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Center of Pressure Location of the Hoof with and without Hoof Wedges

P. COLAHAN, D. LEACH and G. MUIR

Department of Large Animal Clinical Sciences, University of Florida, Gainesville, FL 32610-0136, USA and Department of Veterinary Anatomy, Western College of Veterinary Medicine, University of Saskatchewan, Saskatoon, Saskatchewan, S7N 0W0, Canada

ABSTRACT. A new method of assessing the distribution of pressure on the hoof was developed using a recording device and film sensitive to pressure. The technique was applied to 8 left and 5 right *in vitro* loaded forelimbs of young Quarterhorse type horses obtained from an abattoir and 5 left and 4 right forelimbs of 5 standing young Quarterhorses. The effect of hoof orientation was determined on the cadaver specimens by placing wedges beneath the hoof. The cadaver limbs were loaded using a pneumatically powered limb jig. The center of pressure was located on or medial to the central sulcus of the frog in the standing horses and the cadaveric specimens. Wedging the lateral side shifted the center laterally and wedging the medial side shifted it medially. Shifting of the center by wedging has not been reported previously and may aid modeling and biomechanical analysis of the forelimb and farriery.

Key words: Horses; biomechanics; load distribution.

INTRODUCTION

An understanding of the biomechanics of locomotion is critical to the prevention and treatment of musculoskeletal injuries in athletic horses.[6,9] The distribution of forces through the limb, including the mechanics of the dissipation or concentration of forces and the fatigue of the components of the limb, is extremely complex.[7] Because the larger forces, those of the stance phase of the stride, are introduced into the limb through the hoof, the distribution of the forces on the solar aspect of the hoof is a logical point to begin the study of the internal forces of locomotion.

Knowledge of the distribution of the pressure on the solar aspect of the hoof may provide insight into the mechanics of the forelimb and the effects of trimming and shoeing techniques. Studies of the force distribution on the weight bearing surface of the hoof using force shoes,[2] hydraulic sensing devices[1] and force plates[10] on horses, and pedobarographs for cattle and pigs,[8,11] have been reported. The present study investigates the hoof during the stance phase and addresses the following questions: 1) Can the center of pressure be determined for the hoof using a cadaver limb in a mechanical jig? 2) Does the determination of the center of pressure in this manner approximate the condition in living horses accurately? 3) Does the center of pressure in this system change as hoof orientation is changed by wedging the hoof on the medial side, the lateral side, the heel or the toe? 4) With this system can changes of the center of pressure occurring with changes of fetlock angle be detected?

MATERIALS AND METHODS

A pneumatically powered limb jig designed to position the fetlock joint by moving the hoof along an arc defined by a four bar

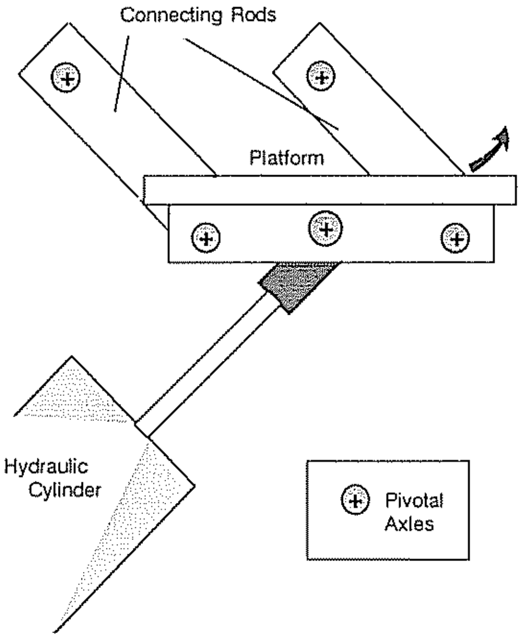

Fig 1 Photograph of the four bar mechanism of the limb jig Arrow indicates the direction of motion of the hoof when placed on the platform.

mechanism was used (Fig 1).[3] This jig maintained the hoof and fetlock in positions mimicking any position of the stance phase of the stride including maximal extension of the fetlock. The jig was powered by an 12.25 cm pneumatic cylinder and compressed air at 690 kPa.

Cadaver limbs of young Quarterhorse type horses were obtained from an abattoir. The hooves were trimmed by a professional farrier and sanded smooth and flat on a stationary belt sander. The live horses were research horses. All horses were evaluated for forelimb soundness and had been trimmed 3 to 5 weeks earlier by the same farrier that trimmed the cadaver limbs prior to testing.

A 1.43 cm diameter hole was drilled through the proximal radius of the cadaver limbs approximately 15 cm distal to the cubital articular surface. The limbs were mounted in the jig by placing each limb with palmar surface of the hoof flat against the platform of the four bar mechanism and passing a 1.27 cm diameter bolt fixed to the jig through the hole in the radius. The limb was secured by a wing nut on the bolt and a steel strap over the mid radius held in place by wing nuts on 1.27 cm diameter bolts. Wooden blocks were placed around the olecranon and against the articular surface to prevent cranial-caudal and proximal-distal motion of the limb and to hold the radius in proper orientation in the jig. The placement of the limb permitted the distal limb between the hoof and the radius to rotate freely and to move freely medially and laterally.

The angle of the surface upon which the hoof rested was established by elevating from the four bar platform the 2 cm thick plywood plate on which the measuring cassette was placed. Elevating one side or one end of the plate by 2 cm wedged the hoof 5° on the toe or heel or 6° medially or laterally. The loading of the limb was accomplished by extending the fetlock to a pre-determined position measured with a goniometer placed on the uppermost aspect of the fetlock joint.

The pressure between the hoof and the platform of the jig was measured with pressure sensitive film (Fugi Prescale Low Pressure Film, Fugi Photo Film Co. Ltd.) held in a cassette made of plywood and Plexiglass.

The cassette and the loading of the cassette in the jig were tested. To evaluate the accuracy of the cassette, a steel horse shoe was placed on the cassette. An aluminum plate was placed on the shoe and the plate, shoe and cassette loaded to 200 kg in a testing machine (Instron Model A 440) at a 0.9 cm diameter point. The calculated location of the point of loading varied from the actual point of loading by 0.6111 cm. The test of the jig loading method was conducted by placing a wooden block in the jig in the place of a cadaver limb and loading a 0.9 cm diameter area on the aluminum plate horse shoe test system used in the previous test. The calculated site of the load varied from the actual site of the load by an average of 0.322 cm. The significence of the shifts observed was tested at significance level 0.01 (*t*-test).

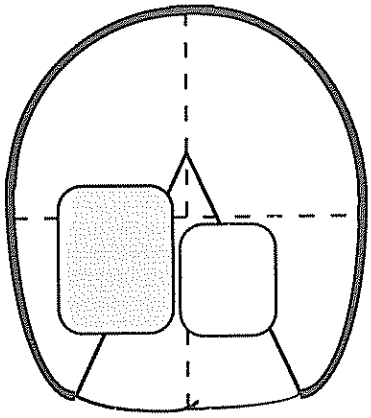

Fig 2 Areas of location of the centers of pressure on the solar aspect of the hoof

This cassette was placed between the platform and the hoof. For live horses, the cassette was placed beneath the hoof on a flat asphalt or concrete surface.

The pressure sensitive film used is a two sheet film system for measuring pressure. The intensity of the color produced on the film was determined and the pressure was measured by a densitometer (Fugi CIPD 100, Fugi Photo Film Co. Ltd.).

The testing procedure was as follows. The limbs were mounted in the jig with the limb positioned and the radius secured so that the metacarpus was perpendicular to hoof platform of the jig and the cassette, containing unexposed pressure sensitive film and an attached sandwich of paper, carbon paper and paper, was placed beneath the hoof. The limb was moved to the appropriate position as determined by the angle of the fetlock measured by a goniometer placed on the uppermost aspect of the fetlock. The outline of the hoof was traced onto the top layer of the sandwich. After 2 min the pressure on the limb was released, and the cassette removed. The film was removed from the cassette, labelled, and attached in proper alignment to the paper on which the tracing and the imprint of the hoof made by the carbon paper were made. The cassette was reloaded, a new paper sandwich attached and replaced beneath the hoof for the next test.

The hooves of the cadaver limbs were tested at fetlock angles of 125° and 110° with the hoof flat and at a fetlock angle of 125° with the hoof wedged up at the four wedged positions. The hooves of the standing horses were evaluated without wedging at a fetlock angle of approximately 130°. The angles for the *in vitro* tests were selected as representative of the angle of extension reached during a moderate trot[5] and at which the fetlock joint is completely extended.[3]

The exposed film was read for pressure in kilograms per square centimeter with the densitometer and the center of pressure determined using a method of weighted proportions similar to that of Barrey[2] calculated from four points on the perimeter of the loaded area of the hoof. The location of the center of pressure was then recorded relative to the central sulcus of the frog and the distance from the toe to the heel. The changes of location for each of the treatments was made in comparison to that obtained with the angle of fetlock at 125° and without wedging. The shifts of positions were noted by the direction the center shifted. The locations of the center of pressure for each of the test positions (the 110° flat and 125° wedged) were compared to the location at the 125° fetlock angle without wedging. For the standing horses only the location of the center of pressure of the hoof without wedging was determined.

RESULTS

All centers of pressure were located medial to the central sulcus at 125° and on the transverse line separating the heel and toe areas or

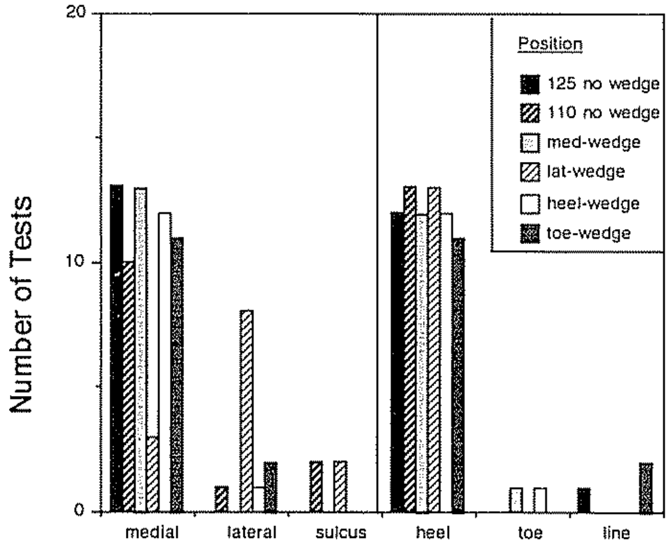

Fig 3 Location of the center of pressure medial or lateral to the central sulcus and dorsal or palmar to a line perpendicular to the central sulcus bisecting the distance from the heel to the toe. Each limb was tested once in each of five positions including at a fetlock angle of 125° without wedges and with the foot wedged medially, laterally, at that toe and at the heel and at 110° fetlock angle without wedges.

in the heel. The centers of pressure were consistently located in the medial heel for most positions except for the lateral wedge when most of the centers were located in the lateral heel (Figs. 2 and 3). This is similar to the location of the center of pressure in the standing horses where the center of pressure was located in the medial heel quadrant of 9 limbs of 5 horses (Fig. 4).

Evaluation of the direction of the shift of the center of pressure indicated that increasing the fetlock angle did not consistently effect the direction of movement of the center of pressure. Wedging the medial aspect of

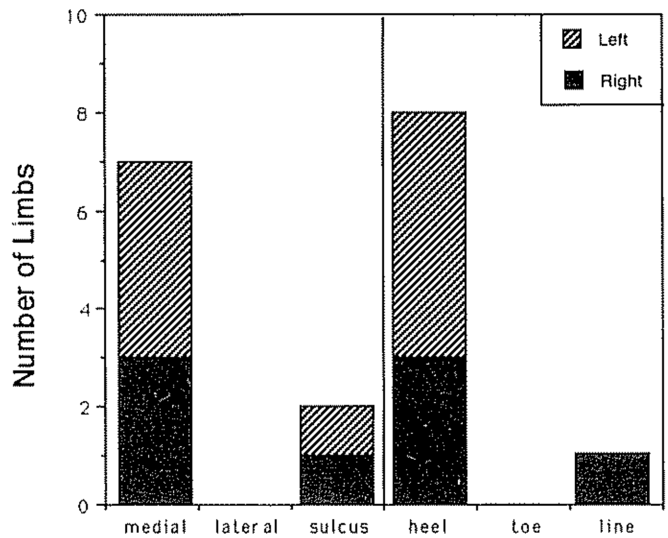

Fig 4 Location of the center of pressure in 9 limbs of 5 young Quarterhorse type horses standing. Position noted as medial or lateral to the central sulcus and dorsal or palmar to a line perpendicular to the central sulcus bisecting the distance from the heel to the toe.

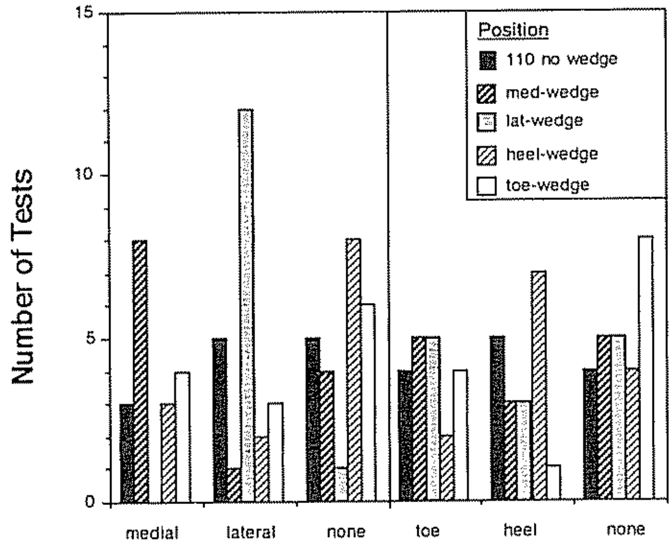

Fig 5 Direction of the shift of the center of pressure from the location of the center of pressure at 125° fetlock angle with the foot flat. The direction of the shift is noted as medial or lateral and toward the heel or the toe.

the hoof either did not move the center or moved it medially (Fig. 5). In all but one case, wedging the lateral side of the hoof shifted the center of pressure laterally. Wedging the toe or the heel of the hoof had no consistent effect on the location of the center of pressure of the hoof (Fig. 5).

DISCUSSION

This method could consistently and reproducibly locate the center of pressure and did so in the medial heel area of the hoof of both cadaver limbs and the living horses. Pedobarographic analysis of young cattle indicated generally more pressure born on the heel and on the lateral digit compared to the medial digit[8] but in the medial digit in another report.[11] The center of pressure measured by force shoes on equine forelimbs produced a location similar to that of this study during part of the stance phase.[2]

In this study, the center of pressure changed with medial and lateral wedging. As the limb was not constrained distal to the carpus, the location and the shifts of the center of pressure are assumed to be accurate representations of loading on the limb. However, the pressure on the toe may be reduced because the deep flexor tendon was applying no active tension. Our failure to detect consistent shifts in the center of pressure location after wedging the toe or heel may be due to this.

A study using force shoes reported a limited cranial-caudal and medial-lateral movement of the center of pressure during the stance phase of the stride.[2] That result was not found here and question 4 posed in this study concerning changes in center of pressure with changes in fetlock angle was answered in the negative, possibly because only a limited part of the stance phase was tested by changing the fetlock angle from 125° to 110° and the sensitivity of the testing method was not sufficient to detect small shifts of the center of pressure.

Possible sources of variation for the limb jig method of testing for center of pressure were the method of trimming the feet, the conformation and condition of the feet, the positioning of the limb in the jig, and the measurement of the angle of the fetlock. One farrier trimmed all the cadaver limbs for the jig and the feet were sanded flat with a stationary belt sander to ensure the feet were flat and smooth. Only feet we determined as normal were used in the *in vitro* studies. The placement and loading of the limb in the jig including drilling the hole in the radius, supporting the proximal radius and ulna and measuring the fetlock angle was standardized as carefully as possible and accomplished by only one person.

The location of the center of pressure in the hooves of standing horses was also determined. The results indicated that the center of pressure was also located in the medial heel of the hoof for the horses tested. Variables present in testing the standing normal horses were the conformation and disposition of the horse and the craftsmanship of the farrier. The same experienced farrier that trimmed the cadaver limbs trimmed the horses and any tests in which the placement of the foot was not flat and/or in which motion was observed were repeated.

This anatomic study was undertaken as part of a group of experiments still being conducted and designed to explore the effects of hoof orientation on the motion and loading of the forelimb. For the farrier and veterinarian, the implications of the information thus far generated could be great. Although this study is limited, the assumption that the forces of locomotion are evenly distributed over the hoof is not supported. Had the pressure been equally distributed the center of pressure would have been located in the geometric center of the hoof. The anatomy of the hoof may represent adaptation to increased force transmission to the medial aspect of the hoof since the medial wall is usually more vertical than the lateral wall.[4,6] However, before this data can be verified a larger number of standing horses with and without wedges must be evaluated.

The effect of wedging or changing the orientation of the hoof on the center of pressure may be of considerable importance because forces may be concentrated in some sites and cause injury. Conversely, forces may be dissipated or sites of concentration moved to treat some conditions. Data on the effects on the medial to lateral and rotational motion of the limb and the pressure in the fetlock joint are currently being analyzed. Further verification of the use of pressure sensitive film for cadaver limbs in the jig and live horses is currently being conducted and may provide a basis for more accurately prescribing therapeutic trimming and shoeing.

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Ground Reaction Force Analysis of Horses Ridden at the Walk and Trot

H. C. SCHAMHARDT, H. W. MERKENS[1] and G. J. V. M. VAN OSCH

Departments of Veterinary Anatomy, and [1]General and Large Animal Surgery, Faculty of Veterinary Medicine, University of Utrecht, P.O. Box 80 157, NL-3508 TD Utrecht, The Netherlands

ABSTRACT. Riding by a skilled and an unexperienced rider were evaluated using ground reaction force measurements of 13 Dutch Warmblood horses at the normal walk and slow trot. The influence of the weight was studied by loading the horses with a sandbag with a mass equivalent to that of the rider. The additional mass increased the ground reaction forces produced by the forelimbs more than those of the hind limbs. At the walk, the force patterns of ridden horses could hardly be distinguished from those loaded with a sandbag. At the ordinary trot, an asymmetry occurred due to sitting in the saddle during the stance phase of the left forelimb and the right hind limb. Comparing sandbag with riding data, the riders were able to shift part of the weight towards the hind limbs. The skills of the riders had minimal influence on the ground reaction force patterns.

Key words Riding; horses; limb loading; force plate; biokinetics.

INTRODUCTION

The weight of the rider will increase the loads on the limbs of the horse and will shift the position of the centre of mass towards the forelimbs. Neither the timing, coordination of limb movement, stride frequency, stride length or vertical acceleration of the body changed significantly when horses were ridden by riders of different mass at the walk, trot or gallop.[1] Carrying loads of 20–30% of the horse's body mass only affected the ground reaction force amplitudes.[7] However, in horse riding, not only the mass of the rider plays a role in the additional load on the limbs, but the skills of the rider may also be important. Although many statements are made about the "proper" way to ride a horse, almost no quantitative studies have been carried out to evaluate these statements.[2]

The purpose of this study was to determine the influence of the mass and the skills of a rider on the loading of all 4 limbs of the horse. The limb loading is quantified on the basis of GRF patterns. This study is focused on GRF obtained during normal walk and slow trot.

MATERIALS AND METHODS

Ground reaction forces were obtained from 13 Dutch Warmblood horses and were measured using a 60×90 cm^2 Kistler type Z4852C quartz crystal piezoelectric force plate. The procedure and equipment to determine the vertical (Fz) and forward/backward (Fy) horizontal GRF have been described.[5,6] At least 8 visually acceptable runs in which both a forelimb, and after a short interval, the ipsilateral hind limb loaded the force plate, were recorded. After normalization of GRF amplitudes to the body mass of the horse (i.e. without the saddle and the rider) and to the duration of the stance phase, an averaged GRF pattern of each limb was constructed and the characteristic peak amplitudes and times of occurrence of each peak were determined. The selected force and peak-time variables are indicated in graphs of representative GRF patterns of