The Veterinary Journal 246 (2019) 7–11

Contents lists available at ScienceDirect

The Veterinary Journal

journal homepage: www.elsevier.com/locate/tvjl

Can the hoof be shod without limiting the heel movement? A comparative study between barefoot, shoeing with conventional shoes and a split-toe shoe

J. Brunsting[a,1], M. Dumoulin[a,1,*], M. Oosterlinck[a], M. Haspeslagh[a], L. Lefère[b], F. Pille[a]

[a] Department of Surgery and Anaesthesiology of Domestic Animals, Faculty of Veterinary Medicine, Ghent University, Salisburylaan 133, 9820 Merelbeke, Belgium

[b] Department of Internal Medicine and Clinical Biology of Large Animals, Faculty of Veterinary Medicine, Ghent University, Salisburylaan 133, 9820 Merelbeke, Belgium

ARTICLE INFO

Article history:
Accepted 29 January 2019

Keywords:
Farriery
Heel movement
Hoof mechanism
Horse
Shoeing

ABSTRACT

Conventional shoeing restricts heel movement, which may have a negative effect on the orthopaedic health of the horse. A randomised crossover experimental study using noninvasive techniques was performed to compare the mediolateral heel movement in barefoot horses, horses shod with a conventional toe clipped shoe and with a new type of shoe with a split toe. In eight horses, 16 forelimbs were tested barefoot, shod with a conventional shoe and with the split-toe (ST) shoe, in random order. A displacement sensor was secured on the heels and measurements were collected continuously at a frequency of 679 Hz while horses were exercised on a treadmill at the walk (1.8 m/s), trot (3.5 m/s) and canter (8 m/s). Differences in heel movement between the conditions were analysed using a generalised estimating equations approach.

The conventional shoe was associated with significantly less heel expansion compared with the ST shoe and barefoot situation in all gaits ($P \leq 0.001$). Heel expansion with the ST shoe was not significantly different from the barefoot condition. For all gaits, shoeing was associated with a significant reduction in heel contraction compared with the barefoot situation ($P \leq 0.038$), except for the heel contraction at the canter using a conventional shoe. In conclusion, the heel expansion with the ST shoe did not differ significantly from when the horse was barefoot, in contrast with the significant restriction of the heel movement when a conventional shoe was used.

© 2019 Elsevier Ltd. All rights reserved.

Introduction

The equine hoof is a flexible structure, and its deformation during locomotion is an important part of the hoof mechanism. During limb loading the dorsoproximal part of the hoof wall moves palmarly while the sole and frog sink and the quarters flare to the side inducing heel expansion (Thomason, 1998; Hinterhofer et al., 2000; Burn and Brockington, 2001; Hinterhofer et al., 2001; Thomason et al., 2001; Hobbs et al., 2004; Hobbs et al., 2009). Besides this heel expansion, there is also a contraction of the heels at the end of the stance phase, during breakover. Hoof deformation has been investigated using strain gauges (Thomason, 1998; Dyhre-Poulsen et al., 1994; Summerley et al., 1998; Thomason et al., 2001; Thomason et al., 2002), photoelastic coating (Davies, 1997; Dejardin et al., 1999), optical systems (finite element analysis; Burn and Brockington, 2001; Roepstorff et al., 2001), Doppler (Hoffmann et al., 2001; Pietra et al., 2004), special horse boots (Barrey, 1990) and a displacement sensor (Yoshihara et al., 2010). The observed heel expansion in previous studies may be explained by two mechanisms. A first theory describes that the expansion of the heels is caused by the pressure on the frog generated by the ground reaction force (Colles, 1989; Roepstorff et al., 2001). A second theory states that heel expansion is caused by distal and palmar displacement of the middle phalanx between the ungular cartilages (Hinterhofer et al., 2000). The hoof mechanism is believed to play an important role in the absorption of the ground reaction force (Dyhre-Poulsen et al., 1994; Yoshihara et al., 2010) and in the perfusion of the hoof (Ratzlaff et al., 1985; Yoshihara et al., 2010; Back and Pille, 2013). Shoeing may have a negative effect on the hoof mechanism by restricting the expansion of the hoof (Balch et al., 1998; Thomason, 1998; Roepstorff et al., 2001; Yoshihara et al., 2010; Parkes and Witte, 2015). To overcome this issue, several horseshoes and shoeing techniques have been

* Corresponding author.
E-mail address: Michele.Dumoulin@ugent.be (M. Dumoulin).

[1] Shared first authorship.

https://doi.org/10.1016/j.tvjl.2019.01.012
1090-0233/© 2019 Elsevier Ltd. All rights reserved.

developed (Eliashar et al., 2002; O'Grady and Poupard, 2003; Curtis, 2006; van Heel et al., 2006; Tanaka et al., 2009; Yoshihara et al., 2010), yet thus far without satisfactory results. The present study investigated the effect of a newly developed horseshoe that has been specifically designed to allow heel expansion. This 'split-toe' (ST) shoe, which has a conventional design with a toe clip and additional side clips between the second and third nail hole, is provided with a partial split at the toe that should be sawn through once the shoe has been nailed on the hoof, resulting in two halves moving independently (Fig. 1).

The aim of this study was to investigate the mediolateral heel movement in barefoot horses, horses shod with a conventional shoe, and horses shod with the ST shoe. It was hypothesised that the ST shoe would present significantly less restriction of the heel expansion than a conventional shoe, when compared with the barefoot condition.

Materials and methods

Horses

Eight healthy, unshod Warmblood horses from the teaching herd of the Faculty of Veterinary Medicine of Ghent University were used (age range, 7–16 years; body mass range, 535–692 kg). Because data collection in this study was not invasive, nor harmful for the participating animals, institutional ethics committee approval was not deemed necessary by the committees' chairperson. All horses were examined clinically and did not present lameness prior to and during the study. The horses were accustomed to treadmill locomotion and the hooves were trimmed one week prior to the study by an experienced farrier and did not present relevant abnormalities in hoof conformation. Forelimb hoof angles were measured on a lateromedial radiograph and were defined as the angle between the dorsal aspect of the pedal bone and ground plane (Moleman et al., 2005).

Data collection

A displacement sensor with a target wire (Lord Sensing-MicroStrain Subminiature DVRT) with a measurement range of 24 mm and an accuracy of 0.1% (0.024 mm) was attached using polyurethane adhesive (Super Fast, Vettec) to the lateral and medial heel bulb, midway between the coronet and the sole. The sensor was connected via a lead wire to an in-line signal conditioner (Lord MicroStrain Demod-DC2) and subsequently to a wireless transducer (Lord MicroStrain SG-link LXRS wireless sensor node) that were both fixed on a tendon boot (Fig. 2). The data were recorded at a frequency of 679 Hz on a notebook computer with a data acquisition system (Lord MicroStrain WSDA LXRS wireless base station) in a dedicated software program (Node commander 2.13.0 Beta). Positive and negative values indicated heel expansion and heel contraction, respectively.

Fig. 1. The split-toe shoe is based on a conventional shoe with a toe clip and two side-clips between the second and third nail hole. The shoe is provided with a partially split toe that is sawn through after being nailed on the hoof, resulting in two halves moving independently.

(a)

(b)

Fig. 2. (A) Horse shod bilaterally with a split-toe shoe and equipped with a tendon boot with sensor nodes attached on the left forelimb. (B) Palmar view of the attached displacement sensor.

Protocol

Both front hooves of all horses were subjected to each of the following trials in random order, based on a computer-generated random number list with a block size of three: barefoot, conventional shoe with a toe clip, and the ST shoe. The conventional shoe with a toe clip was a standard steel shoe (Libero, Mustad) with a thickness of 8 mm. The ST shoe was the same type of shoe, to which two extra side clips were welded between the second and third nail hole. For each horse, all trials were performed consecutively with the displacement sensor kept in place. The ST shoe was tested before (ST BS) and after splitting the toe (ST AS) to test for the net effect on heel movement of adding side-clips to a conventional toe clipped shoe. The nailing pattern was identical in all shoeing types, four nails were used medially and laterally. Before each trial, the system was calibrated with the foot in a non-weightbearing position (zero expansion/contraction), resembling the situation during the swing phase of the hoof. All measurements were performed while the horses were exercised on a treadmill at a walk (1.8 m/s), trot (3.5 m/s) and at a canter (8 m/s). For statistical analyses, the data of 10 consecutive strides of each condition were evaluated using Microsoft Excel.

Statistical analysis

A masked statistical analysis was performed using SPSS 20 (IBM). To estimate the effect of the different shoe types on heel movement in the different gaits (walk, trot and canter), a generalised estimating equations model was used. A separate model was defined for each gait. Heel movement (expansion, contraction and total) was used as the dependent variable and shoeing (barefoot, conventional shoe, ST shoe before [ST BS] and after completely splitting [ST AS]), limb (left vs. right) and hoof angle as independent variables. For all gaits, the model was corrected for dependent observations by including horse as subject effect and limb side, shoe type and repetition as within subject effects. For the canter, the additional effect of the measured limb being leading or trailing was also included in the model. Statistical significance was set at $P \leq 0.05$ and when pairwise comparisons were made, a Bonferroni correction was applied. Unless otherwise stated, data are presented as mean ± standard deviation (SD).

Results

In all horses, a consistent pattern of heel movement was observed during the stance phase. During impact and mid-stance, heel expansion was observed, followed by heel contraction in the final part of the stance phase when breakover occurred (Fig. 3). The amount of heel expansion at the trot (2.47 ± 0.84 mm) and canter (4.97 ± 1.49 mm) was remarkably larger than the amount of expansion at the walk (1.37 ± 0.59 mm), whereas the amount of heel contraction was rather constant in all gaits (1.78 ± 0.58, 1.51 ± 0.53, 1.70 ± 0.53 mm in walk, trot and canter, respectively).

Although the shapes of the heel movement curves were similar in the different shoeing techniques tested, the amount of heel expansion differed. Table 1 and Fig. 4 summarise heel movement for the different situations. When a conventional shoe was used, the overall heel expansion decreased by 36.3% compared with a barefoot situation. There was no significant difference in heel expansion between the conventional shoe and the ST shoe before splitting the shoe, in all gaits. After splitting, the ST shoe allowed significantly more heel expansion than the conventional shoe in all gaits ($P < 0.001$), while there was no significant difference with the barefoot situation. Shoeing significantly limited the heel contraction compared with the barefoot situation in all gaits ($P \leq 0.038$), except for the heel contraction in canter using a conventional shoe.

The eight horses presented a median hoof angle of 50.6° (range 44.6°–57.3°) on lateromedial radiographs. There was no significant effect of the hoof angle on the heel expansion and contraction in any of the shoeing conditions. At the canter, the heel expansion did not differ significantly between the leading (mean expansion, 5.18 mm; SD, 1.51) and the trailing (mean expansion, 4.77 mm; SD, 1.44) limb whereas there was significantly less heel contraction in the leading limb (mean contraction, 1.47 mm; SD, 0.46) compared with the trailing limb (mean contraction, 1.94 mm; SD, 0.50; $P < 0.005$).

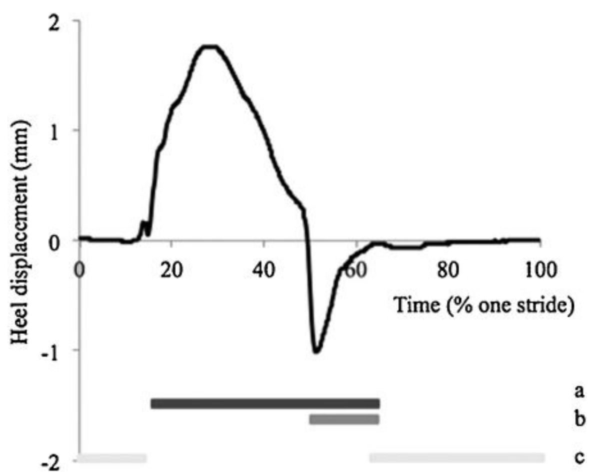

Fig. 3. Representative example of the heel displacement as a function of time in an unshod horse at the trot, through one complete stride. Positive values indicate heel expansion, whereas negative values indicate heel contraction (a: stance phase, b: breakover, c: swing phase).

Discussion

This study quantified the in vivo lateromedial heel movement in the forehooves of horses shod with a newly developed horseshoe ('ST shoe'), and compared this with a conventional toe clipped shoe and the unshod condition. Significantly more heel expansion was observed with the ST shoe compared with a conventional horseshoe, while the heel expansion in horses shod with a ST shoe was not significantly different from a barefoot condition.

Our results demonstrated a 36.3% decrease of heel expansion when a conventional shoe is used compared with the barefoot situation, which is similar to restrictions reported in other studies (Dyhre-Poulsen et al., 1994; Roepstorff et al., 2001; Yoshihara et al., 2010). It is reasonable to assume that this amount of restriction in heel movement observed with conventional shoeing techniques may affect hoof geometry and even orthopaedic health of the horse (Hinterhofer et al., 2001; Roepstorff et al., 2001). It has been reported that traditional shoeing restricts hoof mechanism, increases the weight of the distal limb and increases the shock impact (Back and Pille, 2013). Besides these negative effects of a shoe, the shoe will protect the hoof from excessive wear (Hinterhofer et al., 2001; Eliashar, 2007), provides traction on deformable surfaces (Back and Pille, 2013) and has been observed to improve gait quality (Willemen et al., 1997). As the ST shoe outperformed the other shoes and was not significantly different from the barefoot situation regarding heel expansion, this ST shoeing technique combines the advantages of shoeing with the natural capacity for heel expansion as in the barefoot horse. Heel expansion and the associated deformation is considered important for the perfusion of the distal limb (Ratzlaff et al., 1985; Yoshihara

Table 1
Mean ± standard deviation (SD) heel expansion and contraction (mm) in both forefeet of eight horses with a conventional shoe, the split-toe shoe before splitting (ST BS) and after splitting (ST AS) the toe, and in the barefoot condition, together with the relative percentage of heel movement compared to the reference barefoot situation, at the walk (1.8 m/s), trot (3.5 m/s) and canter (8.0 m/s).

	Walk	%	Trot	%	Canter	%
Heel expansion						
Conventional shoe	$0.97^{a} \pm 0.46$	56%	$1.81^{a} \pm 0.54$	61%	$4.04^{a} \pm 1.15$	74%
ST BS	$1.02^{a} \pm 0.52$	58%	$1.89^{a} \pm 0.55$	63%	$4.21^{a} \pm 1.24$	77%
ST AS	$1.74^{b} \pm 0.49$	100%	$3.23^{b} \pm 0.63$	108%	$6.21^{b} \pm 1.22$	114%
Barefoot	$1.75^{b} \pm 0.35$	100%	$2.98^{b} \pm 0.48$	100%	$5.44^{b} \pm 1.14$	100%
Heel contraction						
Conventional shoe	$1.56^{a,b} \pm 0.48$	71%	$1.40^{a} \pm 0.49$	75%	$1.63^{a,c} \pm 0.53$	85%
ST BS	$1.52^{a} \pm 0.37$	60%	$1.32^{a} \pm 0.40$	71%	$1.59^{a,b} \pm 0.44$	83%
ST AS	$1.84^{b} \pm 0.58$	84%	$1.48^{a} \pm 0.48$	79%	$1.69^{a,b} \pm 0.44$	89%
Barefoot	$2.20^{c} \pm 0.60$	100%	$1.87^{b} \pm 0.55$	100%	$1.91^{c} \pm 0.64$	100%

[a,b,c]Significant differences between barefoot/different shoeing types within each gait ($P < 0.05$).

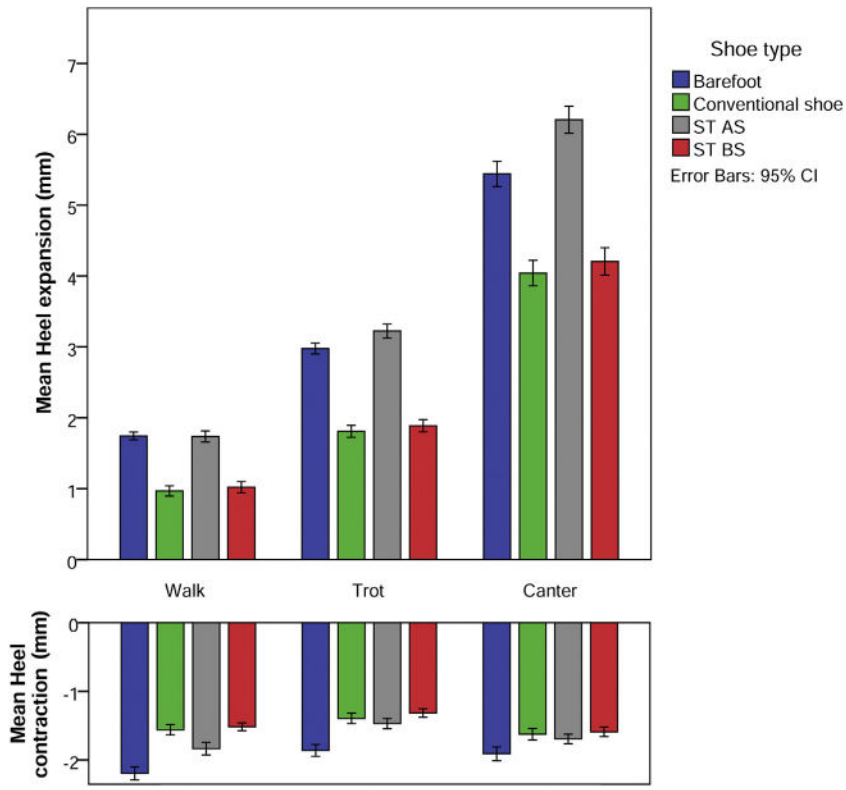

Fig. 4. Mean (95% confidence interval, CI) heel expansion and contraction in the four different situations in both forefeet of eight horses. ST BS, split-toe shoe before splitting; ST AS, split-toe shoe after splitting.

et al., 2010; Back and Pille, 2013) and the dissipation of the ground reaction force during the stance phase (Dyhre-Poulsen et al., 1994), which may both play a role in the prevention of injury (Back and Pille, 2013).

Additionally, compared with conventional shoes the ST shoe may further allow an independent horizontal and vertical movement of the lateral and medial heel on the circle and on uneven surfaces.

Besides heel expansion, this study has also measured heel contraction. Our results demonstrate equivalent restrictive effects of all shoeing techniques on heel contraction, which is similar to previous publications (Roepstorff et al., 2001; Yoshihara et al., 2010). Although the function of heel contraction is not fully understood, it is speculated that it is of minor influence on the hoof mechanism because of the very small amplitude compared with heel expansion. However, the contraction could play a role in the final ejection of blood in the blood-pump mechanism.

It could be argued that the displacement sensor only measures heel movement in a two-dimensional plane, while different shoeing techniques induce three-dimensional hoof deformations. However, heel movement is considered to be the key variable of hoof deformation (Colles, 1989; Dyhre-Poulsen et al., 1994; Roepstorff et al., 2001; Back and Pille, 2013). Therefore, the method used in this study, allowing quantification of lateromedial heel movement in vivo during locomotion, was considered suitable for the purpose of this study. The amplitude of heel movement in the current study is similar as described by Yoshihara et al. (2010) yet higher than reported earlier by Roepstorff et al. (2001). The latter difference may be explained by differences in the exact type of sensor, sensor placement, hoof conformation of the horses enrolled in the study and velocity of testing gaits. Notwithstanding the differences between these studies, it is of utmost importance that the different shoeing conditions in the present study were evaluated without any change in the position of the sensor. Therefore, while absolute values of heel movement have to be interpreted cautiously, the relative comparison between conditions is valid.

A second possible limitation of the study is the use of a treadmill for evaluating the horses at the walk, trot, and canter at constant speeds. It is widely known that overground locomotion is different from treadmill locomotion (Buchner et al., 1994; Thomason, 1998), with longer stance duration and smaller vertical movements in the forelimbs on the treadmill (Buchner et al., 1994). However, the advantage of the use of a treadmill is the standardisation of speed. Although it cannot be excluded that our results on heel movement could differ between treadmill and overground locomotion, the different shoeing techniques and the barefoot situation were all measured under exactly the same circumstances, which allows formulating sound conclusions regarding the comparison of the different shoeing techniques. Nevertheless, it would be very interesting to investigate heel movement during locomotion on a deformable surface such as arena footing. Unfortunately, this could not be performed in the present study since sinking of the heels into the arena footing would cause sensor damage and/or inaccurate data collection.

Further research is needed to evaluate the long-term effects of the ST shoe on soundness and athletic performance. However, preliminary practical experience with the ST shoe in sport horses illustrates that this shoe can easily be applied in a practical setting and stays well in place during a normal shoeing interval of approximately 6 weeks (unpublished data).

Conclusions

In conclusion, conventional shoeing significantly restricted heel expansion during the stance phase, whereas heel expansion with the ST shoe did not differ significantly from the barefoot situation. Since the heel movement plays an important role in the dissipation of the ground reaction force and the perfusion of the distal limb, it is speculated that the ST shoe may be beneficial for the maintenance of soundness and prevention of injury in sport horses. However, a long-term longitudinal study in a large study sample is needed to confirm this.

Conflict of interest statement

None of the authors of this paper has a financial or personal relationship with other people or organisations that could inappropriately influence or bias the content of the paper.

Acknowledgements

The authors thank Didier Rondelez for trimming and shoeing the horses. An abstract containing preliminary results was presented at the 25th ECVS Annual Scientific Meeting in Lisbon, Portugal, 7–9 July 2016.

References

Back, W., Pille, F., 2013. The role of hoof and shoeing, In: Back, W., Clayton, H. (Eds.), Equine Locomotion. Second Edn Saunders Elsevier, London, UK, pp. 147–174.
Balch, K., Butler, D., Collier, M., 1998. Balancing the normal foot: hoof preparation, shoe fit and shoe modification in the performance horse. Equine Vet. Educ. 10, 30–41.
Barrey, E., 1990. Investigation of the vertical hoof force distribution in the equine forelimb with an instrumented horseboot. Equine Vet. J. Suppl. 9, 35–38.
Buchner, H.H., Savelberg, H.H., Schamhardt, H.C., Merkens, H.W., Barneveld, A., 1994. Kinematics of treadmill versus overground locomotion in horses. Vet. Q. 16 Supplement 2, 87–90.
Burn, J.F., Brockington, C., 2001. Quantification of hoof deformation using optical motion capture. Equine Vet. J. Suppl. 33, 50–53.
Colles, C.M., 1989. The relationship of frog pressure to heel expansion. Equine Vet. J. 21, 13–16.
Curtis, S., 2006. Nail-less horseshoeing. In: Curtis, S. (Ed.), Corrective Farriery—A Textbook of Remedial Horseshoeing, Volume 2. R&W Publications Ltd., Newmarket, UK, pp. 495–514.
Davies, H.M., 1997. Noninvasive photoelastic method to show distribution of strain in the hoof wall of a living horse. Equine Vet. J. Suppl. 23, 13–15.
Dejardin, L.M., Arnoczky, S.P., Cloud, G.L., 1999. A method for determination of equine hoof strain patterns using photoelasticity: an in vitro study. Equine Vet. J. 31, 232–237.
Dyhre-Poulsen, P., Smedegaard, H.H., Roed, J., Korsgaard, E., 1994. Equine hoof function investigated by pressure transducers inside the hoof and accelerometers mounted on the first phalanx. Equine Vet. J. 26, 362–366.
Eliashar, E., McGuigan, M.P., Rogers, K.A., Wilson, A.M., 2002. A comparison of three horseshoeing styles on the kinetics of breakover in sound horses. Equine Vet. J. 34, 184–190.
Eliashar, E., 2007. An evidence-based assessment of the biomechanical effects of the common shoeing and farriery techniques. Vet. Clin. North Am. Equine Pract. 23, 425–442.
Hinterhofer, C., Stanek, C., Haider, H., 2000. The effect of flat horseshoes, raised heels and lowered heels on the biomechanics of the equine hoof assessed by finite element analysis (FEA). J. Vet. Med. A Physiol. Pathol. Clin. Med. 47, 73–82.
Hinterhofer, C., Stanek, C., Haider, H., 2001. Finite element analysis (FEA) as a model to predict effects of farriery on the equine hoof. Equine Vet. J. Suppl. 33, 58–62.
Hobbs, S.J., Mather, J., Rolph, C., Richards, J., 2009. The effects of limb posture on relationships between in vitro radial hoof strain, load and Joint angles. Equine Vet. J. 41, 229–232.
Hobbs, S.J., Mather, J., Rolph, C., Bower, J., Matuszewski, B., 2004. In vitro measurement of internal hoof strain. Equine Vet. J. 36, 683–688.
Hoffmann, K.L., Wood, A.K.W., Griffiths, K.A., Evans, D.L., Gill, R.W., Kirby, A.C., 2001. Doppler sonographic measurements of arterial blood flow and their repeatability in the equine foot during weight bearing and non-weight bearing. Res. Vet. Sci. 70, 199–203.
Moleman, M., van Heel, M.C.V., van den Belt, A.J.M., Back, W., 2005. Accuracy of hoof angle measurement devices in comparison with digitally analysed radiographs. Equine Vet. Educ. 17, 319–322.
O'Grady, S.E., Poupard, D.A., 2003. Proper physiologic horseshoeing. Vet. Clin. North Am. Equine Pract. 19, 333–351.
Parkes, R.S.V., Witte, T.H., 2015. The foot-surface interaction and its impact on musculoskeletal adaptation and injury risk in the horse. Equine Vet. J. 47, 519–525.
Pietra, M., Guglielmini, C., Nardi, S., Gandini, G., Cipone, M., 2004. Influence of weight bearing and hoof position on Doppler evaluation of lateral palmar digital arteries in healthy horses. Am. J. Vet. Res. 65, 1211–1215.
Ratzlaff, M.H., Shindell, R.M., DeBowes, R.M., 1985. Changes in digital venous pressures of horses moving at the walk and trot. Am. J. Vet. Res. 46, 1545–1549.
Roepstorff, L., Johnston, C., Drevemo, S., 2001. In vivo and in vitro heel expansion in relation to shoeing and frog pressure. Equine Vet. J. Suppl. 33, 54–57.
Summerley, H.L., Thomason, J.J., Bignell, W.W., 1998. Effect of rider and riding style on deformation of the front hoof wall in warmblood horses. Equine Vet. J. Suppl. 26, 81–85.
Tanaka, K., Hiraga, A., Takahashi, T., Kuwano, A., Morrison, S.E., 2009. Effects of aluminum hinged shoes on the structure of contracted feet in Thoroughbred yearlings. J. Equine Sci. 26, 67–71.
Thomason, J.J., 1998. Variation in surface strain on the equine hoof wall at the midstep with shoeing, gait, substrate, direction of travel, and hoof shape. Equine Vet. J. Suppl. 26, 86–95.
Thomason, J.J., Bignell, W.W., Sears, W., 2001. Components of variation of surface hoof strain with time. Equine Vet. J. Suppl. 33, 63–66.
Thomason, J.J., McClinchey, H.L., Jofriet, J.C., 2002. Analysis of strain and stress in the equine hoof capsule using finite element methods: comparison with principal strains recorded in vivo. Equine Vet. J. 34, 719–725.
van Heel, M.C.V., van Weeren, P.R., Back, W., 2006. Shoeing sound warmblood horses with a rolled toe optimises hoof-unrollment and lowers peak loading during breakover. Equine Vet. J. 38, 258–262.
Willemen, M., Savelberg, H.H.C.M., Barneveld, A., 1997. The improvement of the gait quality of sound trotting warmblood horses by normal shoeing and its effect on the load on the lower forelimb. Livest. Prod. Sci. 52, 145–153.
Yoshihara, E., Takahashi, T., Otsuka, N., Isayama, T., Tomiyama, T., Hiraga, A., Wada, S., 2010. Heel movement in horses: comparison between glued and nailed horse shoes at different speeds. Equine Vet. J. 42, 431–435.