

Effects of barefoot trimming on hoof morphology

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Objective To monitor changes in hoof morphology in response to barefoot trimming.

Methods Seven horses were trimmed every 6 weeks according to barefoot trimming principles, which involved levelling the hoof to live sole, lowering the heels, bevelling the toe and rounding the peripheral wall, while leaving the sole, frog and bars intact. A 4-month period was allowed to lower the heels sufficiently to achieve a hoof shape representative of the barefoot trim. This was regarded as the starting point for morphological adaptations in response to maintenance of the trim. Hoof morphology was measured from lateral, dorsal and solar view photographs and latero-medial radiographs taken at 0, 4 and 16 months. Changes from 0 to 4 months represented differences between a natural hoof shape and the trim, while changes from 4 to 16 months represented adaptive effects during hoof growth.

Results Establishment of the barefoot trim involved significant shortening of the toe, heel and medial and lateral walls, with increases in angulation at the toe, medial and lateral walls, but not at the heel. Maintenance of the trim resulted in a palmar/plantar migration of the heels, with increases in support length, heel angle and solar angle of the distal phalanx (P3).

Conclusions Bevelling the toe and engaging the frog and bars in the weight-bearing function of the foot resulted in elevation of the heel angle and solar angle of P3. These changes may be beneficial in treating under-run heels and negative solar plane angulation of P3.

Keywords barefoot trim; biomechanics; farriery; hoof angle; horses; under-run heels

Abbreviation P3, distal phalanx

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Protecting the foot of the domestic horse represents an important husbandry practice, documented throughout history,¹ that aims to maintain a relatively healthy foot and, hopefully, a horse relatively free of severe or chronic lameness problems. These methods included a wide range of devices from non-metallic materials attached to the foot via straps or harness-like materials to metallic objects resembling the horseshoe of today. While early Greek horsemen preferred breeding methods to ensure healthy feet, for the last several hundred years the metallic horse shoe has been a method of choice.¹ Much research has been performed documenting the biomechanical and physiological effects of shoeing on the foot under

static and dynamic conditions^{2–4} as well as the effects of different ground surfaces.^{5,6} As a result, significant insights have been gained regarding the effects of physical forces during foot-ground impact on the distal limb.^{5,7} The effects of shoeing have been studied,^{4,5} specifically in relation to proprioception,⁸ limb kinematics,⁹ limb kinetics¹⁰ and energetics.¹¹ The findings from these studies indicate that the use of horse shoes is not a panacea and involves some potentially deleterious effects on soundness. This has stimulated an interest in maintaining hooves without shoes and advocates have provided anecdotal observations to support keeping horses barefooted and trimming the hooves in a manner that is believed to promote the health of the unshod hoof.^{12,13} However, there is a need to evaluate the effects of barefoot trimming techniques under modern management conditions.

Studies of wild horses have described the hoof as having a variable shape that is based on a more or less rounded circumference with natural bevelling at the toe, the medial wall and the lateral wall, while the soles can be flat with protruding frogs or concave (arched soles).¹² Ovnicek et al.¹⁴ described four imprint marks located medially and laterally at the heels and toe, a finding that formed the basis for the four-point trim for both shod and barefooted horses. The four-point trim was subsequently shown to be associated with areas of strain concentration above the hoof contact points when weight-bearing on a firm surface.¹⁵ More recently, it has been shown that the substrate over which the horse moves and the climate in which the horse lives affect hoof morphology in wild horses.¹⁶ Consequently, there is no uniform prescription for barefoot trimming. Given the different lifestyles and habitats of wild and domesticated horses, it is controversial whether the wild horse hoof is an appropriate model from which to develop principles for trimming barefooted domesticated horses.¹⁶ Some of the barefoot trimming methods that have been used have resulted in short-term deleterious effects upon the horse's foot due to either excessive removal of tissues from the hoof wall, sole or frog or by placement of the hoof and distal phalanx at an unnatural angle.^{12,13} The longer term effects of maintaining domesticated horses' feet with a barefoot trim have not been evaluated. Since the tissues of the foot are responsive to their loading environment, it is hypothesised that when the sole, frog and bars are incorporated in the weight-bearing apparatus, these structures will hypertrophy and change biochemically in response to locomotor forces. If this is true, then the barefoot trim would be expected to induce changes in the size and shape of the internal structures of the hoof, resulting in alterations in the external morphology.¹⁷ It is expected that these changes would occur over a prolonged period of time, requiring at least one entire growth cycle of the hoof wall to begin to be evident.

The purpose of this study was to investigate the short- and long-term effects of the barefoot trim on hoof conformation. The hypothesis is that lowering of the heels to engage the frog, bars and sole into the weight-bearing apparatus and shortening the foot by bevelling the

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toe, while maintaining the dorsopalmar and mediolateral balance of the foot, will stimulate adaptations within the foot that result in significant changes in its external dimensions. There is little scientific data describing the effects of any type of barefoot trim, particularly in horses that participate in regular exercise in a riding arena or how such trimming may affect the overall conformation and health of the foot for an extended period of time. Thus, the present study was undertaken to trim a group of horses in a specific manner and to document the changes in their feet by digital photography, radiography and quantitative measures over an extended time period while they performed regular exercise.

Materials and methods

The study was performed with approval of the university's animal ethics committee.

Horses and farriery

The subjects were seven adult Arabian horses (height 149 ± 3.2 cm; mass 440 ± 44.8 kg; age 13.6 ± 1.6 years) that are used in a lesson program at the undergraduate level of the university. The horses were maintained on pasture and ridden in an arena with sand footing for 1 to 3 h/day, 5 days a week throughout the period of study, with all horses receiving a similar workload. These horses had been barefooted for a period of 3–4 years previously. The hooves had been allowed to grow naturally with minimal farriery interventions for the previous year. At approximately 8-weekly intervals the toe had been trimmed and the wall rasped as necessary to maintain the toe angle in alignment with the pastern angle.

The barefoot trim of all four feet involved lowering the heels to allow the frog and bars to contact the ground as active participants in the weight-bearing apparatus. Dorsopalmar and dorsoplantar balances were achieved by aligning the dorsal hoof wall (toe angle) with the pastern axis. Mediolateral balance was initially achieved by trimming to the depth of live sole, the waxy textured horn found beneath the flaky superficial horn tissue of the sole.¹⁸ Ultimately, the goal was to trim the wall and lower the heels to the level of the live sole as far back as the widest part of the frog. The heels were lowered gradually over the course of several trimming cycles to avoid creating a negative sole plane for P3 or overloading the ligamentous tissues that support the proximal and distal interphalangeal joints. The frog and bars were not trimmed except to remove loose pieces of horn and excessive growth that extended distal to the wall. The sole was not trimmed further after it had been levelled to the live plane in the initial few trimmings; instead, it was allowed to develop a sickle-shaped sole callus, which is an area of thickened sole between the apex of the frog and the white line at the toe. The wall external to the white line was bevelled around the entire hoof with a rasp.

At the toe, the bevel initially included only the outer hoof wall and then was gradually enlarged to the level of the white line and, as a sole callus developed, the bevel was extended to the dorsal edge of the callus.

At the first evaluation (0-month evaluation), photographs and radiographs were taken prior to trimming the hooves to describe the initial shape of the foot. Each horse was then trimmed according to the above prescription of the barefoot trim while maintaining the parallel align-

ment of the hoof-pastern axis. Trimming was repeated at intervals of 5–6 weeks, gradually lowering the heels to the level of live sole. By the fourth trimming, the hooves conformed to these requirements but had undergone minimal external adaptation to the new method of trimming. Photographs and radiographs were taken one day after the third trim, which was approximately 4 months after the start of the study (4-month evaluation), and was regarded as the starting point for measuring morphological changes in response to the barefoot trim. The horses were then trimmed at 5–6 week intervals, maintaining the prescription of the barefoot trim for a further 12 months. At the end of this time, photographs and radiographs were taken 1 day after trimming to assess the morphological adaptations to the barefoot trim (16-month evaluation). Given that the initial length of the hoof wall at the toe was (mean \pm SD) 8.54 ± 0.85 cm and the hoof wall grows at a rate of about 1 cm/month in unshod horses,¹⁹ this was adequate time for complete regrowth of the hoof wall.

Data collection

For all four feet, morphology of the hoof was assessed using lateral, dorsal and solar view photographs and lateral view radiographs. For the dorsal and lateral view photographs, the horses stood on wooden blocks 5 cm high with a linear calibration in the plane of the coronet. For the solar views, the hoof was raised and photographs were taken with the calibration scale in the plane of the sole. For all photographs, the camera lens was perpendicular to the plane in which measurements were being made. Lateral view radiographs were taken with the horse standing on a wooden block that incorporated a calibration scale. Metron-PX software (EponaTech, Creston, CA, USA) was used to measure linear and angular variables describing hoof conformation and the relationship between P3 and the hoof wall. The following variables were measured in each view:

Lateral View Photographs

Toe length to ground (cm) = length of dorsal hoof wall from hairline at coronet to ground plane.

Toe angle (degrees) = angle between dorsal aspect of hoof wall and the ground plane.

Heel length (cm) = length of heel measured along its palmar/plantar aspect from hairline to ground.

Heel angle (degrees) = angle between palmar/plantar aspect of heel and ground plane.

Support length (cm) = length of the bearing surface of the distal hoof wall excluding the bevel (Figure 1).

Dorsal View Photographs

Medial wall length (cm) = length of medial wall from hairline to ground.

Medial wall angle (degrees) = angle between medial hoof wall and solar plane.

Lateral wall length (cm) = length of lateral wall from hairline to ground.

Lateral wall angle (degrees) = angle between lateral hoof wall and solar plane.

Solar View Photographs

Solar area (cm²) = area within the periphery of the wall (includes wall, sole, frog).

Frog area (cm²) = area within the periphery of the frog.

Heel separation (cm) = distance between the medial and lateral heels at the most palmar/plantar part of the wall.

Heel to bulb length (cm) = distance between a line connecting the most palmar/plantar extent of the wall at the heels and a line connecting the most palmar/plantar part of the bulbs.

Lateral View Radiographs

P3 to start of bevel at the toe (cm) = horizontal distance from the dorsal tip of P3 to the start of the bevel which marks the point where the hoof wall loses contact with the ground (Figure 1).

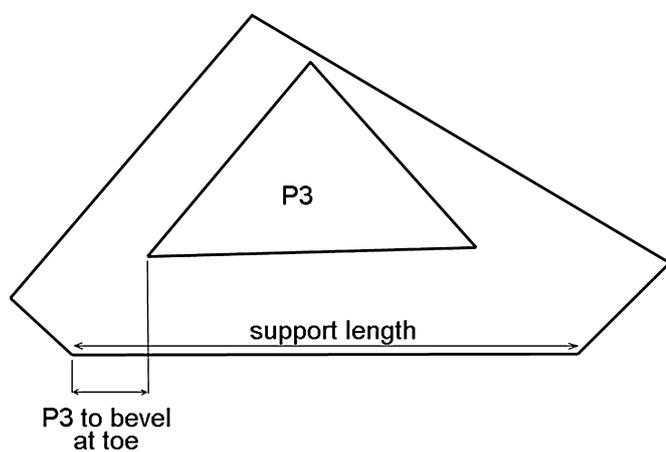


Figure 1. Landmarks used to measure support length of foot (measured from lateral view photographs) and distance from the distal phalanx (P3) to the bevel at the toe (measured from lateral view radiographs).

P3 solar angle (degrees) = angle between the solar surface of P3 and the ground plane. Positive values indicate that the palmar/plantar part of P3 is higher than the dorsal part.

Statistical analysis. Statistical software (SAS Institute Inc., Cary, NC) was used to calculate descriptive statistics (mean, SD) for the morphological variables at each evaluation. A GLM model for repeated measures ANOVA was used to seek changes occurring between 0 months and 4 months, which represented farriery changes from the natural hoof shape to the barefoot trim, and changes between 4 months and 16 months, which represented adaptations in response to maintaining the hoof with the barefoot trim. Preliminary statistical evaluation indicated that fore and hind hooves were changing shape in the same manner. Therefore, data for all limbs were combined in the statistical model with the individual limbs being nested within horse. The statistical tests used a significance level of $P < 0.05$.

Results

Changes from 0 to 4 months

At the start of the study the hooves typically had long walls that were flared around the periphery (Figure 2). The wall appeared to be the main weight-bearing part of the foot since the frog, bars and sole were recessed within the hoof wall. In most cases, the frog was fairly well developed as judged by the fact that it protruded below the level of the surrounding sole (Figure 2) but did not touch the ground when the horse was standing on a hard surface. Some hooves had a small sole callus in front of the apex of the frog.

Removal of the overgrowth of horn and shortening of the wall between the 0-month and 4-month evaluations resulted in a smaller

Table 1. Mean \pm SD of variables summarising morphological changes in all hooves ($n = 28$) of 7 horses from the start of the study (0 months) and at 4 and 16 months after initiating the barefoot trim

Variable	0 months	4 months	16 months
Toe length to ground (cm)	8.54 \pm 0.85 ^A	7.87 \pm 0.42 ^{A,B}	8.05 \pm 0.45 ^B
Toe angle (degrees)	49.90 \pm 4.03 ^A	52.64 \pm 3.79 ^{A,B}	51.45 \pm 3.16 ^B
Heel length (cm)	3.30 \pm 0.56 ^A	2.63 \pm 0.28 ^A	2.64 \pm 0.27
Heel angle (degrees)	35.65 \pm 7.07	38.82 \pm 8.93 ^B	44.28 \pm 5.07 ^B
Inner wall length (cm)	5.71 \pm 0.85 ^A	4.90 \pm 0.50 ^A	4.96 \pm 0.73
Inner wall angle (degrees)	73.62 \pm 5.89 ^A	78.62 \pm 5.46 ^A	78.31 \pm 5.66
Outer wall length (cm)	5.46 \pm 0.71 ^A	4.83 \pm 0.54 ^A	4.79 \pm 0.68
Outer wall angle (degrees)	72.36 \pm 4.91 ^A	76.02 \pm 4.77 ^A	75.68 \pm 3.60
Support length (cm)	11.20 \pm 1.23	10.93 \pm 0.62 ^B	11.59 \pm 0.56 ^B
Solar area (cm ²)	137.18 \pm 15.38 ^A	125.80 \pm 8.69 ^A	120.68 \pm 6.77
Frog area (cm ²)	22.77 \pm 4.65 ^A	27.73 \pm 3.52 ^{A,B}	24.40 \pm 2.96 ^B
Heel separation (cm)	7.68 \pm 0.69 ^A	6.98 \pm 0.60 ^{A,B}	6.57 \pm 0.68 ^B
Heel-bulb length (cm)	2.72 \pm 0.62 ^A	2.10 \pm 0.46 ^A	1.73 \pm 0.35
P3 to bevel at the toe (cm)	3.77 \pm 0.59 ^A	2.82 \pm 0.38 ^A	2.89 \pm 0.41
P3 solar angle (degrees)	3.70 \pm 2.29 ^A	5.85 \pm 1.9 ^{A,B}	7.38 \pm 2.06 ^B

Significant differences over time were detected using repeated measures ANOVA and Tukey B post hoc tests with hoof nested within horse.

^AVariables differ significantly ($P < 0.05$) between 0-month and the 4-month evaluations.

^BVariables differ significantly ($P < 0.05$) between 4-month and the 16-month evaluations.

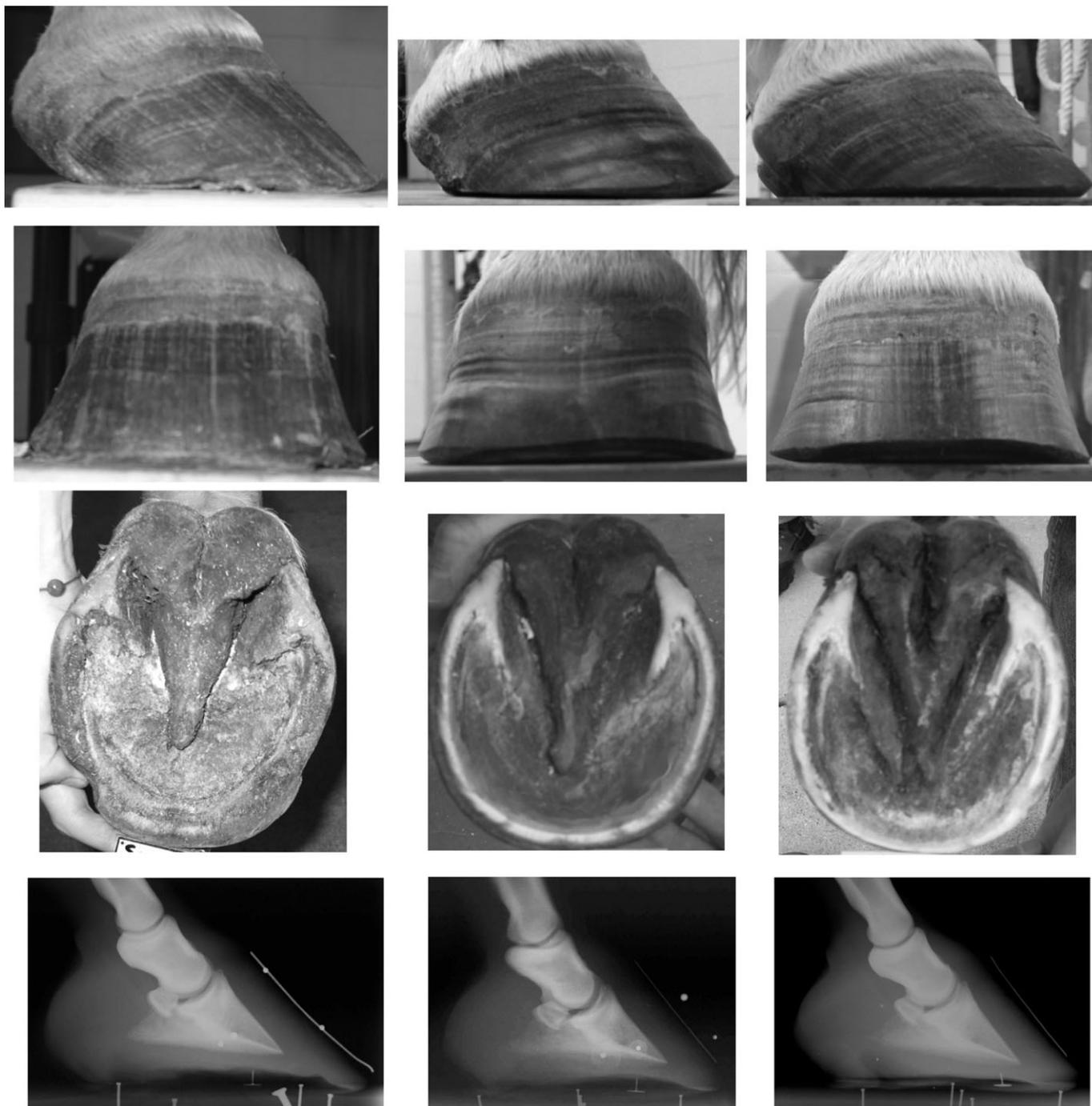


Figure 2. Photographs and radiographs of the right front hoof of one horse at the 0 month evaluation (left column), the 4-month evaluation (centre column) and the 16-month evaluation (right column). The rows show from top to bottom: lateral view photographs, dorsal view photographs, solar view photographs and lateral view radiographs.

hoof, shown by significant reductions in lengths of the toe, heel, medial wall and lateral wall (Table 1, Figures 2, 3). Angles of the toe, medial wall and lateral wall were significantly increased by the initial shortening of the wall and removal of distal flaring. Heel angle did not change significantly. The dorsal view at 4 months (Figure 2) showed a distal deviation of the growth lines at the toe.

On the solar surface there were decreases in solar area, heel separation and distance between the palmar/plantar aspect of the heels and the bulbs, and an increase in frog area. On the radiographs, the distance from the dorsal tip of P3 to the dorsal extremity of the weight-bearing surface at the start of the bevel decreased, while the solar angle of P3 increased.

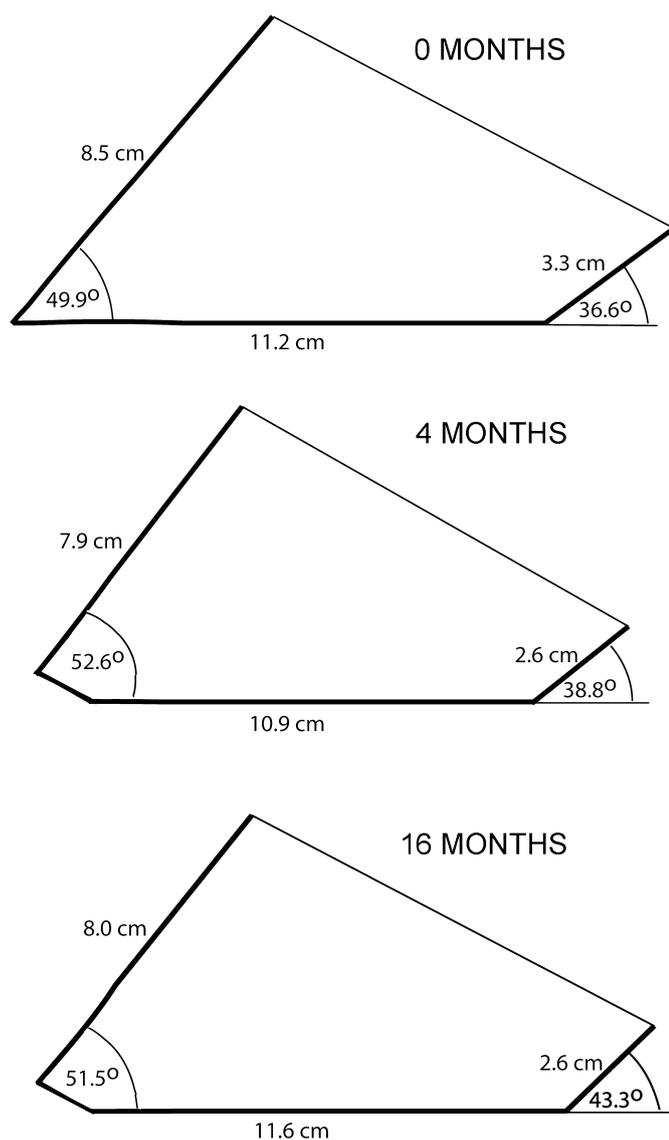


Figure 3. Mean hoof dimensions as seen in the lateral view at 0 month (top), 4 months (middle) and 16 months (bottom).

Changes from 4 months to 16 months

As the barefoot trim was maintained over the next 12 months, the distal wall descended parallel to P3 without flaring toward the ground surface. The position of the bevel at the toe relative to the tip of P3 was maintained and did not change during this period. Heel angle increased significantly from 38.82° to 44.28° without any change in heel length (Table 1, Figures 2, 3) and the solar angle of P3 increased from 5.85° to 7.38°. Heel separation decreased as the heels migrated palmar/plantar to the frog and there was a trend toward a further decrease in heel-bulb length that did not reach statistical significance. The area of the frog decreased during this time.

Discussion

This study has shown significant changes in external morphology of the hoof in response to barefoot trimming that are thought to be a

consequence of alterations in the shape and composition of the internal hoof structures in horses that performed a regular work schedule in a riding arena with sand footing, compared with feral horses. Hoof morphology at the start of the study resembled that of wild horses that move over a relatively soft sandy substrate.¹⁶ Exercise affects the shape of the hoof capsule, whereas P3 tends to retain its size and shape, thus allowing it to act as a stable platform for supporting the capsule and withstanding loads.²⁰ The horses in this study had been accustomed to a consistent exercise regimen for at least 4 years and this did not change during the study, so it is unlikely that exercise, per se, was the cause of the observed changes in hoof morphology. Furthermore, since they had not been shod during the previous 4 years, the horses already showed some adaptations to being barefoot, including having a small sole callus and moderate frog development (Figure 2), which may have facilitated and hastened the transition to the barefoot trim. On the other hand, horses that have been shod continuously for a prolonged period and those that enter a barefoot programme with very long heels or atrophied frogs and bars may take considerably longer than 4 months to make the transition to going barefoot. Seasonal climatic changes may be associated with changes in hoof shape. For example, in an area with wet winters and dry summers, free-ranging horses had significantly lower hoof angles in winter than in summer.²¹ Ideally, a group of controls would have been maintained under the same management and exercise conditions, but it was not possible to acquire a large enough number of horses to divide them into two groups and retain sufficient statistical power to make inter-group comparisons. Since the evaluations at 0 months and 4 months were conducted at different times of year, it is possible that changes during this period were influenced by the weather. However, the 4-month and 16-month evaluations were performed at the same time of year, making it less likely that climatic changes affected differences in hoof shape in response to maintenance of the barefoot trim.

At the start of the study, the hoof walls were somewhat overgrown in spite of regular exercise in a sand arena. Hoof size and shape differed markedly between individual horses at the start of the study (Table 1), as shown by the large standard deviations that resulted in coefficients of variation (CV) greater than 10% for many variables, especially those describing linear dimensions of the hoof wall. The CVs tended to decrease as the hooves were trimmed to conform to the barefoot trim. The possibility cannot be ruled out that the hooves of some horses may have already started to adapt internally during the initial 4 months and it is possible that the morphological changes measured between 4 and 16 months may have underestimated the effects of the barefoot trim. However, this should not affect the interpretation of the results.

During the first 4 months of the study, many changes in hoof morphology reflected alterations in the shape of the hoof that were a direct result of the trimming procedure. Most of the linear dimensions of the hoof decreased as a consequence of removing the wall overgrowth that had accumulated during the period of self-trimming. The associated increases in angulation of the toe, medial wall and lateral wall were due to removal of flaring of the distal wall associated with the overgrowth of horn. Hoof wall strain is inversely related to the angulation of the wall.²² Therefore, removal of flares resulting in a more upright angulation of the medial and lateral walls would be expected to generate lower strains within the wall and laminae. Also, there is

likely to be an effect on hoof loading and regional laminar density as a consequence of reducing tensile stress that tends to separate the walls from the laminae.²³ The increase in toe angle during the initial 4-month period averaged 2.7°. A change of this magnitude over a period of several months allows gradual adaptation of the internal foot tissues and the tendinous and ligamentous structures that support the proximal and distal interphalangeal joints. Therefore, the gradual approach to achieving the required hoof shape at the start of the study was unlikely to cause pathological changes in these tendo-ligamentous structures in which strain is determined mechanically by the interdigital angulations.²⁴

During the 12-month period of maintenance of the barefoot trim, the length of the hoof wall at the heel, medial wall and lateral wall did not change significantly, while toe length increased by a small (0.18 cm) but statistically significant amount. The hoof adapted to the increased weight distribution on the frog and bars by a palmar/plantar migration of the wall at the heels, which was evident as an increase in support length of the hoof. The heel angle became more upright, which was associated with the distal part of the heels moving to a more palmar/plantar position. When viewed from the solar surface, the heels were seen to extend just palmar/plantar to the widest part of the frog behind which the heels converged slightly resulting in a decrease in heel separation. The distance from the heels to the bulb was smaller at the 16-month evaluation than at the 4-month evaluation but this change did not reach statistical significance.

Heel angle increased by an average of almost 9° over the 16 month study period as the heels appeared to migrate in a palmar/plantar direction. Under-run heels, which have been defined somewhat arbitrarily in one study as having the heel angle more than 5° less than the toe angle,²⁵ are a significant problem in domesticated horses and may contribute to catastrophic breakdowns.²⁶ Heel angles similar to those at the 16-month evaluation have been reported in a population of Thoroughbred racehorses.²⁷ The fact that the difference between toe angle and heel angle decreased from 13.8° to 7.2° during the period of maintenance of the barefoot trim was regarded as a positive change. We hypothesise that this was a consequence of bevelling the toe combined with allowing participation of the frog and bars in the weight-bearing function of the foot. The resulting increase in heel angle is interpreted as a beneficial effect that would reduce the risk of injuries associated with under-run heels.²⁶

The unshod hoof deforms in response to loading during the stance phase, whereas shoeing limits deformation of the hoof and expansion of the bulbs.^{28,29} The heel region has an important proprioceptive function mediated through the presence of Pacinian-like corpuscles that are stimulated when the palmar/plantar foot contacts the ground.⁸ The sensory information is incorporated into spinal cord reflexes during locomotion. Contact of the frog and bars with the ground is believed to play an important role in shock attenuation.⁴ In addition, contact of the frog and bars may participate in a haemodynamic mechanism that has been proposed to contribute to energy dissipation by regulating blood flow through the palmar/plantar foot.³⁰ This suggestion is based on the fact that the microvasculature of the palmar/plantar foot has numerous tachykinin receptors (NK1), which, when activated, release endothelium-derived releasing factors (nitric oxide) to promote vasodilatation.³¹⁻³³ An increased microvas-

cular perfusion of the palmar/plantar foot may allow a more effective dissipation of high-frequency impact energies generated when the foot contacts the ground.²⁸ Thus, a major benefit of the barefoot trim is that it enhances the hoof's ability to expand during weight-bearing, which is important both in proprioception and shock absorption.

Frog area increased during the initial 4 months due to frog expansion as a consequence of trimming the walls shorter, which allowed the frog to make contact with the ground and appeared to stimulate growth of the frog tissue as judged by the visual prominence of the frog. During the period of maintenance of the barefoot trim, frog area decreased, which might seem to be a contradictory finding. However, histological evaluation of frog composition has shown a change from predominantly fatty, elastic and myxoid tissue to fibrocartilage as the frog is actively engaged in weight bearing.³⁰ We hypothesise that, over the 12-month maintenance period, the reduction in frog area may have been a consequence of changing its composition from a loose fatty material to a firmer, more resilient and compact texture of fibrocartilage. Contact between the frog and the ground may also contribute to changes in the internal structures of the foot, such as the digital cushion, which is believed to be important in palmar support of the foot. Future examination of the frog and digital cushion will have to address these potential adaptations to changes in hoof shape and the amount and type of exercise. Further indirect evidence of the benefit of engaging the frog in the weight-bearing process may be provided by the finding of aggrecanase-1 as an extra-cellular component of the laminae.³⁴ These molecules are typically found in tissues that sustain compressive loading, which suggests that the laminae are intended to be loaded in compression from below rather than suspending P3 from the wall. This theory is consistent with the idea of spreading the load across a greater solar surface of the foot.³⁵ However, current knowledge of hoof structure and dynamics is incomplete and these ideas, while speculative, may provide a stimulus for further research.

In conclusion, the results presented here indicate that significant morphological changes can take place in the hoof in response to the barefoot trim. Palmar migration of the heels, which resulted in increases in heel angle and support length, together with an increase in solar angulation of P3 were interpreted as potentially beneficial to the health of the foot.

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Errata

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Bilateral skin fold rotation-advancement flaps for the closure of large lumbosacral wounds in three dogs

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Neurological diseases of ruminant livestock in Australia. II: toxic disorders and nutritional deficiencies

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The legend for Figure 2 was incorrect and should be as follows:

Figure 2. Ovine *Clostridium perfringens* type D intoxication (a) Subacute, showing the bilateral, symmetrical necrosis (arrows) in the globus pallidus. (Courtesy of the *Atlas of Veterinary Neuropathology*, College of Veterinary Medicine, Cornell University.) (b) Acute, showing severe endothelial damage (arrows) in the cerebellum; the capillary lining is markedly attenuated and electron-dense. (electron micrograph). Bar = 10 mm.