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A comparison of three horseshoeing styles on the kinetics of breakover in sound horses

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Summary

A variety of horseshoe designs are believed to 'ease' breakover, or the unloading of the foot once the heels leave the ground. In this study, conventional toe-clip shoes, quarter-clip shoes, fitted to the white line at the toe, and Natural Balance horseshoes were fitted to the front feet of 9 sound Irish Draught-cross type horses. Forceplate and video motion analyses were undertaken during trot locomotion to determine the moment arm of the ground reaction force on the distal interphalangeal (DIP) joint, the peak DIP joint moment and the peak compressive force on the navicular bone. DIP joint moment arm during breakover was reduced with both Natural Balance (mean ± s.d. 77 ± 7 mm) and quarter-clip shoes (78 ± 9 mm) compared to the toe-clip shoes (86 ± 6 mm) ($P<0.01$). Peak DIP joint moment was not significantly different (175 ± 37, 171 ± 38 and 175 ± 31 Nmm/kg, in Natural Balance, quarter-clip and toe-clip shoes, respectively) and neither was peak force on the navicular bone (5.52 ± 1.52, 5.79 ± 1.53 and 6.14 ± 1.47 N/kg, respectively). Breakover duration (heel off to toe off) was not significantly reduced by the Natural Balance shoes (39 ± 6 ms) or the quarter-clip shoes (40 ± 6 ms) compared to toe-clip shoes (42 ± 9 ms). This study has demonstrated that the use of Natural Balance shoes reduces the moment arm of the ground reaction force (GRF) during breakover but does not reduce the peak DIP joint moment or the force on the navicular bone.

Introduction

Pulling the toe back or rolling the toe of horseshoes is reported to 'ease' the process of breakover (Turner 1986; Stashak 1987,1998; Wright and Douglas 1993). Traditional farriery books recommend dispensing with a midline toe-clip and rolling or bevelling the toe of the shoe to achieve this (Canfield 1968; Hickman and Humphrey 1988). Studies on foot wear have shown that feral horses rely on a large portion of the sole of the foot to bear weight and loading on the hoof wall is concentrated on 4 points (Ovnicek *et al.* 1995; Ovnicek 1997), of which the 2 cranial ones form a breakover line 2.5–4.0 cm cranial to the apex of the frog. These findings have lead to the development of the 4-point trim and, subsequently, a variety of horseshoes which have a somewhat square toe that moves the cranial extent of ground contact even closer to the heels than the traditional techniques. This design is claimed to advance breakover and reduce the force in the deep digital flexor tendon (DDFT) compared to conventional shoes (Redden 1998). One study, however, showed that a square-toe design did not reduce breakover duration in comparison to traditional shoeing (Clayton *et al.* 1991). Heel wedges have been shown to reduce peak DDFT force and distal interphalangeal (DIP) joint moment (Willemen *et al.* 1999), but we are not aware of equivalent studies on the effect of toe position and profile.

The DIP joint is extended by the ground reaction force (GRF) during stance. In studies of limb biomechanics, the GRF is considered to act at a single point under the foot, the point of zero moment (PZM) (Nigg and Herzog 1994; Wilson *et al.* 1998). The distance between the GRF vector, passing through the PZM, and the centre of rotation of the DIP joint, is the moment arm of the GRF on the DIP joint, and the product of the GRF and its moment arm is the extending moment on the DIP joint at that timepoint.

During most of stance the PZM lies 10–20% of foot-ground contact length cranial to the DIP joint. From 75–85% of stance, the PZM moves towards the toe and the craniocaudal component of the GRF is high, increasing the GRF moment arm on the DIP joint (Wilson *et al.* 1998,2001). This moment arm peaks at 90–95% of stance (Wilson *et al.* 1998,2001). DIP joint moment, however, peaks shortly after midstance (around 60–65% of stance) with a value of 175 Nm (Willemen *et al.* 1999). The DIP joint moment peaks before the moment arm because the resultant GRF falls from midstance onwards. There is a second smaller peak in the DIP joint moment, which occurs when the PZM moves towards the toe at the end of stance. The timing of this peak is a function of the rate of decline of GRF and the rising moment arm.

The extensor moment of the GRF on the DIP joint is balanced by an equal flexing moment generated by the DDFT, with a moment arm created by the tendon running over the navicular bone (Bartel *et al.* 1978). The DDFT force is proportional to its length as it is loaded via the accessory ligament and the muscle's parallel elastic component and acts as a linearly elastic spring (van den Bogert 1989; Jansen *et al.* 1993). The DDFT stretches as the metacarpophalangeal (MCP) and DIP joints extend through stance. After midstance, vertical GRF and, hence, MCP joint angle decrease (McGuigan 2001), but DIP joint angle continues to increase until the heels leave the ground. Therefore, DDFT force peaks at about 60–65% of stance (Willemen *et al.* 1999; Wilson *et al.* 2001); after midstance but before the heels leave the ground. The compressive force on the navicular bone, however, peaks

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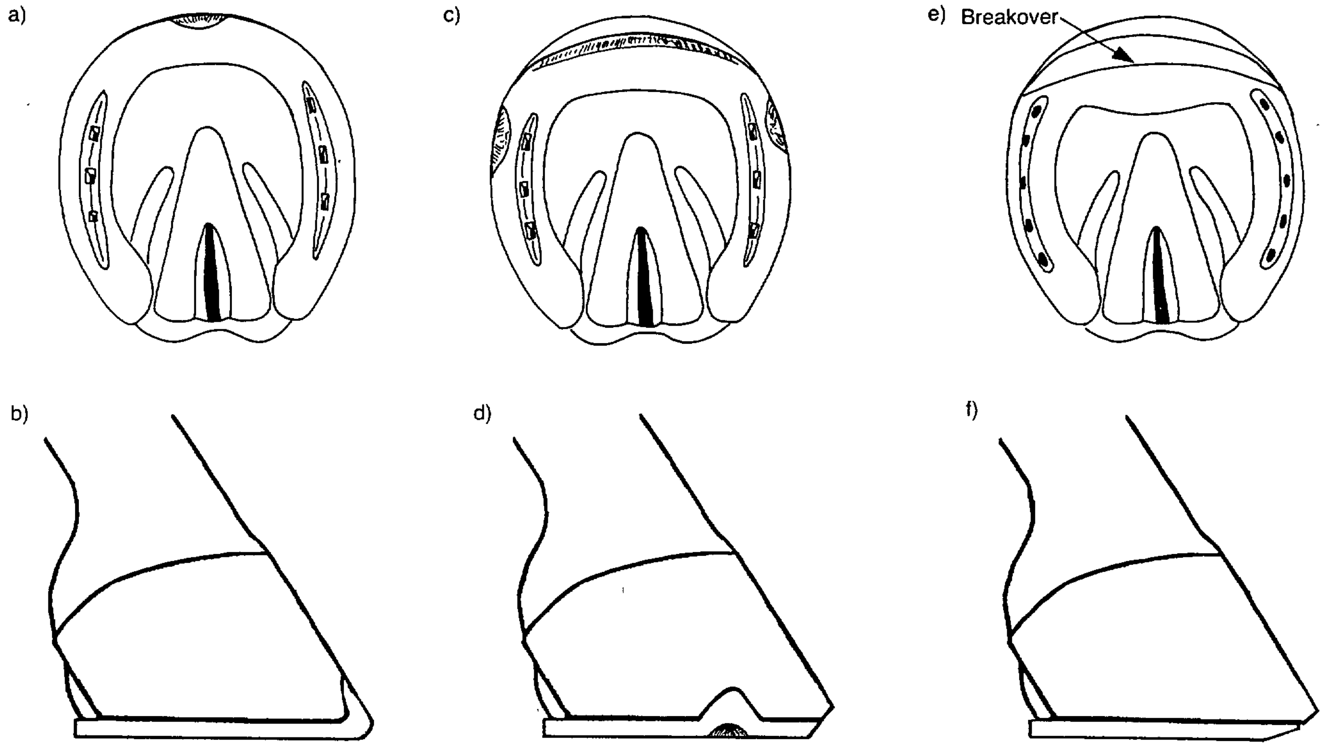

Fig 1: Solar (a) and lateromedial (b) views of the toe-clip shoe, solar (c) and lateromedial (d) views of the quarter-clip shoe and solar (e) and lateromedial (f) views of the Natural Balance shoe.

around 85% of stance (Willemen *et al.* 1999; Wilson *et al.* 2001). This is after peak DIP joint moment/force in the DDFT, because the compressive force on the navicular bone force is proportional not only to DDFT force but also to the angle of deviation of the DDFT around the bone. This angle increases through late stance with DIP joint extension (Willemen *et al.* 1999).

Breakover is the period of rotation of the heels around the toe in the terminal part of stance, i.e. the time from heel off to toe off (Clayton *et al.* 1991). During the cranial excursion of the PZM, in late stance, the heels are gradually unloading. When the PZM reaches the toe the DIP joint moment arm cannot increase further so the extending moment will fall off in line with GRF. The flexing moment then exceeds the extending moment so the DIP joint flexes, i.e. the heels leave the ground. This allows the DDFT to shorten, reducing DDFT strain and force, and reduces the angle of deviation around the navicular bone, further unloading the bone. Pulling the toe back would, therefore, be predicted to result in the PZM reaching the toe earlier and the heels leaving the ground earlier, i.e. at a higher GRF. The peak joint moment arm would therefore be lower but peak joint moment unchanged. The heels would leave the ground at a lower angle of DDFT deviation so navicular bone force would be reduced. The extent of these expected changes is, however, unknown - no effect was seen in the kinematic study of Clayton *et al.* (1991).

The position of the PZM and the GRF vector, and hence the moment arm of the GRF on the DIP joint, can be determined using a combination of forceplate and kinematic motion analysis (Wilson *et al.* 1998). The addition of measurements taken from lateromedial radiographs of the foot enables calculation of the moment arm on the DIP joint and the force exerted by the DDFT on the navicular bone during stance (Willemen *et al.* 1999).

In this study, we used these techniques to test the hypotheses that moving the cranial extent of ground contact towards the heels will: 1) advance breakover, i.e. heel off will occur at a higher GRF but similar DIP joint moment; 2) reduce peak GRF moment arm on the DIP joint in late stance and 3) reduce peak compressive force on the navicular bone.

Materials and methods

Horses

Nine Irish Draught-cross type horses (body mass 539–660 kg, foot-ground contact area 140–152 mm by 152 mm) from the Household Cavalry Mounted Regiment were selected onthe basis of being sound and having good foot balance and conformation by a veterinary surgeon and a farrier. The horses were shod with toe-clipped standard wide web shoes 3 weeks prior to the trial. Each of the following shoe types (Fig 1) were applied to both front feet of each horse, in a Latin square design, at 3 week intervals: 1) conventional wide-web shoes with a toe-clip; 2) wide-web shoes with quarter-clip and 3) Natural Balance shoes[1].

All front feet were prepared so that the trimmed heel terminated close to the widest part of the frog, thereby all shoe types provided the same amount of heel support for an individual horse. The toe-clip and quarter-clip shoes were applied following conventional trimming of the foot (Hickman and Humphrey 1988), with the toe region of the shoe aligned to the dorsal hoof wall or the white line, respectively. For application of the Natural Balance shoes, full sole thickness was maintained cranial to the apex of the frog, and the shoe was fitted with the inside border of the shoe's toe region 9–12 mm (depending on shoe size) cranial to the true edge

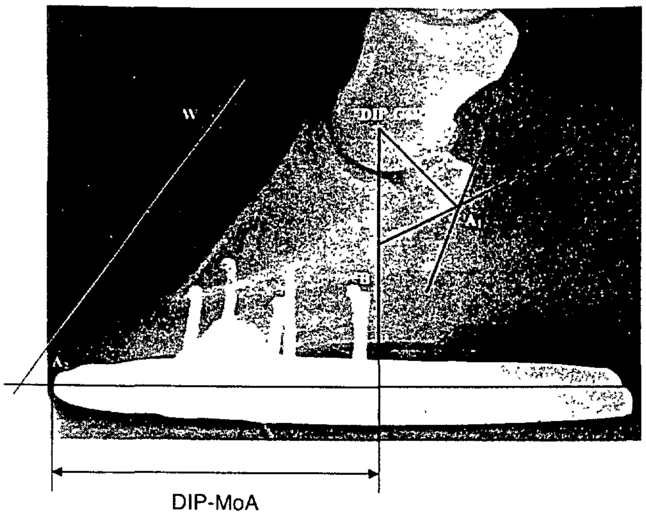

Fig 2: Lateromedial radiograph of a foot with a quarter-clip shoe. DIP-CoR = distal interphalangeal joint centre of rotation; DIP-MoA = DIP joint moment arm measured from the toe region of the shoe to the vertical line (B) drawn from DIP-CoR; C = distance from DIP-CoR to the flexor surface of the navicular bone (DDFT moment arm); A_1 = angle of deviation of the deep digital flexor tendon around the navicular bone; A_2 = dorsal hoof wall angle.

of the frog (Ovnicek 1997), in such a way that complete contact between the toe region of the shoe and the sole was maintained. A farrier from the Household Cavalry Mounted Regiment carried out foot trimming and application of the toe-clip and quarter-clip shoes, and a farrier with extensive experience of the technique applied the Natural Balance shoes. The hind feet were trimmed conventionally and shod with wide web shoes throughout.

Assessment

Immediately following application of the shoes, each horse was trotted up in a straight line on a hard surface and assessed for lameness. Seven days later the horses were assessed for lameness again, weighed and underwent motion analysis. On the day of assessment, hemispherical markers[2] (40 mm in diameter, constructed of high density polystrene and covered in retroreflective tape[3]) were applied to the lateral aspect of the left forelimb and the medial aspect of the right forelimb on the hoof wall, approximately over the centre of rotation of the DIP joint, the centre of rotation of the MCP joint, and over the proximal end of the second (right forelimb) and fourth (left forelimb) metacarpal bones. An additional marker was applied to the left side of the thorax for speed determination. Markers were applied by the same person throughout the study using hot melt glue and a hot glue gun[4].

The horses were trotted by an experienced handler at a speed comfortable for the individual horse, along a forceplate runway within a 25 m long polythene tunnel covered in lightproof material. The forceplate (9287BA)[5] was set in concrete at the midlength of a 6 mm thick, commercial conveyer belt matting runway. A 900 x 600 x 10 mm aluminium plate covered in the same rubber matting was bolted to the top of the forceplate and lay flush with the surrounding rubber matting. The forceplate signal was amplified by an integral, 8 channel charge amplifier, filtered through a low pass filter (6 db/octave from 50 Hz) and logged at 500 samples/s, via a 12 bit AD converter, into a personal computer using software written in LabView[6]. A 3D motion analysis system (ProReflex)[7] was used to determine the position of the markers from the horse's left side at a frame rate of 240 Hz. A minimum of 6 foot strikes were recorded for each forelimb. Data were rejected if the horse was judged not to be moving freely, at constant velocity or if the foot was placed on the edge of the forceplate. Following data collection, a 40 mm metal wire was placed on the midline of the dorsal hoof wall, and lateromedial radiographs of both forefeet were taken using the method described by Stashak (1987).

Data analysis

Standard formulae in a spreadsheet programme (Excel 97)[8] were used to calculate the coordinates of the PZM relative to the forceplate and a previously published polynomial correction (Bobbert and Schamhardt 1990) was applied to improve the accuracy. For each type of shoe, the coordinates of PZM were expressed relative to the centre of rotation of the DIP joint using the method described by Wilson *et al.* (2001). The marker position with respect to the centre of rotation of the DIP joint was determined by using the cranial extent of the shoe as a common reference point on radiographs and direct measurements. DIP joint moment arm was calculated using the PZM and the direction of the GRF vector. The values of moment arm, resultant GRF, digit angle and the angle of the sole to the ground for each run were then reduced to 100 points evenly spaced over stance by linear interpolation (Wilson *et al.* 1998). The stance phase was defined as the period when the vertical GRF was greater than 50 N.

The following measurements were taken from the lateromedial radiographs (Fig 2): 1) the distance from the forwardmost groundbearing point of a particular shoe to a vertical line dropped from the centre of rotation of the DIP joint (DIP-MoA); 2) the distance from the centre of rotation of the DIP joint to the flexor surface of the navicular bone (C); 3) the angle between the parts of the DDFT proximal and distal to the navicular bone (A_1); 4) angle of the digit to the ground and 5) dorsal hoof wall angle (A_2).

The angle of the digit to the ground during the stance phase was calculated using the DIP and MCP joint markers. This was then used in conjunction with the static measurements from the radiograph and the angle of the sole to the ground to calculate the angle between the parts of the DDFT proximal and distal to the navicular bone during stance (Willemen *et al.* 1999).

The measurements from the radiographs were corrected for magnification due to beam divergence using the metal wire placed on the midline of the dorsal hoof wall, and the force in the DDFT and the compressive force of the DDFT on the navicular bone were calculated (Willemen *et al.* 1999; Wilson *et al.* 2001). Force data were normalised for body mass and mediolateral PZM and DIP joint moment arm were expressed as percentage of foot ground contact width and length in the toe-clip shoes to enable averaging of horse data for each shoe type.

Mean curves were produced for each forelimb/shoe type combination, and then averaged to produce a mean ± s.e. plot for each of the shoe types. As the intrahorse (left-right) variability was similar to the interhorse variability, left and right limbs were treated as independent samples therefore; n = 18. The mean data were then scaled and plotted to the averaged stance time for their respective shoe type.

The time when the PZM reached a plateau at the end of its cranial excursion in late stance was determined from the shoulder

TABLE 1: Mean ± s.d., n = 18, for stance time, breakover duration, radiographic DIP joint moment arm, DIP joint moment arm at the beginning of breakover, rate of fall in limb vertical force at the beginning of breakover, peak DIP joint moment, peak force exerted by the DDFT on the navicular bone, and the angle between parts of the DDFT proximal and distal to the navicular bone at the same timepoint of peak force on the bone

	Toe-clip	Quarter-clips	Natural Balance
Stance time (ms)	357 ± 26	351 ± 20	348 ± 24
Breakover duration (ms)	42 ± 9	40 ± 6	39 ± 6
Mean radiographic DIP joint moment arm (mm)	96 ± 4	91 ± 4*	86 ± 4*
DIP joint moment arm at the beginning of breakover (mm)	86 ± 6	78 ± 9*	77 ± 7*
Vertical GRF at the beginning of breakover (N/kg)	1.88 ± 0.36	2.00 ± 0.45	2..08 ± 0.42*
Rate of fall in limb vertical force at the beginning of breakover (N/kg/ms)	0.04 ± 0.01	0.04 ± 0.01	0.05 ± 0.01*
Second peak in DIP joint moment (Nmm/kg)	175 ± 31	171 ± 38	175 ± 37
Time of second peak in DIP joint moment (ms)	306 ± 23	305 ± 13	297 ± 21
Peak force on navicular bone (N/kg)	6.14 ± 1.47	5.79 ± 1.53	5.53 ± 1.52
Time of peak force on navicular bone (ms)	309 ± 23	308 ± 13	300 ± 21
Angle between parts of DDFT proximal and distal to the navicular bone (°)	117 ± 10	121 ± 5	122 ± 12

*Significant difference (P<0.01) in comparison to the toe-clip shoes. DIP = distal interphalangeal, DDFT = deep digital flexor tendon.

region of the graph around 305 msec (Fig 3a). The slope of the PZM line was determined, and the beginning of the plateau defined as the timepoint when the PZM slope was half of the maximum slope during the cranial excursion.

Breakover duration was defined as the time from the beginning of the plateau of PZM (above) to the end of stance (GRF <50 N), and this was determined for each limb/shoe combination.

Statistical analysis was undertaken using a Student's paired *t* test (n = 18, see above). Two comparisons were planned, between the toe-clip and quarter-clip shoes, and between the toe-clip and Natural Balance shoes, so a P value of less than 0.05 was taken as indicating a statistically significant difference.

Results

All values in text and tables are given as mean ± s.d. and the graphs are plotted as mean ± 1 s.e., represented by dotted lines.

Horse 4 was 3/5 (Anon 1991) right fore lame immediately following application of the quarter-clip shoes, but the horse was sound when assessed 7 days later and, therefore, was not excluded from the trial. The other 8 horses remained sound throughout the study.

Speed of trot was 2.66 ± 0.28 m/s with the toe-clip shoes and 2.67 ± 0.15 m/s for both quarter-clip and Natural Balance shoes. Dorsal hoof wall angle was similar in the 3 shoe types; 52.3 ± 5.7° in the toe-clip shoes, 51.1 ± 2.2° in the quarter-clip shoes and 51.0 ± 2.9° in the Natural Balance shoes. Stance time was not significantly different between shoe types; Natural Balance shoes 348 ± 24 ms, quarter-clip shoes 351 ± 20 ms and toe-clip shoes 357 ± 26 ms.

Figure 3a shows the moment arm of the GRF on the DIP joint. In order to compare between different foot sizes, the values on the y-axis are expressed as percentage of foot ground contact length in the toe-clip shoes. With all 3 types of shoes, the moment arm was 5–10% of foot length in the toe-clip shoes (10–15 mm) at the beginning of stance increasing gradually to approximately 25% of foot length in the toe-clip shoes (35–40 mm) at 275 ms of stance.

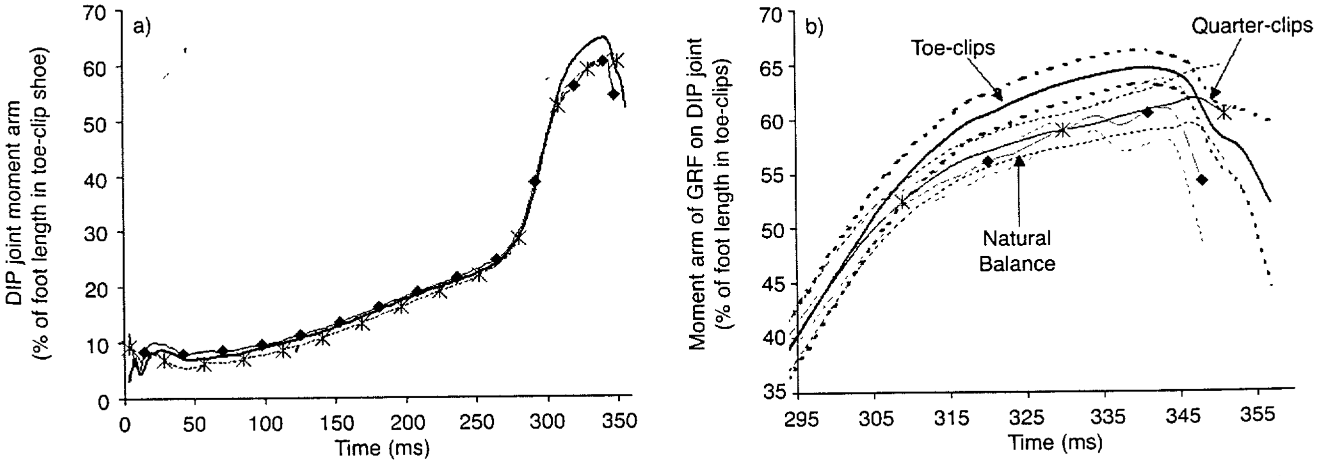

Fig 3: Graph of mean DIP joint moment arm plotted against mean stance time a) for the whole of the stance phase; b) for the end of stance. Plain line = toe-clips; ✳ = quarter-clips; ◆ = Natural Balance. Dotted lines represent ± 1 s.e., n = 18.

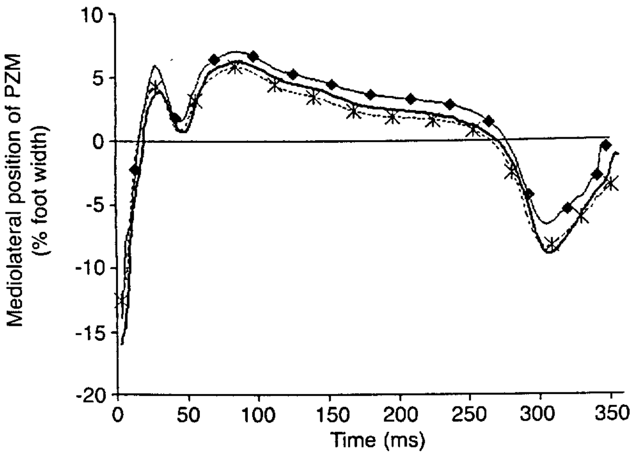

Fig 4: Graph of mediolateral position of PZM plotted against mean stance time for toe-clip (plain line), quarter-clip (✱) and Natural Balance (◆) shoes. Dotted lines represent ± 1 s.e., n = 18. Positive values represent the medial aspect of foot ground contact surface.

The moment arm then increased and reached a plateau as the PZM moved forward and reached the toe (Fig 3a). The 3 plots are indistinguishable until 300 ms, where they diverge and plateau (Fig 3b) around 310–314 ms (Table 1). The DIP joint moment arm at the beginning of the plateau was significantly shorter in both the quarter-clip (78 ± 9 mm) and Natural Balance (77 ± 7 mm) shoes compared with the toe-clip shoes (86 ± 6 mm) ($P<0.01$). This difference was also apparent on the radiographs, where the craniocaudal distance from the centre of rotation of the DIP joint to the cranial extent of the shoe ground contact was significantly reduced with the quarter-clip (91 ± 4 mm, $P<0.001$) and Natural Balance shoes, (86 ± 4 mm, $P<0.001$) compared to the toe-clip shoes (96 ± 4 mm) (Table 1). There was also a positive correlation between the actual (forceplate) and radiographic moment arms in the Natural Balance shoes ($r^2 = 0.45$, $P<0.01$) but not in toe-clip and quarter-clip shoes ($r^2 = 0.13$, $r^2 = 0.00$, respectively). Breakover duration was not significantly shorter with the Natural Balance shoes (39 ± 6 ms) or the quarter-clip shoes (40 ± 6 ms) compared to the toe-clip shoes (42 ± 9 ms).

Mediolateral position of the PZM relative to the foot midline (expressed as a percentage of maximum foot width in the toe-clip shoes) is shown for each shoe type in Figure 4. In all shoe types, horses landed laterally, bore weight just medial of midline and then the PZM moved to the lateral aspect of the foot for the last 20% of stance, as described previously for sound horses (Wilson *et al.* 1998).

The graphs of resultant GRF for the 3 types of shoes (Fig 5a) were similar to those reported previously for normal horses at trot (Willemen *et al.* 1999). The plots for the 3 types of shoes followed an identical pattern until about 310 ms of stance, after which point they diverged (Fig 5b), and the rate of fall of GRF was significantly faster for the Natural Balance (0.046 ± 0.07 N/kg/ms) compared to the toe-clip shoes (0.040 ± 0.009 N/kg/ms) ($P<0.01$), but not significantly different between the quarter-clip (0.042 ± 0.009 N/kg/ms) and toe-clip shoes (Table 1).

Figure 6a shows the DIP joint moment through stance for the 3 shoe types. With all 3 shoe types, the DIP joint moment peaked at 214–221 ms (60–63% of stance) with a magnitude of 249 ± 72 Nmm/kg in the toe-clip shoes, 250 ± 87 Nmm/kg in the quarter-clip shoes and 259 ± 71 Nmm/kg in the Natural Balance shoes. There was a consistent second peak between 297 and 306 ms (Fig 6b) with a magnitude of 175 ± 31 Nmm/kg in the toe-clip shoes, 171 ± 38 Nmm/kg in the quarter-clip shoes and 175 ± 37 Nmm/kg in the Natural Balance shoes. There were no significant differences between shoe types.

Graphs of the compressive force exerted by the DDFT on the navicular bone during stance for the 3 types of shoes (Fig 7a) were similar in shape to those reported previously for normal horses (Willemen *et al.* 1999; Wilson *et al.* 2001). Maximum force exerted on the navicular bone occurred immediately after the DIP moment reached its second peak at 300–308 ms (86–87% of stance) and was 6.14 ± 1.47 N/kg in the toe-clip shoes, 5.79 ± 1.53 N/kg in the quarter-clip shoes and 5.52 ± 1.52 N/kg in the Natural Balance shoes (Fig 7b). These forces were not significantly different between shoe types (Table 1). The angle between the parts of the DDFT proximal and distal to the navicular bone at peak navicular bone force was also not significantly different in the shoe types (Table 1).

Discussion

The repeatability of measuring the various parameters from the lateromedial radiographs was within 5% (McGuigan 2001). DIP

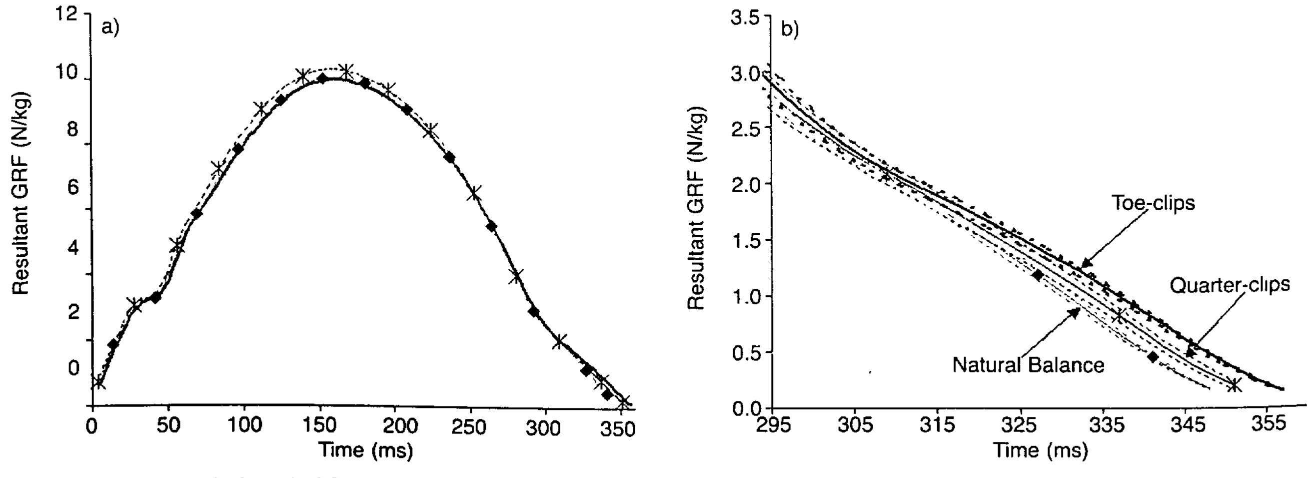

Fig 5: Graph of mean limb vertical force against mean stance time a) for the whole of the stance phase; b) for the end of stance. toe-clip (plain line), quarter-clip (✱) and Natural Balance (◆) shoes. Dotted lines represent ± 1 s.e., n = 18.

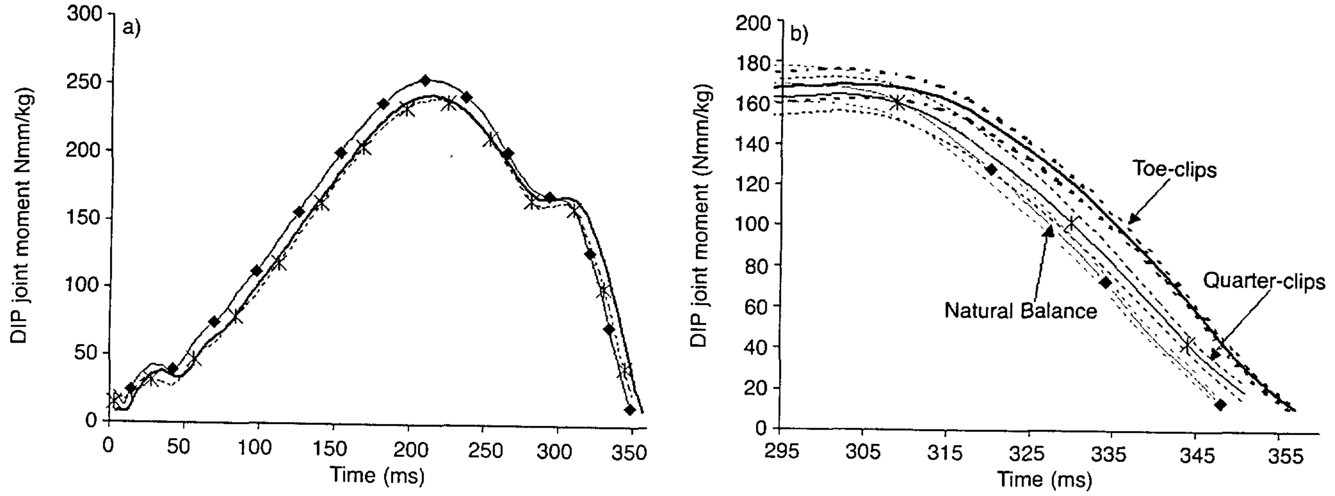

Fig 6: Graph of mean DIP joint moment plotted against mean stance time a) for the whole of the stance phase; b) for the end of stance. Toe clip (plain line), quarter-clip (✻) and Natural Balance shoes (◆). Dotted lines represent ± 1 s.e., n = 18.

joint moment peaked at 60–63% of stance with all shoe types. This is similar to that reported in a previous study (Willemen *et al.* 1999), where joint moment peaked at 65% of stance; however, a second peak in the curve was not apparent in their data. Further consideration of this difference is not possible because DIP moment arm was not reported in that study.

There was a significant reduction in the DIP joint moment arm in late stance following application of the Natural Balance and quarter-clip shoes compared to the toe-clip shoes (Figs 3a,b). This reduction was also evident in the radiographic data (Table 1). There was a strong positive correlation between the actual and radiographic moment arm in the Natural Balance shoes but not in the other 2 shoe types. This was attributed to the shoe toe shape. The Natural Balance shoes had an almost square toe, which means that the final point of weightbearing would correspond to that measured on the radiograph. In the other 2 shoe types, final point of contact lay somewhat lateral to the midline of the foot (Fig 4) and hence behind the point measured on the radiograph due to the curvature of the shoe.

Despite the smaller joint moment arm, the peak moment on the DIP joint during late stance was not reduced in the quarter-clip and Natural Balance shoes. This is because the heels left the ground at the same DIP moment in all 3 types of shoes. As pulling back the toe reduced the DIP joint moment arm, the heels left the ground at a higher vertical GRF, i.e. earlier (Fig 5a,b), and the foot rotated more quickly.

This phenomenon can be explained by considering the mechanics of the distal limb. From 270 ms, the PZM starts to move towards the toe (Fig 3a,b). This displacement occurs because the DIP joint extends through stance, stretching the DDFT. The moment arm of the DDFT on the DIP joint is assumed to be independent of DIP joint angle (Willemen *et al.* 1999). DIP joint moment and DDFT force are, therefore, equivalent and scaled by the moment arm created by the navicular bone. Tendon force and hence the flexor moment generated by the DDFT therefore rise through late stance. This DIP joint flexor moment is balanced by an extensor moment generated by the GRF acting at the PZM. Vertical GRF drops through the second half of stance (Fig 5a) and PZM therefore moves forward, increasing the moment arm of GRF to maintain

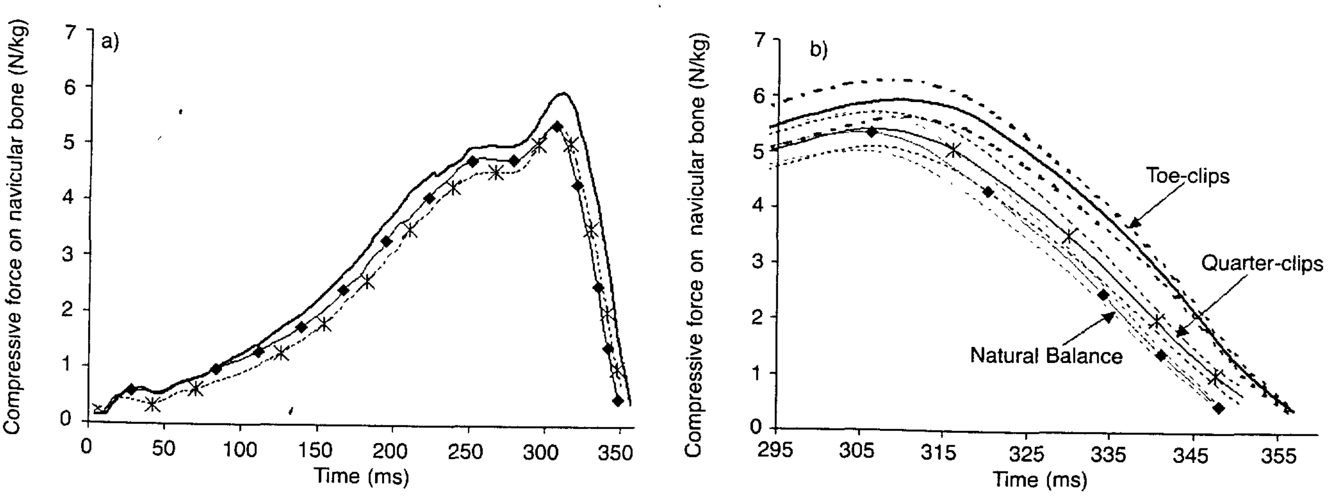

Fig 7: Graph of mean force exerted by the DDFT on the navicular bone plotted against mean stance time a) for the whole of the stance phase; b) for the end of stance Toe clip (plain line), quarter-clip (✻) and Natural Balance shoes (◆). Dotted lines represent ± 1 s.e., n = 18.

the equilibrium around the DIP joint. When the PZM reaches the toe of the respective shoe at approximately 300 ms, the extensor moment arm cannot increase, and the extensor moment must decrease in line with the GRF (Figs 5b, 6b). The flexor moment continues to rise in line with DIP joint angle (somewhat offset by MCP joint flexion after midstance) and, because it exceeds the extensor moment, the DIP joint flexes, levering the heels off the ground. The DDFT shortens as the DIP joint flexes, reducing tendon strain and force and hence maintaining a quasistatic equilibrium of flexor and extensor moments during breakover.

After heel off, the foot rotates around the toe at an angular velocity proportional to the rate of drop off of DIP joint moment (because tendons act as linear elastic springs and the tendon moment arm at the DIP joint is approximately independent of joint angle). Since DIP moment is a product of moment arm and GRF, the rate of decrease of DIP joint moment and hence the DIP joint angular velocity would be expected to be greater with the Natural Balance shoes.

The peak force exerted by the DDFT on the navicular bone was not significantly changed with different shoe types. This force is a function of DIP joint moment and the angle of deviation of the DDFT around the bone (Willemen *et al.* 1999). DIP joint moment at heel off (when navicular bone force peaks) was unchanged, so any reduction in navicular bone force would be the result of a reduction in the angle of deviation of the DDFT around the navicular bone. This could occur via either, elevation of the heels or the heels leaving the ground earlier. The first did not happen here; hoof angle was unchanged and the change in angle of deviation was insufficient to produce a statistically significant effect. The heels would have been expected to leave the ground earlier in the quarter-clip and Natural Balance shoes, but this effect was not significant.

In conclusion, breakover at trot can therefore be considered a passive event, with the heels being levered off the ground when the flexor moment created by the DDFT exceeds the extensor moment of the GRF. In this study, pulling the toe back reduced the moment arm on the DIP joint, but did not reduce the DIP joint moment or the peak force exerted by the DDFT on the navicular bone.

There is a rationale for pulling the toe back to advance breakover. The optimum position of breakover and whether this is different in sound and lame horses was not determined in this study; it may be that the Natural Balance shoes have additional benefit in such cases.

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Manufacturers' addresses

[1]Total Foot Protection, Horsham, West Sussex, UK.
[2]Pinflare Creative Crafts, Hertford, Hertfordshire, UK.
[3]3M, Manchester, UK.
[4]Bostik Ltd., Leicester, Leicestershire, UK
[5]Kistler Instruments Ltd , Alton, Hampshire, UK.
[6]National Instruments, Newbury, Berkshire, UK.
[7]Qualisys AB, Savedalen, Sweden.
[8]Microsoft Corp., Mountain View, California, USA.

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