocks, and the exercise group was maintained in a 0.8-km lane with a mixed terrain of dirt, stones (0.32- to 0.95-cm pea gravel and 5-cm crusher run), and grass. Water and food for the exercise group were located at opposite ends of the lane; calves were fed twice daily, which ensured they walked 3.2 km/d. Pedometers were applied to all calves to measure distance traveled. All calves were slaughtered at 6 months of age. The right forefeet and hind feet were harvested for MRI and CT evaluation.

RESULTS

Control calves walked a mean of 1.1 km daily, whereas the exercised calves walked a mean of 3.2 km daily. Mean digital cushion volume and surface area were 25,335 mm³ and 15,647 mm², respectively, for the exercised calves and 17,026 mm³ and 12,745 mm², respectively, for the control calves. When weight was controlled, mean digital cushion volume and surface area for the exercise group were increased by 37.10% and 18.25%, respectively, from those for the control group.

CONCLUSIONS AND CLINICAL RELEVANCE

Results indicated that exercise on alternative terrain increased the volume and surface area of the digital cushion of the feet of dairy calves, which should make them less susceptible to lameness. (*Am J Vet Res* 2015;76:246–252)

Animal health and welfare are important considerations in the cattle industry. Beef and dairy cattle are most productive when they are free from pain; therefore, development, evaluation, and application of protocols that prevent diseases such as lameness are necessary to produce healthy and productive cattle. Lameness is one of the 2 most costly diseases of dairy cattle in England¹ and is the most costly disease of the US dairy industry, costing producers more than mastitis on a herd basis.² On an individual case basis, lameness (\$478/case) is only slightly less costly than left displaced abomasum (\$489/case) when the prevalence of lameness within the herd is moderate at an estimated 30%.² Results of another study³ indicate that the prevalence of lameness in dairy herds is approximately 20% for primiparous cows and 50% for multiparous cows. Lameness causes substantial negative effects on the production and well-being of dairy cattle; therefore, it is currently considered one of the most important challenges for the US dairy industry to overcome.^{2–5}

Results of multiple studies^{2–9} indicate that lameness predisposes cattle to other conditions that impair

production and reproduction. For some dairy herds, the deleterious effects of lameness on reproduction is especially problematic because the mean first-service pregnancy rate is fairly low (18%).⁶ Results of another study¹⁰ indicate that fertility was decreased by 50% for dairy cows that had foot rot, compared with the fertility for nonlame cows. Dairy cows that become clinically lame during the first 70 days of lactation are 25% as likely to become pregnant as are nonlame cows.⁴ Investigators^{2,9,a} estimate that each episode of lameness costs producers a mean of \$302 to \$446, with the cost positively associated with the severity of lameness. In a 1978 study,⁷ sole ulcers and white line disease were associated with milk production losses of 574 and 369 kg/cow, respectively, during a 305-day lactation. Investigators of a 2010 study¹⁰ report that each case of sole ulcers, digital dermatitis, and foot rot cost dairy producers \$216.07, \$132.96, and \$120.70, respectively. Most of the economic cost for cows with sole ulcers was associated with a decrease in milk production while lame.¹⁰ Those investigators¹⁰ concluded that it was economically beneficial to treat 97.3% of

cows with foot rot, 95.5% of cows with digital dermatitis, and 92.3% of cows with sole ulcer cases. Investigators of another study¹¹ developed and validated decision support models to predict the economic profitability of treating dairy cows with various types of lameness. Results of those studies^{10,11} are important for educating producers about the underlying ramifications of lameness in their herds and how to make appropriate treatment decisions for lame cows.

Although economic modeling is beneficial and important for producers, prevention of lameness is more essential than determining whether it is worth treating. Compared with nonlame cattle, lame cattle are frequently culled prematurely and have a lower carcass weight, conformation class, and fat coverage, which decrease carcass value.^{2,4,8,9} However, early identification and treatment of lame cattle can reduce culling rates and improve carcass value.^{2,4,8,9} Results of a survey² conducted in the United Kingdom suggest that the carcasses of cattle that are sold because they are lame are worth approximately half that of carcasses of cattle that are sold for reasons other than lameness. Investigators of a study⁹ on the effects of lameness on dairy cattle culling concluded that lameness was not associated with increased survival rate in any of the models studied.

Because of the negative effects of lameness on the health and economic productivity of both dairy and beef cattle,^{2-6,10-19} management strategies to prevent lameness in cattle need to be developed, evaluated, and implemented. The production of replacement dairy heifers that have healthy functional feet could have a substantial positive effect on dairy cow health and productivity. Specifically, replacement heifers with feet that have soft and bony tissues with a large volume and surface area over which pressure can be distributed may have a survival advantage. This principle is supported by results of a study¹⁹ in which the forefeet of cattle had a larger surface area and fewer lesions, compared with the hind feet. Additionally, the digital cushion plays an important role in the prevention of lameness in cattle because, unlike horses, cattle do not have a suspensory apparatus and the digital cushion must support a considerably greater proportion of the body weight than the digital cushion of horses.¹⁹ In cattle, a well-developed digital cushion is necessary to cushion and prevent contusions that lead to claw lesions.²⁻⁵ Consequently, maximizing the volume and surface area of the digital cushion and the second and third phalanges might minimize lameness in cattle and make them more resilient and capable of adapting to the rigors of the industry.

The purpose of the study reported here was to determine whether exercise on alternative terrain affected the development of the digital cushion and bony structures of the feet of calves. Our hypothesis was that calves exercised on terrain composed of dirt, stones, and grass would develop larger digital cushions and second and third phalanges with a larger volume, compared with those of calves maintained on grass paddocks.

Materials and Methods

ANIMALS

Twenty 2-month-old weaned Jersey ($n = 4$) and Holstein (16) bull calves were acquired for the study from the dairy unit of the E.V. Smith Research Center at Auburn University. All calves were born within 1 week of each other. Prior to weaning, calves were individually housed in hutches in accordance with standard practices for the dairy industry and were reared with the same management and nutritional protocols. All calves maintained a body condition score of 3.25 to 3.5 out of 5.0 for the duration of the 4-month study. The study protocol was approved by the Institutional Animal Care and Use Committee of Auburn University.

STUDY DESIGN

Within each breed, calves were randomly allocated by means of a random number generator to either an exercise or control group such that there were 2 Jerseys and 8 Holsteins in each group. The calves in the control group were maintained in 0.004-km grass paddocks with free access to water troughs, hay, and pasture for the 4-month duration of the study. The calves in the exercise group were maintained in a 0.8-km lane that consisted of dirt, stones (0.32- to 0.95-cm pea gravel and 5-cm crusher run), and grass with free access to water troughs, hay, and pasture for the duration of the study. Calves in each group were fed a grain specifically developed for growing calves that contained 18% protein in equal portions twice daily, and it was estimated that each calf consumed 3.18 kg of grain/d.

Pedometers were applied to the calves' legs to determine the mean distance traveled per group per day. For the calves in the exercise group, the water and feed troughs were located at opposite ends of the lane, which ensured that the calves would walk a minimum of 3.2 km/d. The calves ran or walked briskly behind the feed truck for the entire length of the lane twice daily when the grain was fed, and then walked leisurely back to the water trough after eating. Thus, the calves in the exercise group ran or walked briskly for approximately 1.6 km and walked leisurely for 1.6 km on a daily basis. Calves in the control group were not similarly encouraged to exercise.

After 4 months of observation, all calves were individually weighed and humanely slaughtered at the Auburn University Meat Science Laboratory in accordance with a humane slaughter protocol approved by the Institutional Animal Care and Use Committee of Auburn University. The laboratory is approved by the American Association for Laboratory Animal Care and is routinely inspected by the USDA. Immediately after slaughter, the right forefeet and hind feet were harvested from all calves for MRI and CT evaluation.

MRI AND CT EVALUATIONS

The MRI unit^b used for the study was located at Auburn University. The scanner maximum gradient

strength was 43 mT/m and the slew rate was 180 mT/m/ms. A 15-channel knee coil was used so that both feet of each calf could be imaged simultaneously. A stack of 2-D, T1-weighted, gradient echo images were obtained in the sagittal plan. The sequence type and parameters included a turbo spin echo with a turbo factor of 10, and 55 slices that were 1.5 mm thick with a 0.15-mm gap between slices. The in-plane field of view was 150 X 150 mm, and the image matrix was 192 X 192 mm for a pixel size of 0.78 X 0.78 X 1.5 mm. The 3-D image coverage was 150 X 150 X 90.75 mm. The repetition time was 6.2 s and the echo time was 74 ms. The readout bandwidth was 286 Hz/pixel, the number of averages was 4, and the total scan time was 8 minutes for each pair of feet.

The CT scanner^c used for the study was located at the University of Utah School of Medicine in Salt Lake City, Utah. Images were acquired at 140 kVP and 300 mA with a slice thickness of 1 mm and a 0.3-mm overlap. The 1-mm image data were filtered in a medium-high reconstruction kernel (bone algorithm) and reconstructed into 0.6-mm-thick images. A workstation and proprietary software^d were used to create coronal and sagittal reformations.

All MRI and CT data were evaluated with 2 software programs^{e,f} by a board-certified radiologist (RKS), who was unaware of the group to which each calf was assigned (ie, blinded). The software programs were used to create 3-D images of the medial and lateral claws of the right forefoot and hind foot of each calf, from which measurements of the digital cushion and second and third phalanges were obtained. An anatomic pathologist (DRW), who was also blinded to the treatment group assignment of each calf, dissected each foot and obtained specimens for histologic evaluation. The gross and histologic results were combined with the MRI and CT findings to determine the exact location of the digital cushion, create 3-D images, and calculate the volumes and surface areas of the digital cushion and bony structures of the foot.

STATISTICAL ANALYSIS

Outcomes of interest were body weight immediately prior to slaughter, number of steps taken and distance traveled daily, total digital cushion volume and surface area, ratio of digital cushion volume to body weight, ratio of the digital cushion surface area to body weight, volumes of the second and third phalanges, and ratio of the third phalanx volume to body weight. For each outcome, comparisons were made between the exercise and control groups and, when appropriate, between the right forefeet and hind feet within and between groups.

For each outcome, the assumption of homogeneity of residual variances was valid and a pooled residual error term was used. A 2-sample *t* test was used to compare the mean body weight immediately prior to slaughter between calves in the exercise and control groups. For the other outcomes, a repeated-measures ANOVA was used for comparisons within

and between groups. The model included fixed effects for treatment group and body weight, and a random effect to account for repeated measures within calves. All analyses were performed with statistical software,^g and values of $P \leq 0.05$ were considered significant. Graphs were created with a commercially available spreadsheet program.^h

Results

ANIMALS

All calves completed the 4-month experimental period. Immediately prior to slaughter, the mean body weight did not differ significantly ($P = 0.757$) between calves in the exercise and control groups; however, the mean body weight for calves in the exercise group (178.59 kg) was 3.9 kg (22%) greater than that for calves in the control group (174.68 kg). Calves in the exercise group walked a mean of 4,000 steps or 3.2 km daily, whereas calves in the control group only walked a mean of 1,200 steps or 1.1 km daily.

A representative MRI image of the distal portion of the right forelimb and hind limb obtained from a calf in the exercise group is provided for reference (**Figure 1**). This information, combined with the CT findings for the corresponding feet, was used to create 3-D images (**Figure 2**) from which measurements were obtained.

DIGITAL CUSHION MEASUREMENTS

When body weight was controlled, the mean total digital cushion volume for calves in the exercise group (25,335 mm³) was 39.23% greater than that for calves in the control group (17,026 mm³), a difference that was significant ($P < 0.001$). Specifically, the mean digital cushion volumes for the lateral claw of the forefoot, medial claw of the forefoot, lateral claw of the

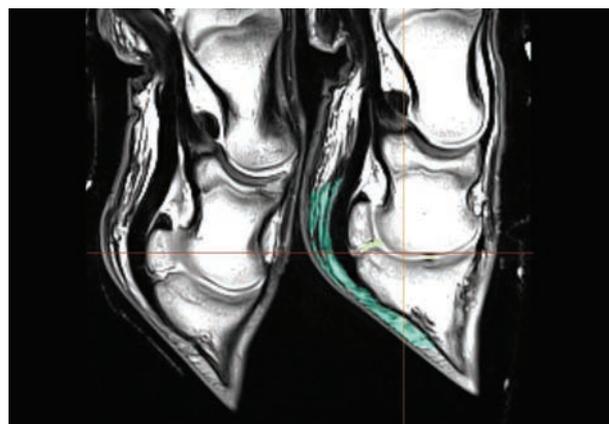


Figure 1—Representative MRI image obtained in the sagittal plane of the distal portion of the right forelimb (right) and hind limb (left) of a 6-month-old Holstein calf that was maintained in an 0.8-km lane that consisted of dirt, stones (0.32- to 0.95-cm pea gravel and 5-cm crusher run), and grass and encouraged by placement of water and feed troughs at opposite ends of the lane to walk at least 3.2 km daily during the 4 preceding months. The digital cushion is highlighted in green in the image of the right forelimb.

hind foot, and medial claw of the hind foot for calves in the exercise group were 40.73%, 38.00%, 44.74%, and 34.68%, respectively, greater than those for the corresponding claws for calves in the control group. Similarly, the mean ratio of the total digital cushion volume to body weight for the calves in the exercise group was 37.10% greater than that for calves in the control group. Specifically, the mean ratios of the digital cushion volume to body weight for the lateral claw of the forefoot, medial claw of the forefoot, lateral claw of the hind foot, and medial claw of the hind foot for calves in the exercise group were 38.11%, 35.86%, 42.63%, and 32.53%, respectively, greater than those for the corresponding claws of the calves in the control group. Within each group, the digital cushion volume did not differ significantly between the forefeet and hind feet ($P = 0.181$) or between the lateral and medial claws ($P = 0.457$).

The mean total digital cushion surface area for calves in the exercise group ($15,647 \text{ mm}^2$) was 20.44% greater than that for the calves in the control group ($12,745 \text{ mm}^2$), a difference that was significant ($P = 0.006$). The mean digital cushion surface area of the forefeet and hindfeet were 8,150 and $7,496 \text{ mm}^2$, respectively, for calves in the exercise group and 5,890 and $6,209 \text{ mm}^2$, respectively, for calves in the control group. Specifically, the mean digital cushion surface

areas for the lateral claw of the forefoot, medial claw of the forefoot, lateral claw of the hind foot, and medial claw of the hind foot for calves in the exercise group were 32.20%, 23.12%, 18.79%, 16.18%, respectively, greater than those for the corresponding claws of calves in the control group. The mean ratio of the total digital cushion surface area to body weight for calves in the exercise group was 18.25% greater than that for the calves in the control group. Likewise, the mean ratios of the digital cushion surface area to body weight for the lateral claw of the forefoot, medial claw of the forefoot, lateral claw of the hind foot, and medial claw of the hind foot for calves in the exercise group were 20.94%, 18.58%, 19.48% and 13.98%, respectively, greater than those for the corresponding claws of the calves in the control group. The mean digital cushion surface areas of the forefeet ($P = 0.001$) and hind feet ($P = 0.020$) of the calves in the exercise group were significantly greater those of calves in the control group. Within each group, the mean digital cushion surface area did not differ significantly ($P = 0.449$) between the medial and lateral claws.

MEASUREMENTS OF THE SECOND AND THIRD PHALANGES

For calves in the exercise group, the mean total volume of the second phalanx was 7.61% greater than that for calves in the control group. Similarly, the mean second phalanx volumes for the lateral and medial claws of calves in the exercise group were 7.75% and 7.48%, respectively, greater than the corresponding volumes in the control calves, differences that were significant ($P \leq 0.05$).

The mean total volume of the third phalanx for calves in the exercise group ($12,604 \text{ mm}^3$) was 9.04% greater than that for calves in the control group ($10,586 \text{ mm}^3$), a difference that was significant ($P = 0.029$). The mean ratio of the total volume of the third phalanx to body weight for calves in the exercise group ($32.3 \text{ mm}^3/\text{kg}$) was also significantly ($P = 0.015$) greater than that for control calves ($27.8 \text{ mm}^3/\text{kg}$). The mean third phalanx volumes for the lateral and medial claws of calves in the exercise group were 9.59% and 8.7%, respectively, greater than those for control calves.

Discussion

Results of the present study indicated that the volumes and surface areas of the digital cushion and second and third phalanges of dairy calves that were maintained on alternative terrain that consisted of dirt, stones, and grass and exercised daily for 4 months were significantly increased, compared with those for similar calves that were maintained in grass paddocks and not encouraged to exercise. Those structures are critical for weight bearing and shock absorption during locomotion. Theoretically, assuming that body weight remains constant, the proportionate amount of stress applied to those structures decreases as their size increases. Thus, an increase in the volumes and

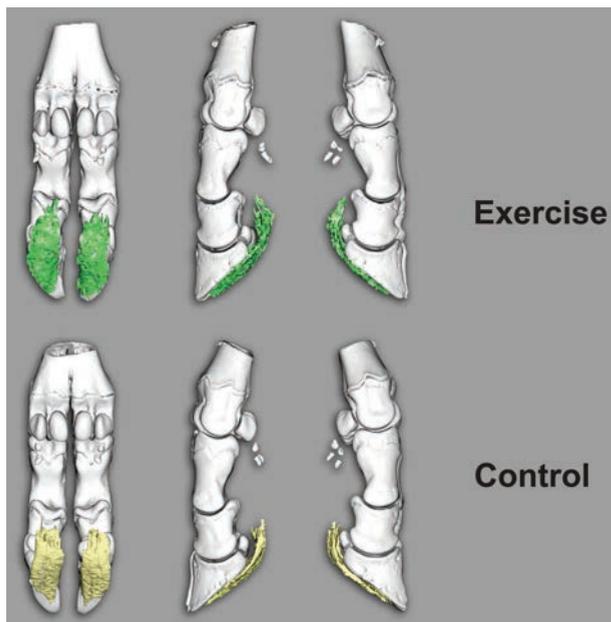


Figure 2—Representative recreated 3-D images of the palmar (left), lateral (middle), and medial (right) aspects of the distal portion of the right forelimbs of 6-month-old dairy calves that were either maintained in a grass paddock and not encouraged to exercise (control) or in a 0.8-km lane that consisted of dirt, stones (0.32- to 0.95-cm pea gravel and 5-cm crusher run), and grass and encouraged by placement of water and feed troughs at opposite ends of the lane to walk at least 3.2 km daily (exercise) for 4 months. The images were created by software programs from data obtained from MRI and CT evaluations. The digital cushion is highlighted in green in the images for the calf in the exercise group and yellow in the images for the calf in the control group.

surface areas of the digital cushion and distal phalanges should have a positive effect on hoof health and cattle welfare.

Lameness in cattle is associated with many factors including genetics, conformation, diet, contagious pathogens, hygiene, housing systems, animal behavior, and management, and many interventions to prevent lameness have been investigated.^{2,11} In the dairy industry, at the herd level, lameness is positively associated with milk production and confinement management systems. Multiple studies¹¹⁻¹⁴ have been conducted to assess the effect of various types of flooring on foot and hoof health. Results of a study¹⁴ that compared rate of claw wear among cows housed on slatted concrete, asphalt, asphalt with rubber-matted stalls, and rubber mats indicate that claw wear was greatest for cows housed on asphalt (lateral claw, 5.30 ± 0.31 mm/mo; medial claw, 5.95 ± 0.33 mm/mo) and least for cows housed on rubber mats (lateral claw, 1.36 ± 0.19 mm/mo; medial claw, 2.02 ± 0.20 mm/mo), which was significantly less than that for cows housed on slatted concrete (lateral claw, 1.55 ± 0.31 mm/mo; medial claw, 2.98 ± 0.33 mm/mo). Simply providing cows that were housed on asphalt with access to rubber-matted stalls resulted in a significant decrease in claw wear (lateral claw, 3.29 ± 0.31 mm/mo; medial claw, 4.10 ± 0.32 mm/mo), compared with cows that were housed on asphalt without access to rubber-matted stalls.¹⁴ The findings of that study¹⁴ highlight the importance of minimizing the amount of time cattle spend on concrete and asphalt. Concrete and asphalt are hard and unforgiving surfaces for all animals, and results of multiple studies^{2,5,9,12-15} suggest that housing cows on more natural terrain is beneficial for hoof and reproductive health. However, the dairy industry requires that cows be housed in a clean environment and waste be intensively managed; thus, hard and slick flooring surfaces pervade for mature lactating cows. Consequently, focus should be placed on the rearing practices of young replacement heifers to identify management practices that enhance the development of healthy feet, which should improve the survivability of those cattle in the production system when they mature.

Understanding the function of the various structures of the bovine foot is important for determining the cause of lameness. The digital cushion acts as a shock absorber and plays a critical role in protecting the sole from contusions.³ Therefore, replacement dairy heifers should be reared in a manner that will maximize the development of the digital cushion. Exercise is an important component in foot development, as evidenced by the results of the present study and another study.¹⁶ In that study,¹⁶ the type of housing in which cattle were maintained was significantly associated with the strength and laxity, laminar morphology, connective tissue development, and biochemistry of the sole. Compared with cattle that were housed in straw-bedded yards (ie, movement was fairly unrestricted), cattle that were housed in cubicles (ie, movement was restricted) had more severe sole lesions and

an altered metabolism that changed the composition of the connective tissues of the foot and impaired the biomechanical resilience of the hoof.¹⁶ In the present study, calves in the exercise group that were forced to walk the length of a 0.8-km lane multiple times per day to access feed and water developed significantly larger digital cushions, compared with calves in the control group that did not have to walk very far to access their food and water.

In addition to exercise, the nature of the flooring on which exercise occurs also affects hoof growth. Results of 1 study¹⁷ indicate that calves housed in pens with slatted floors between 3 and 7 months of age were 1.7 times as likely to be culled, compared with herd mates that were housed in litter-bedded pens between 3 and 7 months of age.

Cattle generally adapt to their environment, and the rate of that adaptation is dependent on the nature of the new environment and how drastically it differs from their previous environment. Changes in housing systems are stressful to cattle. Factors that contribute to that stress include the actual movement to the new environment, reestablishment of the social hierarchy in the new environment, and changes in flooring or terrain, ration, and amount of exercise. Primiparous dairy cows that underwent 4 changes in housing systems prior to calving were 1.4 times as likely to be culled, compared with similar cows that underwent only 2 changes in housing systems prior to calving.¹⁷

Results of the present study and numerous other studies⁹⁻¹⁷ indicate that environment and exercise have a vital role in the development of the bovine foot and hoof. The findings of the present study were similar to those of a similar pilot study¹⁸ performed by our laboratory group. The design of that study¹⁸ was the same as the present study except only 4 calves (2 Holsteins and 2 Jerseys) were assigned to both the exercise and control groups, the exercise period was initiated at 2 weeks of age, and calves were slaughtered at 4 months old. Similar to the present study, the mean weight immediately prior to slaughter did not differ significantly between the exercise and control groups; however, the mean weights of the Jersey and Holstein calves in the control group were 0.64 and 1.95 kg, respectively, higher than the mean weights of the Jersey and Holstein calves in the exercise group.¹⁸ Unlike the present study, the mean surface area of the lateral claw of the third phalanx for the Jersey calves in the exercise group (349 mm^2) was significantly greater than that for the Holstein calves in the control group (90 mm^2).¹⁸ The reason for this drastic difference between the Jerseys of the exercise group and the Holsteins in the control group is unknown. It is possible that Jerseys have a faster rate of bone growth between 2 weeks and 4 months of age or respond and adapt to exercise better than do Holsteins. Also, the Jerseys in the exercise group had to take more steps/km than did their Holstein cohorts because they were smaller.¹⁸ This meant that the Jerseys' feet underwent loading and unloading forces more frequently than did

the Holsteins' feet, which might have stimulated digital blood flow and bone growth. Although the results of that study¹⁸ and the present study clearly indicate that exercise on alternate terrain enhances the development of the digital cushion and bony structures of the feet of dairy calves, further studies are necessary to determine the optimal environment and amount of exercise required to maximize foot development of cattle.

Results of another study³ indicate that the prevalence of sole ulcers and white line disease increases as the thickness of the digital cushion of dairy cattle decreases, and the prevalence of lameness in cows with a digital cushion thickness in the upper quartile was 15% less than that for cows with a digital cushion thickness in the lower quartile. The findings of that study³ were corroborated by those of another study¹⁹ that was conducted to describe the anatomic and histologic changes in the digital cushions of cattle. Anatomic and histologic changes were most frequently observed in the middle pad of the digital cushion.¹⁹ In some cattle, the middle pad of the digital cushion terminated at the end of the flexor process of the third phalanx and provided inferior cushioning that predisposed those cattle to sole ulcers.¹⁹ Cattle with digital cushions that extended past the flexor process of the third phalanx had more cushioning and were at less risk of developing contusions, sole ulcers, and lameness.¹⁹

Cattle with large digital cushions should have feet that are biomechanically resilient and less prone to lameness, which should improve their longevity, and research is warranted to elucidate the housing and management strategies necessary to raise such cattle. Cost-effective management protocols that enhance the hoof health of dairy replacement heifers are generally welcomed and adopted by producers. Management practices that increase the well-being of cattle typically increase their production and longevity, which in turn improves the profitability and sustainability of the operation. On dairy operations, the replacement heifer enterprise is generally viewed as an expense rather than an investment and potential profit center,²⁰ a view that has led to the expansion of the dairy heifer grower industry.²¹ Although the expansion of the dairy heifer grower industry provides opportunities for the dairy industry, there are plenty of challenges associated with raising quality replacement heifers.^{6,20,21} In 2010, the mean cost to raise a dairy heifer ranged between \$1,600 and \$1,850; however, there was no guarantee that investment would result in an acceptable herd replacement.^{20,21} Annual culling rates for dairy herds are usually quite high and variable, ranging from 16% to 45%, with a 30% culling rate considered acceptable, which suggests that the industry is quite rigorous.^{5,6,22} In the beef industry, replacement animals are not truly profitable until they reproduce and raise offspring. Management protocols that improve the health and well-being of herd replacements, including bulls, are likely to maximize

production and be beneficial to both the animals and the producers. These protocols should include interventions to prevent lameness.

Enhancement of the foot development of dairy replacement heifers is likely to result in a decrease in the prevalence of lameness and culling rates (ie, improved longevity), and an improvement in weight gain, fertility, and milk production, all of which translate into an increased profit for producers.²² From an ethical standpoint, it is likely to improve the welfare of those heifers, which is desirable from a marketing and consumer perspective.

In the present study, the digital cushions and second and third phalanges of dairy calves that were maintained on an alternative terrain of dirt, stones, and grass and exercised daily for 4 months were larger than those of similar calves that were maintained in grass paddocks and not encouraged to exercise. These findings suggested that husbandry practices implemented early in life can enhance foot development, which might proactively prevent or reduce the incidence of lameness in mature cattle. Additional research is necessary to determine the type of terrain and exercise necessary to maximize foot development and the appropriate age at which to initiate those interventions.

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Footnotes

- a. Guard C. The cost of lameness and the value of hoof care (abstr), in *Proceedings*. Hoof Care Conf 1997;4.
- b. Verio 3-T clinical scanner unit, Siemens, Malvern, Pa.
- c. 164-slice dual-energy SOMATOM Definition CT unit, Siemens, Malvern, Pa.
- d. Wizard workstation and proprietary software, Siemens, Malvern, Pa.
- e. Mimics, version 14, Materialise HQ, Leuven, Belgium.
- f. D Studio Max, Discreet Logic, Montreal, QC, Canada.
- g. PROC MIXED, SAS, version 9.3, SAS Institute Inc, Cary NC.
- h. Microsoft Excel for Mac, version 14.4.2, Microsoft Corp, Redmond, Wash.

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