Evaluation of displacement of the digital cushion in response to vertical loading in equine forelimbs

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Objective—To evaluate patterns of digital cushion (DC) displacement that occur in response to vertical loading of the distal portion of the forelimb in horses.

Sample Population—Forelimbs from 10 horses with normal feet.

Procedure—Patterns of DC displacement induced by in vitro vertical limb loading were determined. Load-induced displacement of the DC was defined as the magnitude and direction of displacement of 6 radiodense, percutaneously implanted markers in specific regions of the DC. The effects of solar support and nonsupport on displacement of the DC were compared.

Results—Regional displacement of the DC occurred principally along distal and palmar vectors in response to vertical loading. Medial or lateral abaxial displacements were variable and appeared to be dependent on response of the limb to the applied load. Displacement of the DC was not affected by the degree of solar support.

Conclusions and Clinical Relevance—Data indicated that the biomechanical function of the DC is to act as a restraint to the displacement of the second phalanx or as a passive structure that allows flexibility of the caudal two thirds of the foot. Results did not indicate that the DC provides a force that induces displacement of or an active restraint against outward displacement of the hoof wall capsule. (*Am J Vet Res* 2005;66:623–629)

On the basis of the anatomic features and position of the **digital cushion (DC)** within the equine foot, several hypotheses have been proposed regarding its biomechanical function. These include the pressure, depression, sling, and passive theories.[1-8,a,b] The differences among the biomechanical roles proposed by these hypotheses can be categorized by whether they propose an active or passive role for the DC in foot biomechanics and in the directions predicted for regional displacement of the DC as the foot is subjected to load.

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For this purpose, an active role is defined as the DC acting to either induce displacement or restrain displacement of the hoof capsule or skeletal components of the foot and, in doing so, absorbing a portion of the loading energy. Alternatively, a passive role is defined as the DC neither affecting the displacement of foot components nor acting to absorb substantial loading energy. Because differences in regional displacement patterns predicted by the pressure and depression theories are distinct from those of the sling and passive theories, defining DC displacement patterns can be used to test their relative validity.

To our knowledge, the patterns of displacement of the DC in vivo or in vitro in response to various loading conditions have not been reported. The purpose of the study reported here was to evaluate patterns of DC displacement that occur in response to vertical loading of the distal portion of the forelimb in horses. Our hypotheses were that the DC plays a relatively passive role in foot biomechanics and that its displacement is affected by loading conditions.

Materials and Methods

This descriptive study defined the patterns of regional DC displacement in 10 cadaver forelimbs. The pre- and post-load positions of radiodense markers percutaneously implanted at specific points within the DC were compared to describe DC displacement in response to 2 different in vitro vertical loading conditions: the foot placed on a relatively nondeformable flat surface and the foot resting on a highly displaceable but relatively nondeformable surface to provide full solar surface contact and support.

Forelimbs from 10 Quarter Horses or Quarter Horse-crosses with normal feet were obtained from a local abattoir. Feet were considered normal if their conformation fell within that generally accepted as normal for Quarter Horses, there was no external evidence of disease or trauma, and there were no radiographically visible changes consistent with digital disease. Limbs were sectioned transversely at the carpometacarpal joint and frozen. Prior to experiments, each limb was thawed and each foot trimmed according to the procedure outlined by Butler.[9] The length, perimeter, and width of each foot were measured manually by a farrier by use of a tape measure immediately after trimming. By definition, length of the foot was the distance from the coronet to the ground surface along the dorsal midsagittal plane of the foot, perimeter was the distance measured around the outside edge of the foot from medial heel to lateral heel, and width was the distance across the widest part of the foot (medial to lateral).

Feet were radiographed from the lateromedial and palmodorsal projections (15 mA; 66.04 cm between beam origin and cassette) with the toe or lateral-medial hoof wall in contact with the radiograph cassette. Time of exposure varied as needed to allow optimal visualization of the distal phalanx and hoof wall. Subsequently, 6 radiodense markers (1-mm-diameter lead spheres) were percutaneously inserted into the DC with a 12-gauge cannula.[c] The position and technique for marker placement were determined on the basis of results of a pilot study[b] designed to define optimal position and repeatability of marker placement.

Five of the 6 markers were placed in the palmar aspect of the DC. The remaining marker was placed in the dorsal tip of the DC, just distal and palmar to the insertion of the deep digital flexor tendon (**Figure 1**). Of the 5 markers inserted into the palmar aspects of the foot, 3 were situated in the proximal aspect of the DC and the remaining 2 were situated in the distal regions of the DC. Markers were identified as 1 to 6.

Markers 1 and 5 were situated axial to the medial and lateral ungual cartilages in the proximopalmar aspects of the DC and were placed by insertion of the cannula into the proximal surface of the DC to a depth of 1.5 cm. Marker 3 was situated so that its position was equidistant between markers 1 and 5 on the same dorsal plane and depth. Markers 2 and 6 were situated on the same parasagittal planes as were markers 1 and 5, respectively, but on a dorsal plane that approximated the midpoint of the most proximal and distal aspects of the heel bulbs. Marker 4 was inserted into the dorsal aspect of the DC through the solar surface of the foot. For placement of this marker, the cannula was inserted perpendicular to the solar plane of the foot through the center of the frog at the widest point of the foot.

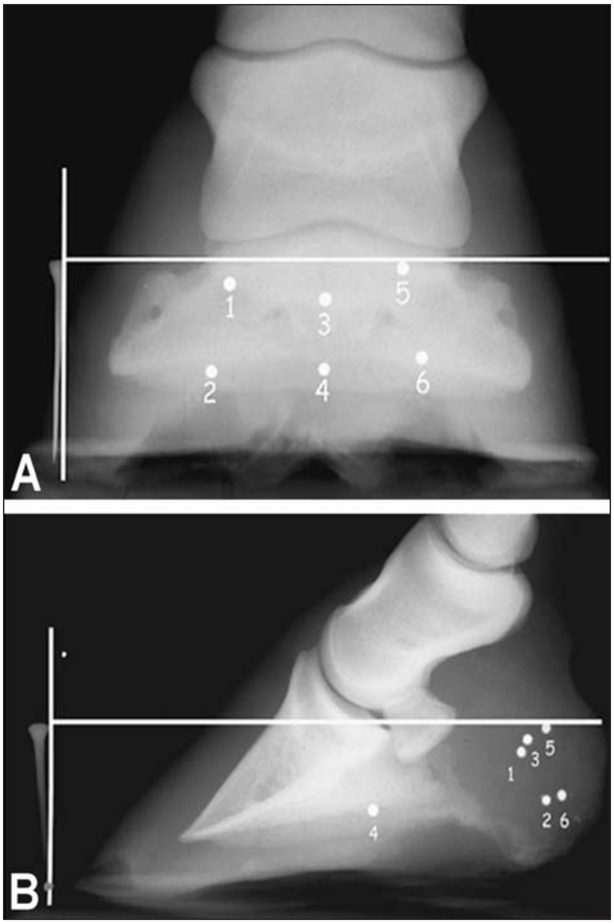

Figure 1—Proximodorsal (A) and lateral (B) radiographic views of an equine forefoot. Notice approximate position and identification of 6 radiodense markers (No. 1 to 6) placed within the matrix of the digital cushion. The vertical and horizontal lines were added during data analysis and used as references for displacement measurements.

After marker placement, each limb was positioned in a hydraulic press designed for vertical loading of the limb. Limb placement was visually controlled so that the midsagittal plane of the metacarpus was aligned with the midsagittal plane of the foot and perpendicular to the solar plane of the trimmed foot. In addition, the mid-dorsal plane of the metacarpus was positioned so that it transected the foot's solar plane in a perpendicular manner, just caudal to the bulbs of the foot. Quantification of load placed on the limb was measured by a load-cell–based force plate positioned under the foot.[10] Because of the need to elevate the foot for radiographic evaluation, a wooden block was placed between the foot and the force plate. After positioning, the control load, consisting of the combined mass of the limb and devices required to restrain and position the limb, was recorded.

For recording the position of the radiodense markers, radiographs were made from the palmodorsal and lateromedial projections. The palmodorsal projection was defined as the one in which the primary beam was directed through the foot's palmar surface on a line that passed through the midsaggittal plane of the foot and was parallel to the bearing (solar) surface of the foot and perpendicular to the cassette held in contact with the dorsal portion of the toe. Half the feet used in this study were radiographed from the lateromedial projection and half from the mediolateral projection. The exposure technique was consistent with that previously described.[b] Radiographs were obtained by use of exposure techniques that allowed optimal visualization of the internal and external radiodense markers rather than the foot itself. The focal point of the radiographs on the foot was estimated to be at the geometric center of the DC markers on the palmodorsal view and at the center of the foot for the lateromedial view. Although the time, distance, exposure, and focal point were adapted as necessary between horses, they were kept constant in individual horses.

To facilitate quantification of DC marker displacements, radiodense external reference markers were positioned in the block elevating the foot. These external markers were placed lateral to the widest part of the foot and immediately dorsal to the foot in a position such that they were not affected by movement of the foot or limb and were not superimposed on implanted markers. The limb was then loaded (load rate, 5 kg/s) until the load increased to 295 kg, and a second set of radiographs was obtained by use of a protocol identical to the control load radiographs. Mean stroke rate of the loading apparatus was 50 mm/s. The external marker positions remained constant between maximum load and control load conditions.

The foot-limb preparation was then raised, and a 2.5-cm layer of washed concrete sand was placed under the foot's solar surface. A 30.48-cm cardboard form was used to create a level 2.5-cm-deep layer of sand. The limb was repositioned and loaded to the control loading conditions, the form and excess sand were removed, and a second set of control and maximum load radiographs were acquired. Foot positioning, load applied, and radiographic technique used in the solar surface loading experiment were the same as the solid-surface experiment.

After data collection and prior to data analysis, each foot was dissected to confirm the position of markers within the DC and examine the DC for subjective evidence of marker migration. Additionally, radiographs were examined to assess and categorize the displacement of the third metacarpophalangeal axis that occurred in response to the vertical loading. Response to loading was defined from the palmodorsal radiographs and classified as a vertical response if no visible

Table 1—Mean ± SD values of vector magnitude (mm) and direction (°) for radiodense marker displacement in equine feet as recorded via palmodorsal (PD) and lateromedial (LM) radiographs. The solar support column defines whether the sole was supported by sand (Yes) or nonsupported (No) as a consequence of the foot being loaded on a relatively rigid surface. The loading response column defines whether the limb had medial or lateral deviation of the metacarpophalangeal joint (slant) or maintained normal joint alignment (vertical).

Marker No.	Vector magnitude (mm)	Vector direction (°)	View	Solar support	Loading response
1	0.432 ± 0.11	188.33 ± 50.7	PD	No	Vertical
1	0.507 ± 0.25	197.83 ± 41.7	PD	Yes	Vertical
1	0.550 ± 0.18	129.50 ± 32.0	LM	No	Vertical
1	0.880 ± 0.39	129.33 ± 20.9	LM	Yes	Vertical
1	0.430 ± 0.14	189.25 ± 17.0	PD	No	Slant
1	0.525 ± 0.22	195.50 ± 49.0	PD	Yes	Slant
1	0.725 ± 0.22	168.25 ± 10.7	LM	No	Slant
1	0.533 ± 0.48	147.50 ± 20.1	LM	Yes	Slant
2	0.550 ± 0.18	183.60 ± 43.0	PD	No	Vertical
2	0.634 ± 0.38	176.40 ± 58.7	PD	Yes	Vertical
2	0.558 ± 0.31	204.20 ± 24.0	LM	No	Vertical
2	0.500 ± 0.25	194.80 ± 35.3	LM	Yes	Vertical
2	0.355 ± 0.26	173.50 ± 15.4	PD	No	Slant
2	0.585 ± 0.33	180.50 ± 79.1	PD	Yes	Slant
2	0.700 ± 0.46	129.75 ± 55.6	LM	No	Slant
2	0.258 ± 0.09	131.25 ± 19.9	LM	Yes	Slant
3	0.903 ± 0.30	171.17 ± 21.6	PD	No	Vertical
3	0.821 ± 0.44	178.33 ± 37.6	PD	Yes	Vertical
3	0.697 ± 0.43	132.67 ± 20.7	LM	No	Vertical
3	0.900 ± 0.28	131.33 ± 20.0	LM	Yes	Vertical
3	0.890 ± 0.15	186.00 ± 8.6	PD	No	Slant
3	0.950 ± 0.32	182.75 ± 48.2	PD	Yes	Slant
3	1.297 ± 0.61	150.75 ± 33.2	LM	No	Slant
3	0.597 ± 0.15	145.75 ± 22.4	LM	Yes	Slant
4	0.457 ± 0.25	154.67 ± 53.7	PD	No	Vertical
4	0.657 ± 0.27	110.28 ± 62.4	PD	Yes	Vertical
4	0.403 ± 0.24	131.50 ± 69.1	LM	No	Vertical
4	0.370 ± 0.26	188.17 ± 51.3	LM	Yes	Vertical
4	0.487 ± 0.34	163.00 ± 41.1	PD	No	Slant
4	0.350 ± 0.42	207.25 ± 59.5	PD	Yes	Slant
4	0.633 ± 0.44	161.50 ± 54.9	LM	No	Slant
4	0.230 ± 0.09	199.00 ± 73.5	LM	Yes	Slant
5	0.668 ± 0.15	147.20 ± 24.0	PD	No	Vertical
5	0.878 ± 0.34	134.40 ± 22.4	PD	Yes	Vertical
5	0.483 ± 0.34	133.60 ± 32.6	LM	No	Vertical
5	0.613 ± 0.52	127.20 ± 21.9	LM	Yes	Vertical
5	0.615 ± 0.32	192.25 ± 13.5	PD	No	Slant
5	0.805 ± 0.37	178.00 ± 40.2	PD	Yes	Slant
5	0.910 ± 0.32	145.25 ± 26.3	LM	No	Slant
5	0.630 ± 0.30	139.50 ±19.6	LM	Yes	Slant
6	0.558 ± 0.24	149.40 ± 24.5	PD	No	Vertical
6	0.746 ± 0.45	132.80 ±16.25	PD	Yes	Vertical
6	0.400 ± 0.21	115.20 ± 44.3	LM	No	Vertical
6	0.614 ± 0.36	142.40 ± 40.7	LM	Yes	Vertical
6	0.757 ± 0.14	203.00 ± 18.2	PD	No	Slant
6	0.490 ± 0.51	168.67 ± 26.5	PD	Yes	Slant
6	0.683 ± 0.40	186.00 ± 12.5	LM	No	Slant
6	0.517 ± 0.16	172.67 ± 25.9	LM	Yes	Slant

(subjectively determined) medial or lateral displacement of the phalangeal axis was evident and as a slant response if either lateral or medial deflection of the bone axis was evident when load was applied.

All radiographs were digitized for analysis. Control and maximum load positions of each marker relative to the fixed external marker were measured by use of an image analysis program.[d] The palmodorsal views were used to define the vertical and medial-lateral marker displacements. The lateromedial radiographs were similarly used to define the vertical and palmodorsal marker displacements. Individual marker displacement was described as the magnitude (cm) and angle (degrees) of the vector formed by a line drawn from the control and maximum load positions. The displacement vector for each marker in each plane was determined by plotting the x, y, and z coordinates from the vertical, medial-lateral, and dorsal-palmar displacement measurements. Because it was theoretically possible that magnification associated with the radiographic technique could have affected the validity of measurements, the diameter of markers 1 and 5 and 2 and 6 on the lateromedial projections and markers 2 and 4 on the palmodorsal projections was compared to determine the magnitude of magnification.

Magnitude and angular displacement data were plotted with the initial position of each individual marker serving as the origin. Given the slight variations in marker displacements associated with the feet having different conformations coupled with the likelihood of regional variations in DC

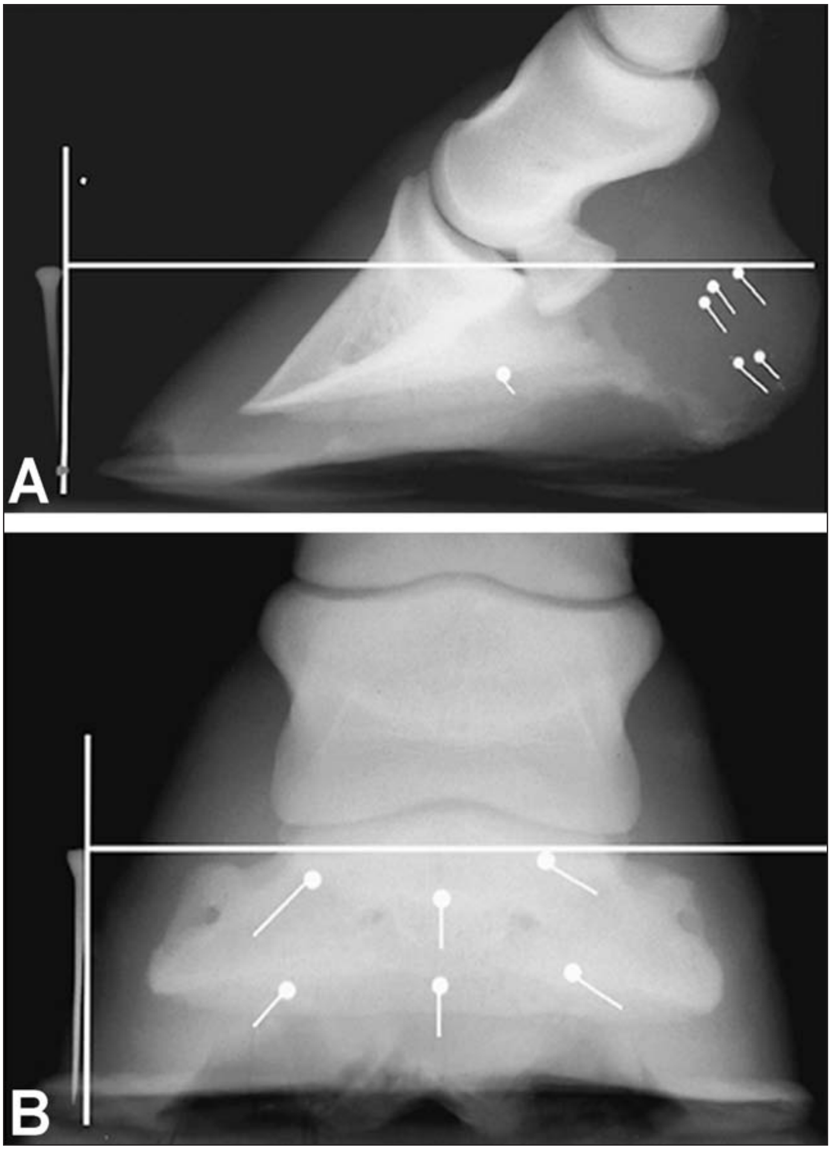

Figure 2—Lateral (A) and proximodorsal (B) radiographic views of an equine forefoot. Notice the symmetrical abaxial displacement pattern of the radiodense markers indicated by the white lines drawn adjacent to each marker and characteristic of the vertical response of the foot to vertical loading of the limb. The lines depict the general direction of marker displacement; the magnitude has been accentuated for purposes of visibility.

displacement, plots were completed for each individual horse to determine the pattern of DC displacement. In the palmodorsal view, the proximal (vertical axis) coordinate was 0°, medial and lateral coordinates were 90° and 270°, respectively, and the distal (vertical) coordinate was 180°. In the lateromedial radiographs, displacement was described relative to the initial position of each individual marker; the proximal (vertical axis) coordinate was 0°, dorsal and palmar coordinates were 90° and 270°, respectively, and the distal (vertical) coordinate was 180°. The magnitude of the vectors was calculated as the length of the hypotenuse of a right triangle by use of the Pythagorean theorem ($a^2 + b^2 = c^2$), and the direction of the vector displacement in relation to its initial position was determined by calculating the arc tangent.

Statistical analyses—A series of paired *t* tests was used to determine whether the control and maximum load positions of each marker were different. Mean vector magnitude and angle of displacement of each marker were calculated for each view. Data were plotted and categorized on the basis of whether the digit responded to the vertical loading via a vertical or slant response. Analysis for potential differences in marker displacement attributable to the degree of solar support was completed by use of a Wilcoxon signed rank test because plotted data appeared slightly nonparametric. For all comparisons, $P \leq 0.05$ was considered significant. The sample size was determined to provide a > 90% power to detect a 20% change in the mean of the magnitude of marker displacement.

Results

Mean ± SDs of the external measurements of the trimmed study feet were as follows: length, 7.77 ± 0.5 cm; perimeter, 33.96 ± 1.8 cm; width, 12.25 ± 0.5 cm. Dissection of the feet revealed that 4 individual markers from 3 feet were not properly placed in the DC and were deleted from data analysis. In addition, there was no evidence of tearing of the matrix of the DC that would predispose to migration of the markers during loading.

Loading from the control load (4.6 kg) to maximum load (295 kg) conditions resulted in substantial and predictable distal displacement of the third metacarpus and phalanges, such that the phalangeal axis was approximately parallel to the ground surface. The position of the solar surface did not move during loading. Seven of the feet were categorized as having a vertical response, and 3 had a slant response of the phalangeal axis subsequent to imposition of the vertical load conditions.

Comparison of the control and loaded x-y-z coordinate positions of markers when loading was completed with the solar surface nonsupported indicated that significant displacement of all markers occurred. Mean displacement of markers recorded from the palmodorsal view was 0.592 ± 0.18 cm at an angular direction of 175.88 ± 13.7°. In the lateromedial view, mean displacement vector was 0.6087 ± 0.134 cm at an angular direction of 128.96 ± 8.5° (**Table 1**). Comparison of the diameter of markers 1 and 5 and 2 and 6 on the lateromedial projections and markers 2 and 4 on the palmodorsal projections indicated that magnification of the more distant markers was < 1% (0.02 mm) by use of the described radiographic technique.

Plotting of the displacement vector for each marker in each horse indicated that 3 distinct displacement patterns were evident. In all 3 patterns, markers were typically displaced toward the ground surface and the bulbs of the foot (distal and palmar displacements).

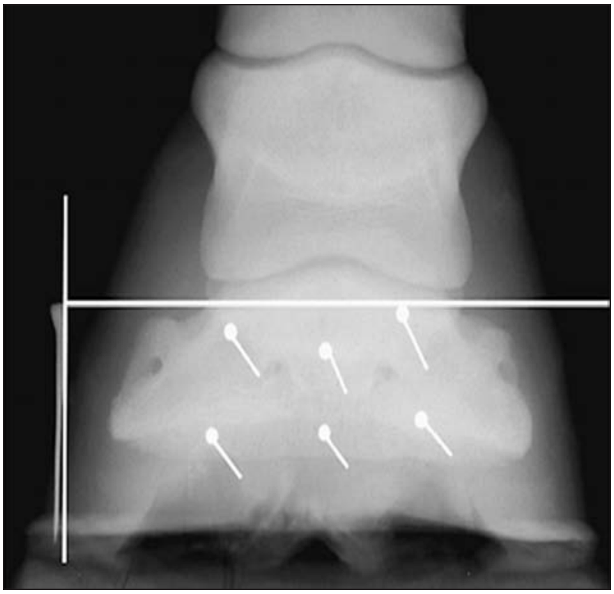

Figure 3—Proximodorsal radiographic view of an equine forefoot. Notice the uniform medial displacement of the radiodense markers indicated by the white lines drawn adjacent to each marker and characteristic of a slant response to vertical loading of the limb. The lines depict the general direction of marker displacement; the magnitude has been accentuated for purposes of visibility.

The differences noted between patterns were in the relative uniformity in the abaxial or axial displacement of the markers. Pattern 1 (n = 6 feet) reflected a symmetrical, distal and abaxial displacement of those markers situated in the medial and lateral regions of the DC (markers 1, 2, 5, and 6) and vertical distal and palmar displacements of the markers located in the central regions of the DC (markers 3 and 4; **Figure 2**). Pattern 1 marker displacement was characteristic of feet that had a vertical response to vertical loading of the limb. Pattern 2 (n = 3) reflected uniform displacement of all markers either medially or laterally while moving distal and palmar (**Figure 3**). Pattern 2 marker displacement was restricted to feet that had a slant response to vertical loading of the limb. Characteristically, marker displacement was in the same direction as displacement of the phalanges. The medial versus lateral displacement of the DC that resulted from variable (medial vs lateral) metacarpophalangeal displacement in the slant load resulted in large SDs (Table 1) with the mean not indicating the true direction of the markers. Pattern 3 reflected a combination of the displacements observed in patterns 1 and 2 and was observed in forelimbs from 1 horse, which appeared to respond to vertical loading with a vertical response. Although the angular displacement of specific markers was significantly ($P < 0.001$) different, the mean magnitude of the vector for pattern 1 (0.5965 ± 0.171 cm) and pattern 2 (0.5525 ± 0.184 cm) was not different ($P = 0.432$).

Analysis of marker displacement with the solar surface supported and nonsupported revealed no differences. Wilcoxon signed rank analysis indicated that the mean *P* values recorded for the vector magnitude and direction were 0.480 ± 0.35 and 0.607 ± 0.44, respectively.

Discussion

The use of 6 markers implanted in specific regions of the DC was based on the theoretical predictions of how the DC was expected to displace during the loading conditions we used and the need to be able to distinguish between specific markers via planar radiographic views. Although a greater number of markers located in additional sites within the DC would enhance the ability to detect regional DC displacements, this would increase the likelihood that markers would become superimposed after displacement, making it impossible to quantify displacement vectors.

The use of external anatomic reference points to facilitate optimal marker placement proved quite successful because only 4 of 60 markers were not in the intended position. Data from these makers were deleted from the described analysis procedures. Differences in the conformation of individual feet did, however, result in variable positioning of markers. The effect of these slight variations in marker position on DC displacement was compensated for by plotting the pre– and post–marker position on each individual digitized radiograph. Given the lack of radiographic or anatomic evidence of marker migration, it seemed that the use of percutaneous markers was sufficient to accomplish our goals.

The in vitro loaded-limb preparation we used was similar to that used in other studies,[11-13] and the use of freezing and thawing has no negative effects on the preparation. Loading to a maximum load of 295 kg approximates the load placed on a single forefoot in response to lifting the other forefoot in a 450-kg horse.[14] The load rate of 5 kg/s and stroke rate of 50 mm/s were consistent with the slow application of load one might expect as a horse shifts its mass between its forefeet when standing.[15]

Given that the limbs we used were transected at the carpal-metacarpal joint, some of the support provided by the superficial and deep digital flexor tendons was absent. This resulted in an exaggerated extension of the metacarpophalangeal and phalangeal joints. Because the descent of the second phalanx is potentially a major factor in inducing DC displacement, the displacements recorded in this study were interpreted as being of greater magnitude than that expected in the intact limb at the applied loads. However, the direction of DC displacement was assumed to be unaffected by the lack of tendon support.

Compared with the recorded marker magnification of the more distant markers (< 1%; 0.02 mm), the mean distance of marker displacement was approximately 0.5 cm. Thus, the effect of marker magnification of this magnitude was considered unimportant. Similarly, because the focal point, distance, and other factors used in this study were constant, effects of parallax were constant and considered to have a minimal effect on data interpretation.

The vertical loading protocol used in this study was designed to mimic the midstance loads encountered during walking or when the horse was standing with the opposite foot lifted. In our study, nonuniformity in the response to loading was observed with 7 of the limbs displaced vertically, and 3 had medial or lateral displacement of the metacarpophalangeal joint. This nonuniformity was attributed to the nonphysiologic design of the loading device.[16] During in vivo loading, only the solar surface of the foot is relatively fixed in position. Because the upper portion of the forelimb is attached to the thorax by muscle and the horse can shift its body mass relative to the foot, the upper limb cannot be considered to be in a fixed position. The design of the loading device fixed both the upper and lower end of limb preparation in preset positions relative to each other. Thus, as load was applied, any subtle malpositioning of the limb, lack of parallel alignment of the solar and upper surfaces, or conformational or functional asymmetry of the limb would result in a nonvertical response to loading.

In our study, the possibility of an uneven dorsopalmar load was perceived as being just as likely as uneven mediolateral loading. The physiologic effects and the relative ability to detect effects of uneven dorsopalmar loading are distinct from medial or lateral phalangeal displacement. A horse's limb is designed for maximal flexion and extension along its dorsopalmar axis. Uneven loading along this vector would be reflected as subtle variances in the magnitude of extension as the foot was loaded. The inability of the limb to physiologically compensate for uneven mediolateral loading results in the metacarpophalangeal joint being displaced out of the sagittal plane, which is easily detected.

Under physiologic conditions, mediolateral displacement of the metacarpophalangeal joint undoubtedly occurs secondary to foot placement on nonhorizontal surfaces or when the horse's body mass is positioned medial or lateral to the limb at the midstance phase of the stride. Thus, the data regarding the DC response to the nonvertical response to loading were not deleted from this study and were considered to reflect how the horse's foot can compensate biomechanically under these conditions.

The displacement patterns of the DC markers were inconsistent with those predicted by the pressure and depression theories. The pressure theory suggests that the tissues of the DC are trapped between the foot's descending axial skeleton and solar components during loading.[1-5] During loading, the DC (which is envisioned as an incompressible material) actively contributes to abaxial and palmar displacement of the quarters, heels, and bulbs of the hoof capsule. Intuitively, regional displacement of the DC in the pressure theory predicts that abaxial regions of the DC must also displace abaxially as the DC deforms, to place compressive forces on the quarters and heels. Alternatively, the depression theory suggests that the elastic components of the DC are displaced secondary to hoof capsule distortion that occurs consequential to load application and that the DC acts as an energy-absorbing mechanism as its elastic components are distended.[1,6-8,b] If this hypothesis was valid, abaxial displacement of the DC should also be present. Because the principal movement of abaxial markers in our study was along abaxial, distal, and palmar vectors, the data argue against the validity of the pressure and depression theories, as they are described in the literature.

The DC displacement patterns observed in our study were consistent with those predicted by the sling and passive theories. The sling hypothesis suggests that the DC acts as a physical restraint (sling) to restrict downward displacement of the second phalanx during load application and, in doing so, actively absorbs some of the imposed loading energy. Alternatively, the passive theory suggests that the DC plays an unimportant role in inducing or restraining displacement of foot components, either capsular or skeletal, during loading.[b] Instead, the passive theory implies that the primary biomechanical role of the DC is to allow sufficient mobility of the caudal two thirds of the foot for the foot to endure the variable loading conditions to which it is subjected. Both the sling and passive theories argue that the principal direction of displacement must be (sling theory) or can be (passive theory) in distal and palmar directions. If the fibrous and elastic tissues that traverse the DC between the ungual cartilages act as a restraint for the palmar surface of the second phalanx, the DC should be displaced in the direction that the phalanx displaces. If the digit's response to a vertically applied load is a vertical response of the second phalanx, the DC should displace in bilaterally symmetrical distal and palmar directions. Alternatively, if the digit's response to the vertical loading results in a lateral or medial displacement of the second phalanx, the displacement of the DC should likewise be asymmetrical, resulting in the pattern 2 marker displacement observed in our study.

The major difference between the passive and sling theories for DC function is that the passive theory suggests an inability of the DC to effectively restrain the descent of the second phalanx during loading. Because the descent of the second phalanx could result in passive displacement of the DC in the same patterns as when it was displaced while acting in restraint of the hoof capsule, it is impossible to separate these 2 theories by use of the pattern of DC displacement as a criterion.

The lack of an effect of solar support on DC displacement was surprising. Recent data suggest that on deformable surfaces, the sole and frog are major weight-bearing structures.[17] In addition, it is proposed that solar support provided by a displaceable or deformable surface should theoretically inhibit distal displacement of the DC while increasing its abaxial displacement; experimental studies[18,19] have reported conflicting data regarding the effect of ground surface pressure against the frog and displacement of the hoof capsule. The material properties of the washed concrete sand used in this experiment are not known. Sand was chosen to apply solar pressure because of its ability to readily displace and thus conform to the contour of the foot's solar surface, but at the same time, sand is unlikely to compress during loading. Because minimal amounts of sand were displaced during loading and the volume of displaced sand was approximately equal among horses' forelimbs, it was assumed that the goal of loading the solar surface was achieved. This was further supported by the presence of sand under the foot when the foot was lifted after loading. Experimental results suggest that DC displacement was independent of solar support. It was unknown whether the lack of an effect was related to the relatively low maximum load used in our study, the effect of trimming, or the lack of a shoe on the foot.

Overall, our results indicated that displacement of the DC during vertical loading occurs in patterns consistent with response to palmar displacement of the second phalanx. During displacement of the DC, it is possible that the DC is acting to restrain displacements of the foot components or that it is displacing passively in response to the imposed forces. Thus, the hypothesis that the DC is a passive structure was consistent with, but was not confirmed by, the results of this study. Results were also consistent with displacement of the DC being independent of solar support.

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