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Original Research

Effect of a Half Pad on Pressure Distribution in Sitting Trot and Canter Beneath a Saddle Fitted to Industry Guidelines

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ABSTRACT

Using a half pad beneath a saddle can be beneficial for improving saddle fit. However, there is a paucity of evidence on half pad use when used beneath a correctly fitted saddle. The aim was to quantify the effect that three different half pads have on pressure distribution beneath a saddle fitted following industry guidelines. Twelve nonlame horses were ridden by experienced riders in sitting trot and canter on each rein (three repeats). Saddle fit, with a high-withered cotton saddle cloth (control) compared with three half pads (viscoelastic gel, wool, and medical-grade, closed-cell foam), was evaluated by five qualified saddle fitters. A Pliance (Novel) pressure mat determined saddle pressures. Mean and peak pressures (kPa) beneath the saddle were compared using a general linear mixed model with horse as a random factor and half pad type and rein as fixed factors with a Bonferroni post hoc correction ($P \leq .05$). In sitting trot, in the cranial region, peak ($P = .008$) and mean pressures ($P = .03$) were highest when using the gel half pad compared with the control. In the caudal region in sitting trot, mean pressures were lowest when using the wool half pad ($P = .0002$). In canter, increased peak ($P = .04$) and mean ($P = .02$) pressures were found in the cranial region of the saddle with the gel half pad. In canter, with the foam half pad, reduced mean pressure ($P = .002$) in the caudal region was found. It is essential that the use and type of a half pad, to be used beneath a well-fitted saddle, is discussed with a qualified saddle fitter.

1. Introduction

There is a growing body of evidence on the effect that incorrect saddle fit can have on equine health and performance [1–8]. However, there is a paucity of evidence on the effect that a layer placed beneath the saddle has on saddle pressures and saddle fit. In the United Kingdom, saddles are generally fitted to the horse and rider by a Society of Master Saddler (SMS) qualified saddle fitter. The SMS provides guidelines (www.mastersaddlers.co.uk; accessed 2018) on criteria related to correct saddle fit, along with a framework where candidates can train and become a qualified saddle fitter. The current guidelines (SMS) suggest that ideally, saddles should be fitted with a cotton saddle cloth. Despite these guidelines, some horse owners choose to place a layer (from hereon: half pad) between the saddle and horse, with the assumption that in doing so, this will improve equine back comfort and may improve performance. A study surveying 1011 riders from 16 equestrian sports found that 98% of riders used a half pad beneath the saddle [9]. Overall, 64.6% of respondents who used more than one layer resulted in a >1 cm increase in thickness being placed beneath the saddle [9]. Improving saddle fit, horse comfort, and reducing back sores were some of the factors being cited for the use of a half pad. The aforementioned study does not provide details on saddle fit, that is, if the saddles were fitted with or without the half pad. Among some saddle fitters and equine professionals, the self-prescribed use of a half pad raises concerns as to whether the saddle remains a correct fit when a half pad is used. The use of a half pad beneath a saddle, which had not been fitted to accommodate the increased thickness, may reduce the space in the saddle gullet or the channel of the panel between the saddle and the horse's back [10].

In these cases, focal areas of pressure beneath the cranial aspect of the saddle may occur. The waist or twist of the saddle refers to the narrowest part of the saddle, which can be associated with a

Animal welfare/ethical statement: The study was approved by the ethics and welfare committee of the first author's institution.

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narrower channel width between the saddle panels. It is speculated that when using a half pad, this could alter a saddle, which was regarded as a correct fit to a fit, which is too narrow. In this case, the half pad might induce focal pressures to the epaxial musculature in the region of the 10th to the 13th thoracic vertebrae (T10–T13) or in the region of the saddle tree points, which may compromise back and locomotor function. It seems possible that if a half pad were to be used without consideration for the increased thickness beneath the saddle, particularly beneath the cranial aspect of the saddle, this will consequently lead to a change in saddle fit, which, in turn, may alter whole horse kinematics and horse-saddle kinetics.

Although limited in extent, half pads have received some scientific scrutiny. The use of a gel, leather, foam, and reindeer fur half pad beneath a correctly fitted saddle has been quantified when ridden on a treadmill. Reindeer fur decreased maximum overall force (MOF) from 1,000 N to 796 N at the walk and from 1,650 N to 1,437 N at the trot. It was reported that none of the half pads led to an increase in MOF [11]. At the walk, when used beneath saddles, which were excessively wide, foam and gel pads reduced the MOF. At the trot, gel and reindeer fur reduced MOF [6]. In contrast to the previous findings, in excessively wide saddles, the use of a leather pad was shown to increase MOF [12]. Recently, half pads have been used to reduce the lateral displacement of a saddle, which consistently displaces laterally to one side. In these horses (and saddles), medical-grade, closed-cell foam shims of different thicknesses (thin: 5 mm or thick: 10 mm) were inserted into a half pad featuring pockets in each quarter. After their insertion, the saddle became more centrally positioned with a more uniformed pressure distribution between the left and right saddle panels [13].

The aim of this study was to investigate the effect of half pads, made of viscoelastic gel (from hereon: gel), wool, and medical-grade, closed-cell foam (from hereon: foam), on saddle pressure distribution. The study concentrates on the use of half pads with a saddle fitted correctly with only a cotton saddle cloth underneath, following industry guidelines (SMS). The objectives of this study were to investigate the effect of gel, wool, and foam half pads on saddle pressures in the (1) cranial and caudal (left + right) regions of the saddle, (2) T10-T13 lateral from the midline, and (3) region of the saddle tree points. It is hypothesized that when using a half pad, there would be (1) an increase in mean and peak pressures in the cranial region of the saddle, (2) an increase in mean and peak pressures in the caudal region of the saddle, (3) increased mean and peak pressures in the region of T10-T13, and (4) increased mean and peak pressures in the region of the saddle tree points.

2. Materials and Methods

This study was approved by the ethics and welfare committee of the first author's institution, project number URN 20181785-2. Informed written consent was obtained before participation in the study. At the time of the study, all riders were free from any injuries and could withdraw their participation from the study at any point.

2.1. Horses

A convenience sample of 12 adult sports horses and their riders was recruited via Facebook. Inclusion criteria were that horses were (1) free from lameness as perceived by their owners, (2) in competitive work, and (3) within a 2-hour journey time of the proposed data collection site. The horses were all in competitive work (Advanced-Grand Prix Dressage), ranged in height at the withers from 1.60 to 1.75 m with (mean ± standard deviation [SD]) of 1.65 ± 0.05 m, had a body mass between 475 and 620 kg (561 ± 34 kg) and were aged 9–13 years (11 ± 3 years). Horses were of a similar type and conformation with well-defined epaxial musculature. On the day of data collection, the horses' gait asymmetry was quantified using a validated sensor system, and all horses underwent a subjective veterinary assessment performed by an experienced veterinary surgeon, which included visual observations in walk and trot from both the rear and lateral view. No overt signs of lameness were observed.

2.2. Riders

Ten female and two male riders took part in the study. All riders were of an experienced level, competing at British Dressage, Advanced—Grand Prix Dressage (mean ± SD) height 1.72 m ± 0.15, body mass 69 ± 06 kg.

2.3. Saddles

Inclusion criteria were that all saddles had been checked by a Society of Master Saddlers Qualified Saddle Fitter (SMSQSF) within 1 month preceding the study, and saddles were deemed a correct fit following industry guidelines. On the day, saddles were independently checked by five SMSQSF who were unaware of the study aims. All saddles were checked for fit both statically [14] and dynamically following the SMS published guidelines, and no overt signs of poor saddle fit were observed. Saddles were all dressage type and were wool flocked. The twist (narrowest part of the gullet) defined as the distance between the two medial edges of the left and right panel ranged from 57.15 mm to 76.2 mm. Seat size (measured the skirt nail to the center of the cantle) ranged from 431.8 to 444.5 mm. The stirrup length, which each rider was accustomed to, was used throughout all data collection.

2.4. Half Pads

As a control, all saddles were fitted following industry guidelines with a high-withered saddle cloth (length: 58 cm withers to base, 54 cm lowest point to base of cloth × width: 63 cm), with girth strap loops and "D" ring attachments.

Three commercially available half pads were investigated:

(1) Gel half pad—a viscoelastic gel pad (length: 59 cm, width: 44 cm [cranial], width: 28 cm [caudal]) constructed as one unit without a central spine and not conforming to back shape.
(2) Wool half pad—natural wool fibers designed to follow the contours of the horse's back (length: 57 cm, width: 23 cm [cranial], width: 27 cm [caudal]) and fitted with "D" ring attachments. The pad was constructed in two parts, with the left and right sides being connected via a webbing spine (2.5 cm thickness).
(3) Foam half pad—a 5 mm medical-grade, closed-cell foam half pad, designed to follow the contours of the horse's back, with an outer cotton sleeve (length: 56 cm, width: 24 cm [cranial], width: 28 cm [caudal]). The pad was constructed in two parts, with the left and right sides being connected via a webbing spine (2.5 cm thickness).

A new half pad was used for each horse. In all experiments, the half pads were fitted between the control (saddle cloth) and the saddle. Half pad displacement ventrally, cranially, and caudally was subjectively evaluated by the same qualified saddle fitter (MF) throughout data collection and at the end of each condition.

2.5. Study Protocol

Each horse underwent a 15-minute warm-up period self-prescribed by the rider for each condition (control, gel, wool, and foam), which included walk, trot, and canter on both the left and right reins. This was followed by a prescribed sitting trot and canter protocol, during which horse-saddle kinetics and limb kinematics were assessed. Data were collected during straight line locomotion in sitting trot and seated canter (from hereon: canter) on both the left and right rein. All measurements were performed on the same outdoor (60 × 20 m) arena surface. The arena dimensions allowed for 11 (trot) and 15 (canter) repeated straight strides along the long side of the arena. Hence, 11 strides in trot and 15 strides in canter were included in the kinetic analysis, with both the start and end points being determined using two cones. Three repeats in sitting trot and canter on the left and right rein were collected for each condition (control, gel, wool, and foam half pad). Conditions, including the control, were investigated in a random order.

2.6. Saddle Kinetics

Kinetic data between the saddle and the horse were recorded using a pressure mapping system (Pliance System, Novel, MSA600, sampling rate 50 Hz) with simultaneous video capture. The pressure mat consisted of 256 sensors, divided into two halves of 128 sensors on the left and right side of the spine (with no sensors in the central region above the vertebrae). On each side of the pressure mat, sensors were arranged into eight columns (longitudinal) and 16 rows (transverse; Fig. 1).

Location of pressure was defined as follows:

(1) Cranial region—transverse Rows 1–8 and Columns A–H (left side) and I–P (right side; Fig. 1).
(2) Caudal region—transverse Rows 9–16 and Columns A–H (left side) and I–P (right side; Fig. 1).
(3) T10–T13 region—transverse Rows 4–7 and Columns H (left side) and I (right side; Fig. 1).

The pressure mat was calibrated following manufacturers guidelines (Pliance, Novel). Before measuring, the pressure mat was zeroed without the saddle, girth, or rider [1] and was fitted so that the pressure mat was on top of the horse's skin and beneath the saddle cloth and saddle as previously described [15–17]. For repeatability of mat positioning relative to the horses back and the saddle, skin paint was applied to the horse's midline representing the cranial and caudal margins of the pressure mat, and small stickers were applied to the mat, representing the cranial and caudal margins of the saddle. Peak pressures (kPa) and mean pressure (kPa) in trot and canter for all saddle conditions were collected. Averaged peak pressures were determined for every stride, and mean pressures were determined from all loaded sensor cells <2 kPa. Data were included from 11 repeated trot strides and 15 repeated canter strides, from the Pliance synchronized video, both the start and end points were determined by maximal protraction of the inside hind limb on both reins.

2.7. Kinematics—Two-Dimensional Motion Capture

To determine any changes in force production (as derived from quantifying fetlock hyperextension [18]), kinematic data were recorded with a high-speed video camera system, using 12 skin markers (30 mm diameter) placed on each horse using double-sided tape. Marker locations were identified by manual palpation of anatomic landmarks identifying joint centers and segment ends. Once located, white skin paint was used to mark each reference point for accurate marker replacement, in case a marker became loose or fell off.

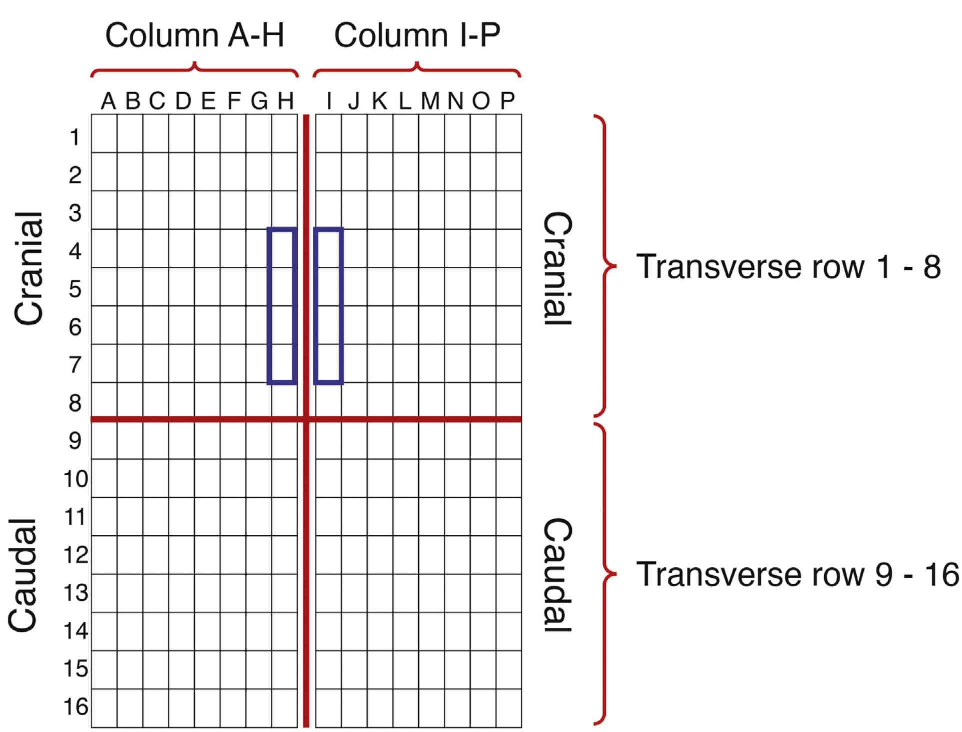

Fig. 1. Illustration of the Pliance pressure mapping sensors. Cranial region = transverse Rows 1–8 and Columns A–H/I–P, caudal region = transverse Rows 9–16 and Columns A–H/I–P. T10–T13 region = transverse cells 4–7, Row H and Row I, represented by the blue box.

Markers were located on the following anatomic positions on both sides of the horse:

Forelimb: (1) head of the splint bone, (2) distal aspect of the metacarpus over the lateral collateral ligament (LCL) of the metacarpophalangeal joint, and (3) origin of the LCL of the distal interphalangeal joint.

Hindlimb: (4) talus, (5) distal aspect of the metatarsus over the lateral collateral ligament of the metatarsophalangeal joint, and (6) origin of the LCL of the distal interphalangeal joint.

One high-speed camera (Quintic) was positioned at a 10-m distance from the experiment track, capturing the lateral aspect of the horse (spatial resolution 1,300 × 400, 300 fps), with a field of view capturing two complete strides (width of field of view, 5 m, i.e., approximately 3.8 mm/pixel for the 5 m field of view) in trot and canter. A halogen light was used to illuminate the markers. High-speed video data were recorded and downloaded to a laptop (Lenovo) and processed using two-dimensional motion capture software (Quintic Biomechanics). Automatic marker tracking was used to investigate maximum fetlock hyperextension during stance for front (palmar angle between markers [1–3]) for the forelimb and between markers [4–6] for the hind limb. All raw data were smoothed using a fourth-order Butterworth low-pass filter with a cutoff frequency of 10 Hz [19].

2.8. Data Collection

From the saddle kinetics, in sitting trot, data were collected from 11 consecutive strides from three repeats, totaling 33 ± 3 (mean ± SD) strides used for analysis. In canter, data were collected from 15 consecutive strides from three repeats, totaling 45 ± 5 (mean ± SD) on both left and right rein for each horse and saddle condition.

Outcome parameters for the pressure distribution between saddle conditions were as follows:

(1) Peak and mean pressure beneath the cranial aspect of the saddle (kPa).
(2) Peak and mean pressure beneath the caudal aspect of the saddle (kPa).
(3) Mean peak pressure of the T10–T13 region—transverse rows, Sensors 4–7 and Columns H (left side) and I (right side; Fig. 1).

From the two-dimensional kinematic analysis, data were collected from two consecutive strides with three repeats, totaling six strides used for analysis for both trot and canter on both left/right rein for each horse for all conditions.

Outcome parameters for each condition were maximum fetlock hyperextension front and hind during midstance.

2.9. Statistical Analysis

Statistical analysis was performed in SPSS (version 22; IBM, Armonk, USA).

2.9.1.Influence of Speed

As many kinematic parameters are influenced by speed, differences in speed between conditions were assessed using a repeated measures analysis of variance by obtaining stride length and stride time from the two-dimensional kinematic analysis for each trial for each condition. No significant differences were found (all $P \geq .05$; for trot and canter), and as a consequence, speed was not entered into the mixed model analysis (described below).

2.9.2Influence of Half Pads

Initially, implemented general linear models did not show a significant influence of rein (left, right) on kinetic saddle data ($P \geq .05$ for trot and canter). Hence, the final general linear mixed model was implemented for kinetic data as outcome parameters (peak pressure [kPa] and mean pressure [kPa]) with half pad (control, gel, wool, and foam half pad) as a fixed factor and horse as a random factor. Two separate general linear models were created: one for trot and one for canter. For comparisons between kinematics and half pads, a general linear model was created for both trot and canter on the left and right rein independently, resulting in four general linear models being created.

For all models (kinetics and kinematics), a Bonferroni post hoc analysis was carried out to determine differences between pairs of conditions (control, gel, wool, and foam half pad) and a significance level set at $P \leq .05$ for all outcome parameters. Instead of applying the Bonferroni correction on the significance level, alpha, this study reported the Bonferroni adjusted P values (P values based on Fisher's least significant difference multiplied by the number of comparisons done). This allows assessment of significance with reference to the traditional alpha of 5%, without increasing type II errors.

Table 1
Mean and SD saddle pressure data for mean and peak (kPa) saddle pressures in the cranial/caudal region of the saddle and Sensors 4–7 (Rows 4–7, Columns H and I).

Measurement Parameter	Control (Mean ± SD)	Gel (Mean ± SD)	Wool (Mean ± SD)	Foam (Mean ± SD)	Main Effects (P Value)	Pairwise Bonferroni Post Hoc ($P \leq .05$)
Peak cranial (kPa)	36.8 ± 8.4	41.2 ± 12.1	33.3 ± 5.3	35.5 ± 9.8	0.008	Gel—wool, $P = .005$ Gel—foam, $P = .05$
Peak caudal (kPa)	22.7 ± 2.4	22.7 ± 3.6	20.7 ± 3.0	22.4 ± 2.5	0.07	—
Mean cranial (kPa)	14.9 ± 2.5	17.5 ± 4.8	15.3 ± 3.4	15.8 ± 2.6	0.03	Control—gel, $P = .03$
Mean caudal (kPa)	9.9 ± 1.2	9.3 ± 1.3	8.4 ± 1.2	9.7 ± 1.7	0.0002	Control—wool, $P \leq .0001$ Foam—wool, $P = .004$
Mean Sensor 4 (kPa)	14.8 ± 9.4	31.4 ± 22.2	18.9 ± 12.1	21.5 ± 12.4	0.0002	Control—gel, $P \leq .0001$ Gel—wool, $P = .006$ Gel—foam, $P = .04$
Mean Sensor 5 (kPa)	18.9 ± 7.9	34.2 ± 15.4	21.8 ± 9.2	25.6 ± 17.3	0.00002	Control—gel, $P \leq 0.0001$ Gel—wool, $P = .001$ Gel—foam, $P = .03$
Mean Sensor 6 (kPa)	19.7 ± 7.3	24.8 ± 6.1	22.8 ± 9.3	20.4 ± 14.3	0.25	—
Mean Sensor 7 (kPa)	15.8 ± 5.9	18.1 ± 9.4	14.8 ± 7.4	16.1 ± 8.1	0.64	—

Abbreviations: SD, standard deviation.
Data collected from 31 repeated strides in sitting trot on both the left and right rein from 12 horses for all conditions. Left and right rein data pooled with a significance level set at $P < .05$ with a Bonferroni post hoc adjustment to determine differences between conditions, with only significant post hoc results being presented (Bonferroni adjusted alpha 5%).

3. Results

3.1. Horse Inclusion

All horses underwent a lameness evaluation by one veterinary surgeon, and all horses were deemed fit to perform. From the objective movement asymmetry measures in trot on the straight, horses had (mean ± SD) asymmetry values: HD_{min}, 5.2 ± 2.2 mm and HD_{max} 3.3 ± 2.3 mm, Pelvis Min_{Diff} 3.2 ± 1.6 mm, and Pelvis Max_{Diff} 3.01 ± 1.6 mm.

3.2. Kinetic Data—Pressure Distribution in Sitting Trot

Differences in peak pressures were found beneath the cranial region (P = .008). Post hoc analysis showed an increase in peak pressures beneath the cranial region of the saddle with the gel half pad were found compared with the wool (P = .005) and foam half pad ($P \leq .05$). In the caudal region, peak pressures did not differ between half pads and the control (P = .07). Differences in mean pressures in the cranial region were found (P = .03). Post hoc analysis showed an increase in mean pressures when using the gel half pad compared with the control (P = .03). Differences in mean pressures were found in the caudal region (0.0002). Post hoc analysis showed a decrease in mean pressures was found with the wool half pad compared with the control ($P \leq .0001$) and the foam half pad (P = .004; Table 1, Figs. 2 and 3).

Mean peak pressure (average of peak pressures for every stride) at Cell 4 (Row 4, Columns H and I; Fig. 1) showed a higher peak pressure with the use of the gel half pad compared with the control ($P \leq .0001$), the wool pad (P = .006), and the foam half pad (P = .04). Mean pressure at Cell 5 (Row 5, Columns H and I; Fig. 1) showed a higher peak pressure with the use of the gel half pad compared with the control ($P \leq .0001$), the wool pad (P = .001), and the foam half pad (P = .03). No differences in mean peak pressure were found at Cells 6 (P = .25) and 7 (P = .64) between half pads (Table 1, Figs. 2 and 3).

3.3. Kinetic Data—Pressure Distribution in Canter

In canter, in the cranial region, peak pressures were found to differ between half pads (P = .04). Post hoc analysis showed no significant differences between conditions ($P > .05$). Differences were found in mean pressures in the cranial region (P = .02). Post hoc analysis showed an increase in mean pressure beneath the cranial region of the saddle with the gel half pad compared with the control (P = .05), wool (P = .03), and foam (P = .05) half pad. Mean pressures differed in the caudal region (P = .002). Post hoc analysis showed a decrease in mean pressure with the foam half pad compared with the control (P = .02; Table 2, Figs. 2 and 3).

Post hoc analysis showed an increase in mean peak pressure at Cell 4 (Row 4, Columns H and I; Fig. 1) when using the gel half pad compared with the control ($P \leq .0001$), wool (P = .002), and foam half pads (P = .03). An increase in mean peak pressure at Cell 5 (Row 5, Columns H and I) was found when using the gel half pad compared with the control (P = .006) and wool half pad (P = .05). No differences in mean peak pressure at Cells 6 (P = .07) and 7 (P = 1.45) between half pads (Table 2; Figs. 2 and 3).

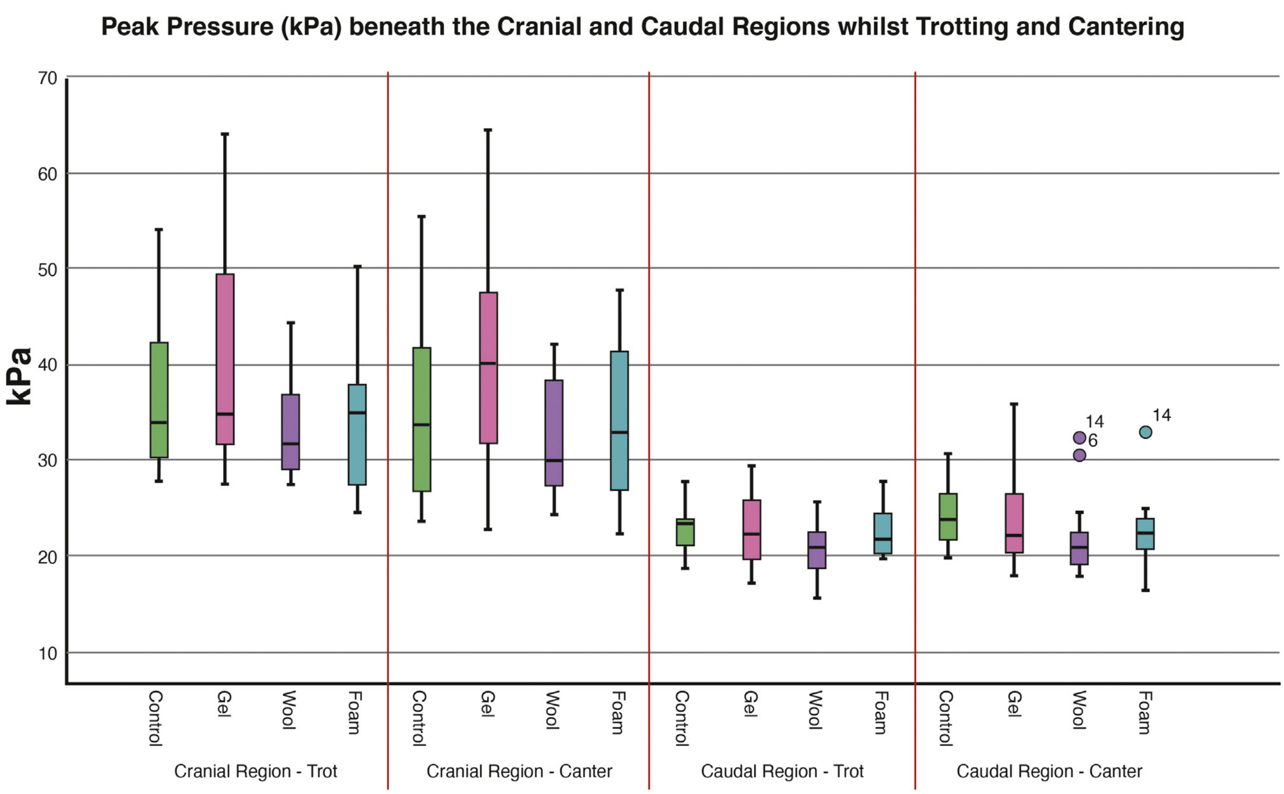

Fig. 2. Peak saddle pressure (kPa) beneath the cranial and caudal regions of the saddle whilst trotting and cantering. Boxplots displaying peak pressure distribution beneath the saddle in the cranial and caudal regions of 12 horses while being ridden in sitting trot and collected canter. The central line represents the median; the box represents the 25th and 75th percentiles; and the whiskers represent the maxima and minima not considered to be outliers. ° represents outliers. In sitting trot, post hoc analysis showed an increase in peak pressures beneath the cranial region of the saddle with the gel half pad was found compared with the wool (P = .005) and foam half pad ($P \leq 0.05$). In the caudal region, peak pressures did not differ between half pads and the control (P = .07). In canter in the cranial region, peak pressures were found to differ between half pads (P = .04); however, post hoc analysis showed no significant differences between conditions ($P > .05$).

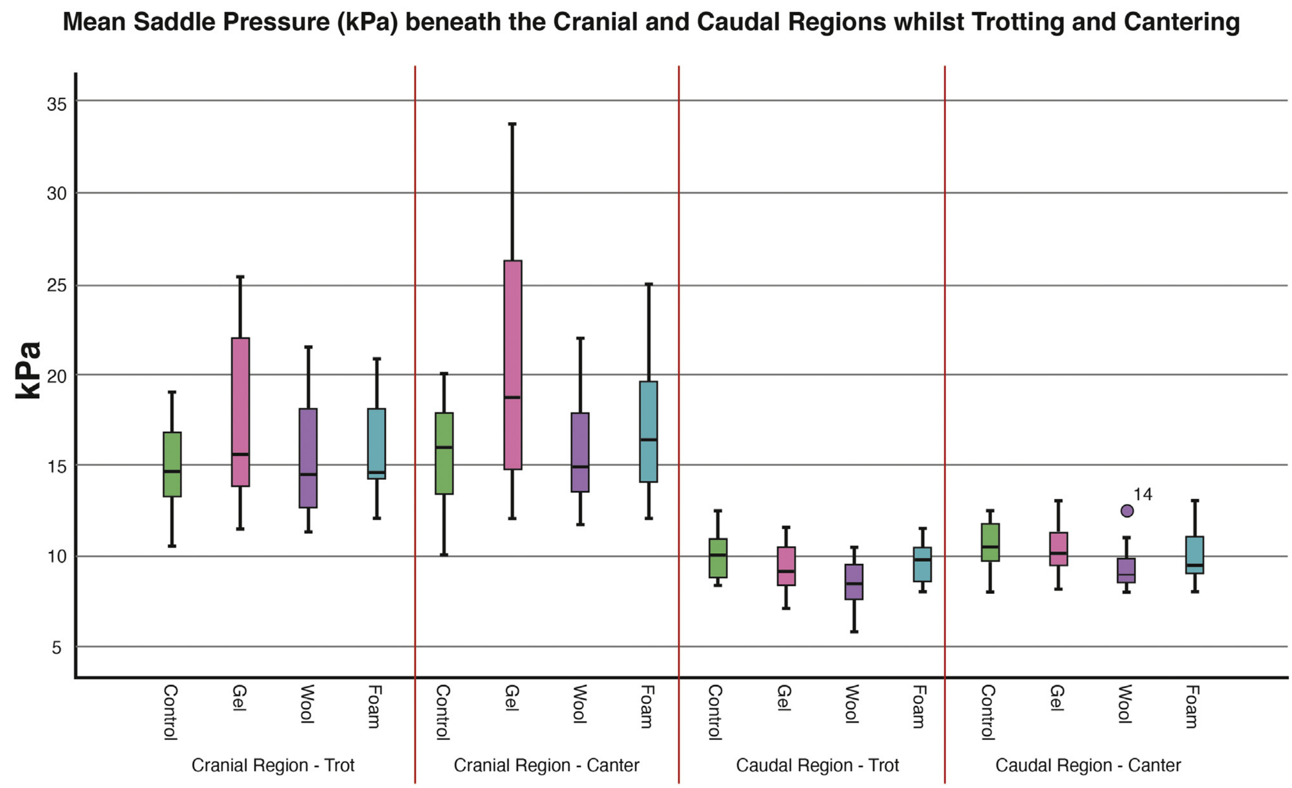

Fig. 3. Mean saddle pressure (kPa) beneath the cranial and caudal regions of the saddle whilst trotting and cantering. Boxplots displaying mean pressure distribution beneath the saddle in the cranial and caudal regions of 12 horses while being ridden in sitting trot and collected canter. The central line represents the median; the box represents the 25th and 75th percentiles; and the whiskers represent the maxima and minima not considered to be outliers. ° represents outliers. In sitting trot, post hoc analysis showed an increase in mean pressures beneath the cranial region of the saddle was found when using the gel half pad compared with the control ($P = .03$). In the caudal region, a decrease in mean pressures was found with the wool half pad compared with the control ($P \leq .0001$) and foam half pad ($P = .004$). In canter, post hoc analysis showed an increase in mean pressure beneath the cranial region of the saddle with the gel half pad compared with the control ($P = .05$), wool ($P = .03$), and foam ($P = .05$) half pad. Post hoc analysis showed a decrease in mean pressure with the foam half pad compared with the control ($P = .02$).

3.4. Kinematic Data in Trot and Canter

No significant differences (all $P > .07$) were found for fetlock hyperextension front and hind between the control and half pads (Table 3).

4. Discussion

The aim of this study was to determine whether using a half pad beneath a saddle, which had been fitted following industry guidelines ([SMS] without a half pad beneath), is associated with increased saddle pressures beneath the cranial and caudal regions of the saddle and in the region of T10-T13. The saddles in the present study had been fitted following published guidelines (SMS) and checked preceding the study and on the day by five qualified saddle fitters (SMS). The qualified saddle fitters assessing saddle fit on the day were blinded to the study aims. Saddles were fitted with a cotton saddle cloth (as per industry guidelines), which was used as a control. Therefore, saddles in this study were not fitted to accommodate the additional thickness between the horse's back and the saddle, which any of the experimental half pads may have created.

In trot, peak pressures occurred beneath the saddle on the contralateral side to the forelimb during midstance, which is similar to the timings reported elsewhere [17]. In canter, peak pressures occurred during the stance phase of the inside forelimb, likely as a result of canter lead. In accordance with our hypothesis, in this study, we report that using a half pad beneath the saddle altered saddle pressure distribution in both the cranial and caudal regions of the saddle. In partial support of the experimental hypothesis, in sitting trot and canter, the gel half pad resulted in an increase in mean and peak pressure in the cranial region of the saddle. In contrast, the foam and wool half pad showed no differences when compared with the control. In sitting trot, the wool half pad showed a decrease in mean pressures in the caudal region of the saddle compared with the control and foam half pad. In canter, both the foam and wool half pad were associated with a significant decrease in mean pressure in the caudal regions of the saddle compared with the control. This region may be influenced more by the rider as has been reported when ridden in walk, whereas the cranial region pressure may be influenced more by the horse [20]. Therefore, in cases where the rider is not sufficiently coupled with the horse (out of balance), it may be useful for riders (in conjunction with a saddle fitter) to consider the use of a foam or wool half pad to help with cushioning the pressures the caudal thoracic spine is exposed to during ridden exercise [12].

In both sitting trot and canter, the gel half pad resulted in increased mean and peak pressures beneath the cranial region of the saddle when compared with the control. It is proposed that because of the properties of the gel half pad, during locomotion, it is being pulled down. In the present study, half pad displacement was assessed visually by the same qualified saddle fitter (MF); it was subjectively assessed that the gel half pad displaced ventrally (after initially being lifted up into the gullet) in seven of the 12 horses compared with the wool and foam half pad, which—assessed subjectively—remained in position throughout the exercise test. It

Table 2
Mean and SD saddle pressure data for mean and peak (kPa) saddle pressures in the cranial/caudal region of the saddle and Sensors 4–7 (Rows 4–7, Columns H and I).

Measurement Parameter	Control (Mean ± SD)	Gel (Mean ± SD)	Wool (Mean ± SD)	Foam (Mean ± SD)	Main Effects (*P* Value)	Pairwise Bonferroni Post Hoc ($P \leq .05$)
Peak cranial (kPa)	35.3 ± 10.4	40.2 ± 12.5	34.1 ± 11.1	34.8 ± 9.3	0.04	—
Peak caudal (kPa)	24.2 ± 3.1	23.7 ± 5.4	21.9 ± 4.1	22.41 ± 3.7	0.09	—
Mean cranial (kPa)	15.7 ± 3.5	18.4 ± 5.2	15.5 ± 3.4	16.8 ± 3.5	0.02	Control—gel, $P = .05$ Wool—gel, $P = .03$ Foam—gel, $P = .05$
Mean caudal (kPa)	10.6 ± 1.4	10.3 ± 1.3	9.4 ± 1.1	9.3 ± 1.4	0.002	Control—foam, $P = .02$
Mean Sensor 4 (kPa)	16.9 ± 9.0	30.6 ± 16.4	19.0 ± 8.8	19.5 ± 11.8	0.00009	Control—gel, $P \leq .00001$ Gel—wool, $P = .002$ Gel—foam, $P = .003$
Mean Sensor 5 (kPa)	22.0 ± 11.1	32.7 ± 11.6	24.4 ± 9.6	21.1 ± 12.0	0.001	Control—gel, $P = .006$ Gel—wool, $P = .05$ Gel—foam, $P = .002$
Mean Sensor 6 (kPa)	20.5 ± 8.1	27.0 ± 7.5	25.9 ± 17.5	19.17 ± 8.8	0.07	—
Mean Sensor 7 (kPa)	15.5 ± 4	19.3 ± 7.5	18.4 ± 11.2	14.2 ± 7.6	1.45	—

Abbreviations: SD, standard deviation.
Data collected from 45 repeated strides in sitting canter on both the left and right rein from 12 horses for all conditions. Left and right rein data pooled with a significance level set at $P < .05$ with a Bonferroni post hoc adjustment to determine differences between conditions, with only significant post hoc results being presented (Bonferroni adjusted alpha 5%).

is likely that the wool and foam half pad remained in position because of the construction of the respective half pads. The foam and wool half pad included a central webbed spine, connecting the left and right sides of the half pad, which provides an element of rigidity, and, because of its properties, the foam pad can absorb shear forces and hence likely withstand locomotor and saddle forces, which may otherwise cause the half pad to displace. Furthermore, the design of the gel half pad without a central spine or rigid component has limited properties to dissipate shear forces and may be more prone to being displaced in the presence of locomotor and saddle forces. The observed displacement of the gel half pad in effect draws down on the horse's back and may contribute to explaining the increased peak and mean pressures in the cranial region of the saddle when in sitting trot and canter. In the present study, the pressure mat was positioned longitudinally on the back; therefore, we cannot determine if the ventral displacement of the gel half pad resulted in an increase in pressure directly on the midline of the back. If the study were to be repeated, positioning the pressure mat transversely along the back would be able to quantify if pressures occur directly on the midline because of the displacement of the gel half pad.

The findings presented here are, in part, in accordance with those presented elsewhere, where the use of a gel, leather, foam, and reindeer fur half pad beneath excessively wide saddles had been investigated. Although walking on a treadmill (with a rider), the gel and foam half pad reduced the MOF, and in trot, the gel and reindeer fur pad were associated with reduced overall maximum force [12]. The same group found that MOF beneath a fitted saddle was reduced when using reindeer fur [11] when walking and trotting on a treadmill. When interpreting the differences being presented here and those of Kotschwar et al. [11], there are several important considerations. First, the present study quantified the use of a half pad beneath a saddle, which was fitted following industry (SMS) guidelines. Second, the present study was performed over ground and not on a treadmill [21,22], and finally, the half pads used previously are of different material properties to the ones used in the present study. It is hence likely that their performance in reducing pressures will vary. That said, the findings of Kotschwar et al. [11,12] and of the present study indicate that using half pads of varying materials beneath a saddle, which is (1) fitted excessively wide, (2) fitted using lowest overall force as a parameter for correct fit, and (3) fitted correctly following industry guidelines (SMS) can be associated with a reduction in saddle pressures particularly in the caudal region of the saddle. Hence, it is essential that horse owners consider carefully the half pad's application and properties when selecting. The wool and foam half pad showed similar pressure reducing properties. However, it is worth considering that the half pads used in the present study were all unused, and for example, using a new wool half pad compared with a used one may show different results. Therefore, the inclusion of partly worn half pads may be a useful undertaking in future studies and would enable an assessment of alterations in the material properties in

Table 3
Mean and SD kinematic data while in sitting trot and canter from six strides on both the left and right rein for all half pad conditions and the control.

Measurement Parameter	Sitting Trot		Canter	
	Left Rein	Right Rein	Left Rein	Right Rein
	Maximum Front Fetlock Hyperextension (°)	Maximum Front Fetlock Hyperextension (°)	Maximum Front Fetlock Hyperextension (°)	Maximum Front Fetlock Hyperextension (°)
Control (mean ± SD)	248.2 ÷ 8.3	245.5 ÷ 6.8	246.4 ÷ 9.0	245.4÷6.6
Gel half pad (mean ± SD)	248.8 ÷ 8.5	248.7 ÷ 5.7	245.3÷10.1	242.2 ÷ 6.9
Wool half pad (mean ± SD)	248.4 ÷ 8.8	248.4 ÷ 5.9	245.2 ÷ 9.9	247.3 ÷ 3.9
Foam half pad (mean ± SD)	247.6 ÷ 10.0	245.2 ÷ 6.3	244.3÷8.6	245.7 ÷ 6.8
P value	.71	.10	.75	.15
Post hoc: Bonferroni	—	—	—	—

Abbreviations: SD, standard deviation.
No significant difference ($P \geq .07$) was found between the half pads and the control for fetlock hyperextension.

relation to degradation with use. This seems particularly applicable to the wool half pad, where it is speculated that the crimp of the wool fibers in a used pad (>3 months old) would be reduced and thus likely affect its pressure reducing properties.

The forces exposed to the horse's back while trotting and cantering have been reported [23]. In the present study, in sitting trot and canter, the use of a wool and foam half pad beneath a correctly fitted saddle was associated with reduced mean and peak pressures in the caudal regions of the saddle. There is concern within the equine industry that the placing of a half pad beneath a saddle, which has not been fitted to accommodate the increased thickness, may result in areas of high pressure in the region of T10-T13 [24]. Pressures in this region have previously been shown to have an effect on trot [17], jumping [25], and racehorse [26] kinematics. In the present study, in sitting trot and canter in the region of the 10th and 11th thoracic vertebrae (represented by Rows 4 and 5 and Columns H and I; Figs. 1, 4, and 5), a significantly higher mean peak pressure was found with the gel half pad compared with the control and the remaining half pads. All the saddles were a correct fit; however, the pressures observed in the present study were higher than the values correlated to back pain (sitting trot peak pressures >34.5 kPa under the cranial region of the saddle and >31 kPa under the caudal region of the saddle as well as mean pressures >13.2 kPa and >10.0 kPa, respectively, [27]). The differences here could be attributed to a different horse population; in the present study, dressage horses were studied. It is speculated that the athletic

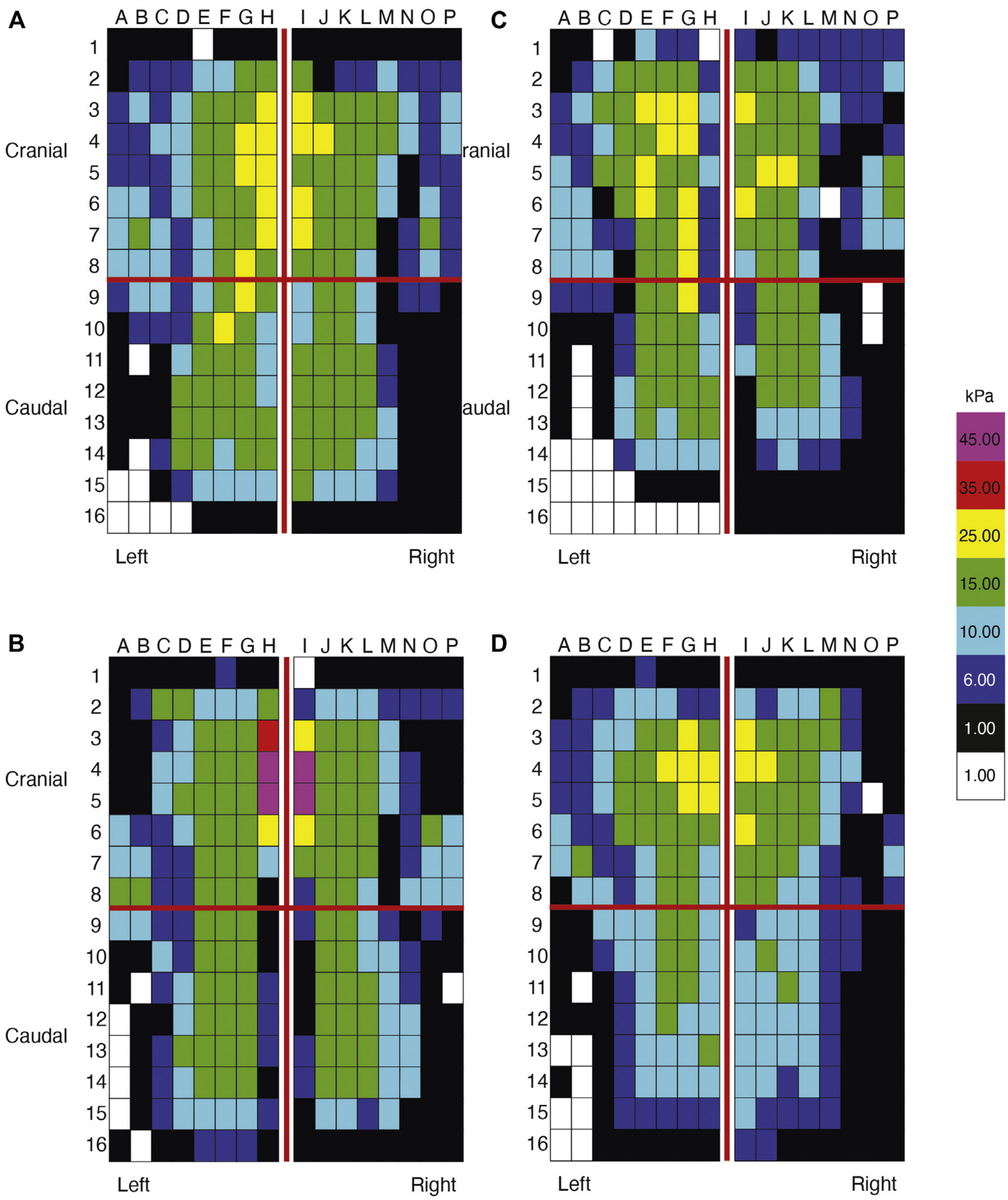

Fig. 4. Mean saddle pressure distribution (kPa) beneath the experimental half pads and control while in sitting trot. Pressure distribution for 33 repeated motion cycles for one horse on both the left and right rein with the lowest mean saddle pressures for all conditions. (A) (top left) = control, (B) (bottom left) = gel half pad, (C) (top right) = wool half pad, and (D) (bottom right) = foam half pad. Cranial, caudal regions and left and right sides of the pressure mat identified.

ability of the horse may have influenced saddle pressures. Although pressure values were higher than published thresholds [27], when using the gel half pad, peak and mean saddle pressure values increased when compared with the control; therefore, half pad selection (materials and type) are essential factors to consider.

The saddles used in the present study were not fitted to accommodate the additional thickness of the half pad, suggesting that the placing of a half pad beneath reduces the distance between the medial aspect of the two panels (gullet width) and hence leads to increased pressures in the region. For those considering the use of a half pad, it is essential its fit in relation to the saddle is discussed with a qualified saddle fitter. The saddles used in the present study were not narrow in the gullet/channel (57.15–76.2 mm). In cases where the saddle has a narrow gullet/channel, the increased thickness of the half pad might result in increased pressures in the cranial region (T10-T11) of the saddle. However, the present study does not provide supporting evidence for this as all of the saddles were of a sufficient width in the gullet width.

Fetlock kinematics were quantified in trot and canter to determine whether changes in mean and peak pressures beneath the saddle were as a result of the half pads and/or as a result of a change

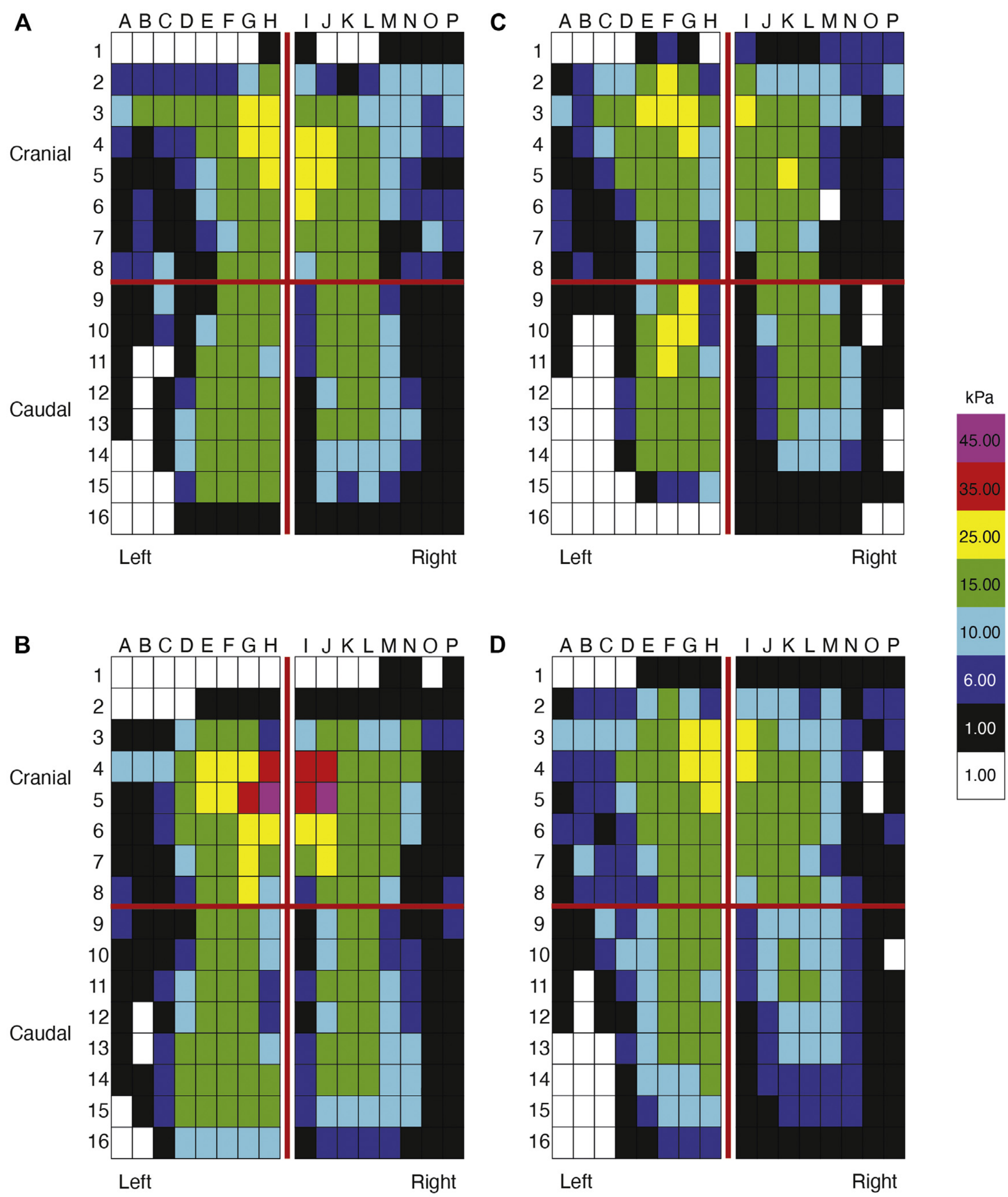

Fig. 5. Saddle mean pressure distribution (kPa) beneath the experimental half pads and control while in canter. Pressure distribution for 33 repeated motion cycles on both the left and right rein for one horse with the lowest mean saddle pressures for all conditions. (A) (top left) = control, (B) (bottom left) = gel half pad, (C) (top right) = wool half pad, and (D) (bottom right) = foam half pad. Cranial, caudal regions and left and right sides of the pressure mat identified.

in peak vertical force (derived from fetlock hyperextension [18]). In the present study, no differences were observed in fetlock hyperextension between half pad conditions, suggesting that although there was an increase/decrease in peak and mean pressures between horse and saddle with the half pads, this was not related to a change in peak vertical ground reaction forces. If the study were to be repeated, using an embedded force platform would allow for a more comprehensive analysis of the ground reaction forces when trotting and cantering with different half pads. Changes in limb angles (maximum carpal and tarsal flexion) in relation to reduced saddle pressures in the region of the 10th to 13th thoracic vertebrae, along with changes [17] in thoracolumbar spinal kinematics [28] with three different saddle widths have been reported. The use of additional markers to investigate joint kinematics and or back sensors/markers [29–31] would be of interest and allow for a more comprehensive comparison between studies. Given that speed can affect stride characteristics [32,33] and saddle pressures [34], it is possible that alterations in locomotor parameters and/or saddle pressures were the result of a change in speed. However, in the present study, speed did not affect any of the four outcome parameters. The sample size of the present study with 12 horses is comparatively small. The findings reported describe immediate changes within each horse as a function of the experimental variable (type of half pad), and a longitudinal study would be advantageous to quantify the long-term effects of using a half pad. These may be different from the short-term effects because of the properties of any half pad potentially altering over time. In cases where the half pad is being used to reduce existing areas of high pressure, over time, these areas of high pressures may appear elsewhere. Therefore, in these cases, it is likely that the half pad has simply moved the location of pressure [10]. This study quantified the use of a half pad while performing sitting trot and seated canter. Future research quantifying the use of a half pad when the horse is ridden in other gaits as well as other riding positions such as rising trot, standing canter, and jumping is warranted. Finally, this study only quantified three half pads; the authors appreciate that there are multiple half pads available and future research should quantify the effect that additional half pads have on saddle pressure distribution.

5. Conclusion

In canter, the use of a foam or wool half pad beneath a saddle, which has not been fitted to accommodate a half pad, may help to reduce peak pressures in the caudal region of the saddle. However, the use of gel half pads resulted in increased peak pressures in both sitting trot and canter in the cranial region of the saddle. It is speculated that these increased peak pressures arose as a result of the characteristics of viscoelastic gel and its pressure absorbing properties. It appears essential that horse owners seek professional advice on the use, type, materials, and suitability of using a half pad in relation to their horses' requirements and saddle fitting needs. Caution should be taken over applying these findings to all saddle designs, as, unlike the saddles used in the present study, some saddles may have a narrow gullet, in which case there might not be sufficient clearance to accommodate a half pad. This further highlights the need for horse owners and equine professionals to discuss the use of a half pad with a qualified saddle fitter on an individual horse basis.

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References

[1] de Cocq P, van Weeren R, Back W. Saddle pressure measuring: validity, reliability and power to discriminate between different saddle-fits. Vet J 2006;172:265–73.
[2] Dyson S, Carson S, Fisher M. Saddle fitting, recognising an ill-fitting saddle and the consequences of an ill-fitting saddle to horse and rider. Equine Vet Educ 2015;27:533–43.
[3] Greve L, Dyson S. The horse-saddle-rider interaction. Vet J 2013;195:275–81.
[4] Greve L, Dyson S. Saddle fit and management: an investigation of the association with equine thoracolumbar asymmetries, horse and rider health. Equine Vet J 2015;47:415–21.
[5] Greve L, Dyson S. The interrelationship of lameness, saddle slip and back shape in the general sports horse population. Equine Vet J 2014;46:687–94.
[6] Harman J. Tack and sadde fit. Vet Clin 1999;15:247–61.
[7] Von Peinen K, Wiestner T, von Rechenberg B, Weishaupt M. Relationship between saddle pressure measurements and clinical signs of saddle soreness at the withers. Equine Vet J Suppl 2010;38:650–3.
[8] Warner S, Koch T, Pfau T. Inertial sensors for assessment of back movement in horses during locomotion over ground. Equine Vet J Suppl 2010;38:417–24.
[9] Hawson L, McLean A, McGreevy P. A retrospective survey of riders' opinions of the use of saddle pads in horses. J Vet Behav Clin Appl Res 2013;8:74–81.
[10] Harman J. The horses' pain-free back and saddle-fit book: ensure soundness and comfort with back analysis and correct use of saddles and pads. North Pomfret, Vermont: Trafalgar Square Publishing; 2004.
[11] Kotschwar AB, Baltacis A, Peham C. The effects of different saddle pads on forces and pressure distribution beneath a fitting saddle. Equine Vet J 2010;42:114–8.
[12] Kotschwar AB, Baltacis A, Peham C. The influence of different saddle pads on force and pressure changes beneath saddles with excessively wide trees. Vet J 2010;184:322–5.
[13] Mackechnie-Guire R, Mackechnie-Guire E, Fisher M, Mathie H, Bush R, Pfau T, Weller R. Relationship between saddle and rider kinematics, horse locomotion and thoracolumbar pressures in sound horses. J Equine Vet Sci 2018;69:43–52.
[14] Guire R, Weller R, Fisher M, Beavis J. Investigation looking at the repeatability of 20 Society of Master Saddlers qualified saddle fitters' observations during static saddle fit. J Equine Vet Sci 2017;56:1–5.
[15] Murray R, Guire R, Fisher M, Fairfax V. Girth pressure measurements reveal high peak pressures that can be avoided using an alternative girth design that also results in increased limb protraction and flexion in the swing phase. Vet J 2013;198:92–7.
[16] Murray R, Guire R, Fisher M, Fairfax V. A bridle designed to avoid peak pressure locations under the headpiece and noseband is associated with more uniform pressure and increased carpal and tarsal flexion, compared with the horse's usual bridle. J Equine Vet Sci 2015;35:947–55.
[17] Murray R, Guire R, Fisher M, Fairfax V. Reducing peak pressures under the saddle panel at the level of the 10th to 13th thoracic vertebrae may be associated with improved gait features, even when saddles are fitted to published guidelines. J Equine Vet Sci 2017;54:60–9.
[18] McGuigan M, Wilson A. The effect of gait and digital flexor muscle activation on limb compliance in the forelimb of the horse Equus caballus. J Exp Biol 2003;206:1325–36.
[19] Willmott A, Dapena J. The planarity of the stickface motion in the field hockey hit. J Sports Sci 2012;30:369–77.
[20] Peinen K, Wiestner T, Bogisch S, Roepstorff L, Weeren P, Weishaupt M. Relationship between the forces acting on the horse's back and the movements of rider and horse while walking on a treadmill. Equine Vet J 2009;41:285–91.
[21] Álvarez G, Rhodin M, Byström A, Back W, Weeren P. Back kinematics of healthy trotting horses during treadmill versus over ground locomotion. Equine Vet J 2009;41:297–300.
[22] Buchner H, Savelberg H, Schamhardt H, Merkens H, Barneveld A. Kinematics of treadmill versus overground locomotion in horses. Vet Q 1994;16:87–90.
[23] Fruehwirth B, Peham C, Scheidl M, Schobesberger H. Evaluation of pressure distribution under an English saddle at walk, trot and canter. Equine Vet J 2004;36:754–7.
[24] Harman J. Practical use of a computerized saddle pressure measuring device to determine the effects of saddle pads on the horse's back. J Equine Vet Sci 1994;14:606–11.
[25] Murray R, Mackechnie-Guire R, Fisher M, Fairfax V. Reducing peak pressures under the saddle at thoracic vertebrae 10-13 is associated with alteration in jump kinematics. Comp Exerc Physiol 2018;67:40–6.
[26] Murray R, Mackechnie-Guire R, Fisher M, Fairfax V. Could pressure distribution under race-exercise saddles affect limb kinematics and lumbosacral flexion in the galloping racehorse? J Equine Vet Sci 2019;81:102795.
[27] Nyikos S, Werner D, Müller J, Buess C, Keel R, Kalpen A, Vontobel H, Von Plocki K, Auer J, Von Rechenberg B. Measurements of saddle pressure in conjunction with back problems in horses. Pferdeheilkunde 2005;21:187–98.
[28] MacKechnie-Guire R, MacKechnie-Guire E, Fairfax V, Fisher D, Fisher M, Pfau T. The effect of tree width on thoracolumbar and limb kinematics, saddle

pressure distribution, and thoracolumbar dimensions in sports horses in trot and canter. Animals (Basel) 2019;9:842.
[29] Martin P, Cheze L, Pourcelot P, Desquilbet L, Duray L, Chateau H. Effect of the rider position during rising trot on the horses biomechanics (back and trunk kinematics and pressure under the saddle). J Biomech 2016;49:1027–33.
[30] Martin P, Cheze L, Pourcelot P, Desquilbet L, Duray L, Chateau H. Effects of large saddle panels on the biomechanics of the equine back during rising trot: preliminary results. J Equine Vet Sci 2017;48:15–22.
[31] Martin P, Cheze L, Pourcelot P, Desquilbet L, Duray L, Chateau H. Effects of the rider on the kinematics of the equine spine under the saddle during the trot using inertial measurement units: methodological study and preliminary results. Vet J 2017;221:6–10.
[32] Robert C, Audigie F, Valette J, Pourcelot P, Denoix J. Effects of treadmill speed on the mechanics of the back in the trotting saddle horse. Equine Vet J Suppl 2001;33:154–9.
[33] Khumsap S, Clayton H, Lanovaz J, Bouchey M. Effect of walking velocity on forelimb kinematics and kinetics. Equine Vet J Suppl 2002;34:325–9.
[34] Bogisch S, Geser-Von Peinen K, Wiestner T, Roepstorff L, Weishaupt M. Influence of velocity on horse and rider movement and resulting saddle forces at walk and trot. Comp Exerc Physiol 2014;10:23–32.