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Original Research

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

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ABSTRACT

Saddle–horse interaction is increasingly linked with back pain, performance, and welfare issues. Saddle fit and work quality influence alterations in back shape with exercise at thoracic vertebra 13 level (T13) with exercise. The objectives of experiments were to: determine a repeatable zone and stride point of peak pressure under saddles fitted to industry guidelines; compare peak pressure in this zone and limb kinematics in collected trot between horses own saddles (S) and a saddle designed to reduce pressure at T10–T13 (F); compare thoracolumbar width change after exercise between S and F and with F after 3 months use. Elite dressage ($n = 13$) horses/riders with no lameness/performance problem had pressure mat data acquired under S, fitted by four qualified saddle fitters, to determine zones of peak pressure. Pressure mat data at T10–T13, forelimb/hindlimb protraction, and carpal/tarsal flexion acquired using simultaneous high-speed motion capture, and difference in thoracolumbar dimensions (T8, T18 at 3, 15 cm) between before and after exercise was compared between S and F. Peak pressures were consistently detected axially around T10–T13 (sensors A4–A7, H4–H7). Peak pressures were significantly less with F than S for each cell and pooled (55%–68% difference. $P = .01$ to $<.0001$). Saddle F was associated with 13% greater forelimb and 22.7% hindlimb protraction, 3.5° greater carpal and 4.3° tarsal flexion ($P = .02$ to $.0001$), and greater increase in thoracolumbar dimensions after exercise ($P = .01$ to $<.0001$). Saddles fitted to published guidelines may still have a nonideal interface with horses. Reducing peak pressures around T10–T13 was associated with improved limb kinematics in trot and greater thoracolumbar expansion after exercise.

1. Introduction

Saddle–horse interaction is increasingly recognized as associated with back pain, poor performance, and welfare issues [1–4]. Recent studies have shown that alterations in back shape under the saddle at thoracic vertebra 13 level (T13) with exercise were influenced by saddle fit and work quality [5]. Back width after ridden exercise increased when horses were ridden more correctly, in better fitting saddles and with a more skilled rider. A relationship between muscle development scores and back kinematics during sitting trot has been reported [6]. Better abdominal,

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thoracic, and lumbosacral musculature were associated with improved thoracolumbar and lumbosacral flexion and greater elevation of the withers relative to the tuber sacrale, which is likely to influence back shape and pressure under the saddle [6]. However, how posture, gait, and saddle pressure are related has not previously been investigated.

The horse's back moves in three planes: flexion/extension, lateral bending, and axial rotation, which are likely to affect pressure patterns under the saddle. At trot, maximal back flexion occurs during the swing phase, whereas maximal extension occurs during the stance phase when the forelimb and diagonal hindlimb are load bearing [7–9]. It might therefore be expected that there would be certain repeatable points in the stride where the pressure under the saddle in the midthoracic region would be maximal.

Postural control during exercise is managed by a balance between the back extensors, which moderate flexion (longissimus dorsi, intercostalis, gluteus medius) and the back flexors which moderate extension. As collection increases, there is increased flexion of the limbs and elevation of the thorax relative to the pelvis. The rectus abdominis, external abdominal oblique, pectorals, and thoracic serratus ventralis lift the thorax and abdomen and flex the thoracolumbar and lumbosacral regions [10–12]. It has previously been shown that girth pressure at the junction of various muscles involved in retraction and movement of the forelimb and flexion of the thoracic and lumbar regions was associated with alteration in gait and posture [13]. Following this pattern, it is possible that excessive pressure over the muscles in the thoracic region could also be having an effect on movement.

We hypothesized that A (1) there will be a repeatable zone of peak pressure under standard saddle panels and (2) the zone of peak pressure will occur at a repeatable point in the stride; and B (1) reducing peak pressures at this high pressure zone will improve stride kinematics and (2) reducing peak pressures will improve thoracolumbar posture. The objectives of experiment 1 were to: (1) objectively determine a repeatable zone of peak pressure under saddles fitted to Society of Master Saddler (SMS) guidelines; (2) determine the point in the stride when there is maximum peak pressure in this zone. Experiment 2: (1) compare peak pressure in the high pressure zone and limb kinematics between the horse's own saddle (saddle S) and a saddle designed to reduce peak pressure (saddle F) at T10–T13 in collected trot; (2) compare the change in thoracolumbar width before and after exercise between saddle S and F. Experiment 3: compare the change in thoracolumbar width before and after exercise in saddle F after 3 months use of saddle F, with findings in experiment 2.

2. Materials and Methods

Thirteen elite dressage horses (nine geldings, two stallions, and two mares; age range 8–16 years; height 162–175 cm) competing internationally at small and big tour level and four elite professional male and three female riders were used for the study. All horses were on a regular program of veterinary management and physiotherapy and were deemed fit and without lameness. The study was approved by the ethical review committee of the Animal Health Trust (14/2016, approval date February 11, 2016), and there was informed owner consent. All horses were ridden by their usual rider.

2.1. Experiment 1: Assessment of Position Under the Saddle and Timing in the Stride of Peak Pressure Under Standard Saddles That Have Been Fitted to SMS Guidelines

Saddles on 13 horses that had been fitted to SMS guidelines [14] were used for the study. All saddles had been regularly assessed by qualified saddle fitters prior to the study and were the usual saddle used by each horse.

All horses had templates of the thoracolumbar shape recorded prior to exercise and immediately following exercise, using a flexible curve ruler (Blundell Harling 600 mm) with the horse standing square on a hard, level surface, following the SMS guidelines [5,14]. This information was used for the design of saddle F in experiment 2.

Four qualified registered SMS saddle fitters independently assessed the fit of saddles on 13 horses. Saddles were included in the assessment process after ruling out structural faults (including loss of integrity of the tree) and confirming that the panel flock or foam was in good condition. Every saddle was assessed by all four saddle fitters independently, following the SMS criteria for fitting saddles under static and dynamic conditions (Table 1). Saddle fit was assessed in a straight line and on a circle in walk, trot, and canter on both reins. Saddle position and presence or absence of saddle movement in medial–lateral, dorsal–palmar, and cranial–caudal planes were recorded.

2.1.1. Data Collection

Pressure mat data were acquired under the panel either side of the gullet of the saddle using a pressure mat (600 mm long and 200 mm wide for left and right side, 256 sensors long and 256 sensors wide arranged in 16 columns and 8 rows for each of left and right sides) (Sensor Elastisens MSA600, Pliance, Novel gmbh) (sampling rate 50 Hz) positioned under the saddle. The pad is divided into

Table 1
Society of Master Saddlers criteria for fitting saddles under static and dynamic conditions [14].

Assessment Type	Criteria	Classification for Horses 1–13
Static	Fit of tree width and shape	Correct
	Saddle length	Correct
	Saddle design	Correct
	Panel pressure	Correct
	Balance of saddle	Correct
	Clearance of spine and withers	Correct
	Position of girth straps in relation to conformation	Correct
Dynamic	Lifting at the back	Not visible
	Movement side to side	Not visible
	Slipping to one side	Not visible
	Movement forward/backward	Not visible
	Negative effect on rider's position	Not visible
	Negative effect on horse's normal way of going	Not visible

Four saddle fitters independently assessed all the saddles included in the study.

two halves with clearance of the vertebrae where no sensors are present. The mat was initialized to zero without the saddle, rider, or girth, ensuring that the mat remained central. Prior to testing, repeatability of positioning of the pressure mat under the saddle and repeatability of data collection were confirmed.

Horses were acclimatized to the experimental environment and warmed up in walk, trot, and canter on both reins for a period of 20 minutes. All measurements were performed on a Martin Collins wax-coated arena surface, groomed prior to testing and in between horses. Horses were ridden in sitting trot along a 14-m-long, 1-m-wide track, between markers placed 10-m apart. Pressure data were collected for five consecutive strides from three passes on both the left and right rein. Data were not included if the horse lost straightness, tripped, or made an obvious alteration in gait pattern (e.g. shying) in which case an additional pass was undertaken. Pressure mat data were captured using blue tooth technology, and simultaneous video footage was recorded (50 Hz Panasonic).

Magnitude of peak pressure at each sensor was recorded, and the locations under the saddle of highest peak pressures during trotting were identified. The timing of peak pressures was compared with the simultaneous video data to identify the point in the stride at which the peak pressures occurred.

When the location of maximal peak pressures was established, the construction of the saddle was redesigned to reduce pressure at this location.

2.2. Experiment 2: Effect of Saddle Design on Thoracolumbar Dimensions, Peak Pressure Under the Saddle at T10–T13, and Gait Parameters

Using a crossover design, thoracolumbar dimensions, pressures under the saddle at the level of T10–T13 (cells A4–A7 and H4–H7), and limb kinematics were compared between 1. The horses own saddle fitted and checked by four different qualified saddle fitters (experiment 1, saddle S) and 2. A saddle designed to reduce pressure over T13 (saddle F), fitted and checked by the four qualified saddle fitters.

In saddle F, the tree was shaped to accommodate the musculature of the sport horse during exercise (Fig. 1). The longitudinal edges of the tree were aligned with the horse's anatomic shape during exercise, based on template shape after exercise from experiment 1. The solid arm of the panel (perpendicular to the long axis at the front of the tree) was shortened to reduce the length of potential restriction at the front of the saddle. The stirrup bars were attached to the exterior of the tree, away from the horse. The girth billets were aligned to prevent the panel restricting expansion of the thorax and widening of the back at this location during exercise. The panels were lined with pressure absorbing material and shaped to interface with the shape of the horse's back during exercise.

2.2.1. Data Collection

2.2.1.1. Thoracolumbar Dimensions. Measurements of dorsal thoracolumbar body shape of each horse were obtained

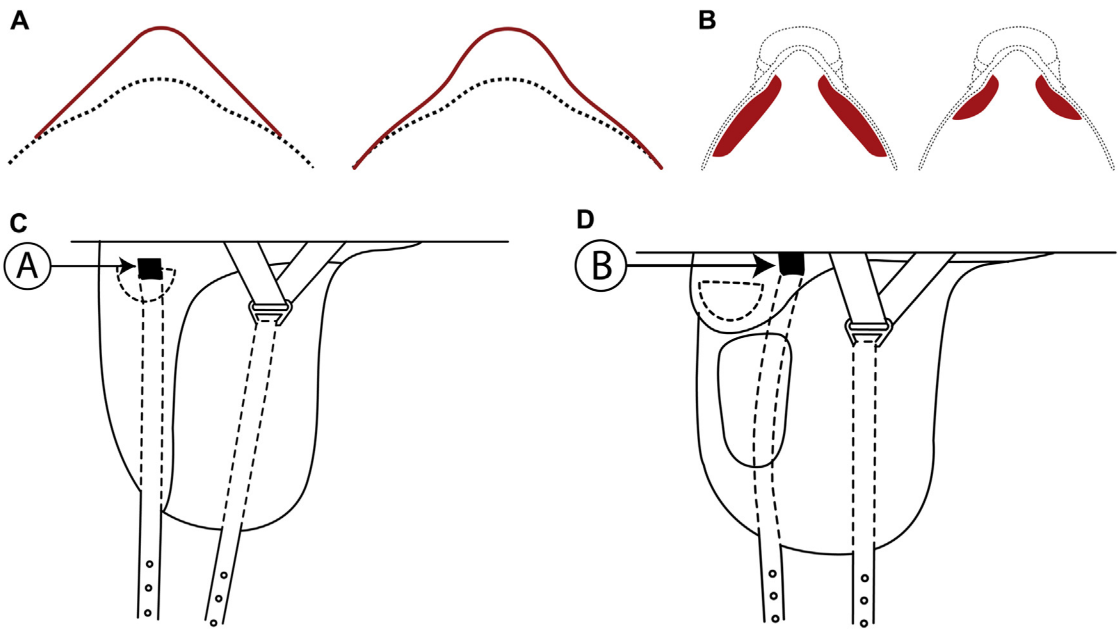

Fig. 1. (A). Axial cross section of the thoracic shape of a Warmblood horse after exercise (dotted line) and tree shape (continuous line). The left picture represents tree shape in a traditional saddle (saddle S) and the right picture (F) represents tree shape in saddle F. (B) Axial cross section through the cranial part of a saddle in line with the arms of the panel to show the length of the fixed panel in a traditional saddle (left, saddle S) and shorter length of the fixed section of the panel in saddle F (right). (C) Side view of a saddle showing location of girth strap attachments in a traditional saddle where the point strap is attached to the point of the tree, which runs down the arm of the panel. (D) Side view of a saddle showing location of girth strap attachments in saddle F where the point strap is attached to the main body of the tree behind the arm of the panel.

with the horse standing square on a hard, level surface, following the SMS guidelines [14]. The thoracolumbar dimensions (widths at 3 cm and 15 cm ventral to the dorsal midline) were measured at the level of the eighteenth (T18) and eighth (T8) thoracic vertebrae [5,15]. A Flexible Curve Ruler (Blundell Harling 600 mm) was shaped around the dorsum, perpendicular to the dorsal midline at two levels: T8 and T18. A single investigator performed all the measurements. The final shape was drawn on graph paper and the width measured at 3 cm and 15 cm ventral to the dorsal midline, as previously described. For each saddle, measurements were obtained immediately before exercise began and immediately after ridden exercise ended. The ratio of width after exercise to width before exercise was calculated at each location, for all horses in both saddles, and the results were compared between saddles. Repeatability of this methodology has been previously shown in other studies [15], and intraobserver repeatability was confirmed for this investigator in the current study. (Coefficient of variance was less than 0.01 for all measurements using five repetitions on five horses.)

2.2.1.2. Peak Pressure Under the Saddle. Pressure mat data were acquired under the panel either side of the gullet of the saddle at the level of T10–T13 (cells A4–A7 on right side and H4–H7 on left side) following the same protocol as experiment 1. Data acquisition was synchronized with the high-speed motion capture used for gait analysis.

2.2.1.3. Gait Analysis. Skin markers were placed on each horse using 3M ECE104 reflective tape [7]. Marker locations were identified by manual palpation of anatomic landmarks identifying joint centers and segment ends. Markers were located over the atlas, scapular spine, head of humerus, lateral condyle of humerus, tuber sacrale, lateral condyle of the femur, talus, ulnar carpal bone, lateral extent of metacarpal/metatarsal condyles, and lateral collateral ligament (LCL) of the distal interphalangeal joint. To reduce variability, the same bridle, girth, and other equipment were used for all comparisons, with only the saddle being altered.

The testing protocol was performed with the horse in saddles S and F in a crossover design. In seven horses, saddle S was tested first, and in six horses, saddle F was tested first. After changing the saddle, horses were given 20 minutes to acclimatize to the new saddle before repeating the testing protocol.

High-speed motion capture was carried out using two Casio EX-FH25 cameras, capturing at 240 Hz, synchronized with the pressure mat data collection. The cameras were each placed 10 m from the testing location, parallel to the testing track with a field of view capturing two complete stride cycles from either side of the horse simultaneously. Two 240 W halogen spot lights were used on each side to illuminate the markers, located 10 m from the testing area. High-speed video data were processed using Quintic Biomechanics (Quintic). Automatic marker tracking was

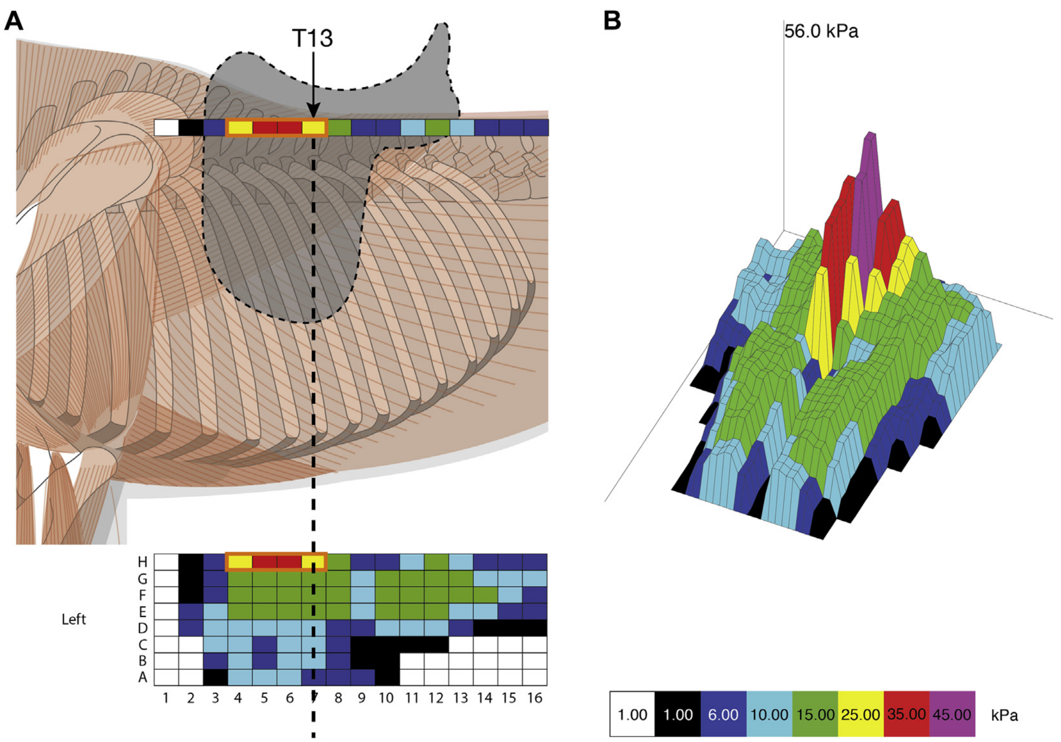

Fig. 2. (A) Diagrammatic representation of the saddle position over the spine. (B) Pattern of peak pressure distribution detected by the pressure mat under saddle S for horse 2, ridden in sitting trot in a straight line, showing high peak pressures at cells A4–A7 (right side) and H4–H7 (left side) either side of the spine in the region of T10–T13. This is representative of the pressure distribution detected under saddle S for all horses. The scale at the bottom of the picture shows the scale for peak pressure measurements at each location.

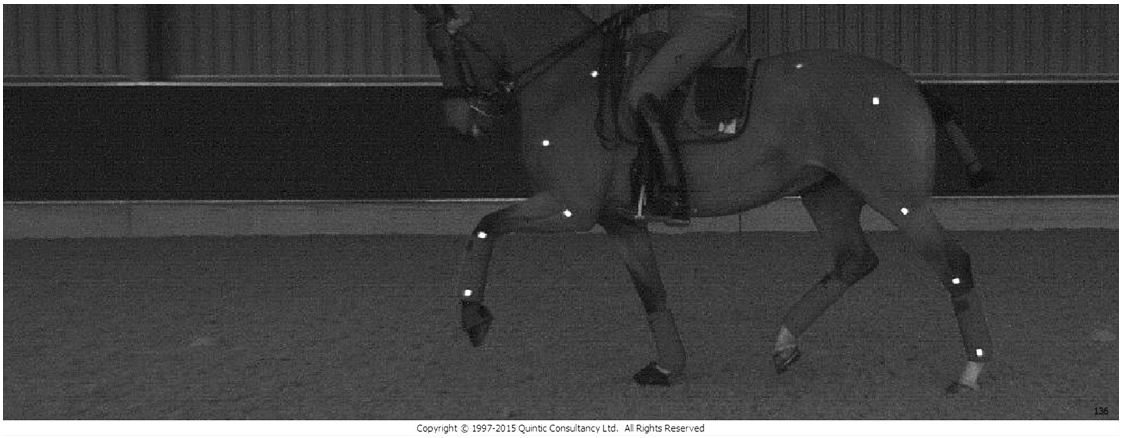

Fig. 3. Timing of peak pressure under the saddle at cells A4–A7/H4–H7 in relation to stride pattern: Peak pressures were observed on the contralateral side in the last quarter of the diagonal stance phase.

used to investigate limb protraction and carpal/tarsal flexion during flight as previously described and validated [7]. One whole stride was tracked from 20 frames prior to point of contact between the surface and the heel, using the central stride in the field of view. Marker tracking was cross-checked manually: in cases where markers had been mistracked then this was corrected with the Quintic Editing Tracking Suite. All data were smoothed using the Butterworth filtering system within Quintic with each "x" and "y" coordinates being filtered independently using a high-pass filter with a cutoff frequency of 1 Hz.

For data collection, all measurements were performed on the same arena surface and trotting track as experiment 1, following the same warm up protocol. Three passes on both the left and right rein were recorded. Pressure data were collected for five consecutive strides with the kinematic data being collected for two consecutive strides both with three repeats on the left and right rein in sitting trot.

Simultaneous high-speed motion capture determined forelimb/hindlimb protraction and carpal/tarsal flexion during swing at trot using standard anatomic marker placement. Forelimb protraction was defined as the horizontal distance from the scapular spine to the LCL marker at maximal protraction before ground contact; hindlimb protraction as horizontal distance from the Tuber Coxae marker to the LCL marker at maximal protraction before ground contact. Carpal flexion was defined as the angle between the ulna, ulnar carpal bone, and metacarpal condyle markers at maximal carpal flexion during flight and tarsal flexion as the angle between the lateral condyle of the femur, talus, and metatarsal condyle markers at maximal tarsal flexion during flight [13,16].

2.2.1.4. Repeatability. The repeatability of the pressure mat used has already been described at this and other locations, and the high-speed motion capture technique has previously been shown to be repeatable [13,16,17]. To confirm correct values, the mat was calibrated at the start of the study and recalibrated during the study to follow the manufacturer's guidelines, as well as routinely initialized to zero between each measurement set.

Table 2
Mean ratio of thoracolumbar width measured using a flexicurve immediately after exercise to immediately before exercise, for 13 horses in their own saddle (saddle S) and a saddle designed to reduce peak pressures under the saddle at T13 (saddle F).

Measurement Location	Saddle S	Saddle F	Saddles F–S	*P* Value
T8 3 cm	0.035	0.144	0.108	<.0001
T8 15 cm	0.047	0.193	0.147	.0162
T18 3 cm	0.078	0.224	0.146	<.0001
T18 15 cm	0.052	0.160	0.108	<.0001

The thoracolumbar dimensions (widths at 3 cm and 15 cm ventral to the dorsal midline) were measured at the level of the eighteenth (T18) and eighth (T8) thoracic vertebrae as previously described [5,15].

2.3. Experiment 3: Thoracolumbar Dimensions Before and After Exercise After 3 Months Using Saddle F

Ten of the 13 experimental horses were ridden for 3 months in saddle F. At the end of the 3 months, measurements of dorsal thoracolumbar body shape of each horse were obtained before and after exercise, following the protocol in experiment 2. The ratio of width after exercise to width before exercise was calculated at each location. The width before and after exercise was compared with the findings in experiment 2 within each horse.

2.4. Data Analysis

Descriptive data analysis was undertaken to investigate the data, and a Shapiro–Wilks normality test was used to determine data distribution. A Paired Student's *t* test (for parametric data) or Wilcoxon sign rank test (for nonparametric data) was performed to determine the effect of saddles S and F on the thoracolumbar dimensions, pressure mat, and gait parameters within each horse. All analyses were performed using a statistical analysis software (Analyse-It for Microsoft Excel version 3) with a significance level of $P < .05$.

3. Results

3.1. Experiment 1: Assessment of Position Under the Saddle and Timing in the Stride of Peak Pressure Under Standard Saddles That Have Been Fitted to SMS Guidelines

Thirteen different 17½ inch dressage saddles were included, using 1 saddle per horse. Saddles were made by seven different manufacturers. These included 11 monoflap, 2 twin flap, 11 flocked panel, 2 foam panel, and no air panels. All saddles assessed were considered by all four assessors to fit the horses, following SMS guidelines (Table 1) so no saddles were excluded from the study. There was 100% agreement for all criteria between all independent saddle fitters on the results of the SMS assessment.

Peak pressures were consistently detected axially in the region of T10–T13, at sensor numbers A4–A7 (right side) and H4–H7 (left side) in all horses (Fig. 2). Although different locations of pressures varied between saddles and between horses, there was consistent high peak pressures in all saddles in cells A4–A7 (right) and H4–H7 (left).

During each stride, the peak pressures occurred at these sensors A4–A7/H4–H7 on the contralateral side in the last quarter of the diagonal stance phase in all horses. The peak at 75% of the diagonal stance phase had the highest peak (Fig. 3).

3.2. Experiment 2: Effect of Saddle Design on Thoracolumbar Dimensions, Peak Pressure Under the Saddle at T10–T13, and Gait Parameters

3.2.1. Thoracolumbar Dimensions

The ratio of thoracolumbar width before and after exercise at T8 and at T18 was significantly greater in saddle F than in saddle S at both 3 cm and 15 cm from the dorsal extent (Table 2). The difference was maximal at T8 dorsally and T18 further ventrally.

3.2.2. Peak Pressure Under the Saddle at T13

Due to failure of the bluetooth connection on one horse, pressure mat measurements were only obtained for both saddles in 12 horses, and data from the 13th horse were not included in the comparison (Table 3).

3.2.3. Comparison Between Left and Right

For saddle S, total of peak pressures on the right was significantly greater than the left. However, no significant difference between left and right was detected for saddle F.

3.2.4. Comparison Between Saddle Types

Mean peak pressures were significantly less with saddles F than S for left peak pressures, right peak pressures, and total of peak pressures per side and pooled between left and right sides (Fig. 4). With saddle F, peak pressure on the left side was on average approximately 68% less than S for cell H4, 58% for H5, 55% for H6, and 46% for H7. On the right, saddle F, peak pressure was on average approximately 68% less than S for A4, 58% for A5, 50% for A6, and 43% for A7.

3.2.5. Gait Features

3.2.5.1. Speed. Mean speed for horses with saddle S was 0.86 ms^{-1}, and saddle F was 0.86 ms^{-1}. No significant difference in speed was detected between the two saddles within individual horses ($P > .6$).

3.2.5.2. Limb Protraction and Flexion. Interstride variation for these features had a Coefficient of variance of $\leq$ 4% (Tables 4 and 5).

3.2.5.2.1. Comparison Between Left and Right. No significant difference was detected between left and right for forelimb and hindlimb protraction with any saddle type. Left carpal flexion had significantly larger angle (i.e. less flexed) than right carpal flexion using both saddles S and F. Left tarsal flexion had significantly smaller angle (i.e. more flexed) than right using both saddles S and F.

Table 3

The peak pressure (kPa) in pressure mat cells A4–A7 (right side) and H4–H7 (left side) (Figure 2) observed under the saddle of dressage horses at trot, wearing their own saddle (saddle S) fitted to Society of Master Saddlers guidelines or with a saddle designed to reduce pressure at T13 and fitted to the same guidelines (saddle F). There was significantly lower peak pressure under saddles F than S.

Location	Side	No. Observations	Mean F Peak Pressure (kPa) Mean ± SD	Mean S Peak Pressure (kPa) Mean ± SD	Difference (F–S) Peak Pressure (kPa)	*P* Value
H4	Left	12	8.81 ± 6.2	27.65 ± 7.7	−18.84	<.0001
H5	Left	12	10.36 ± 6.2	24.86 ± 8.6	−14.50	.0012
H6	Left	12	9.88 ± 7.2	22.07 ± 9.6	−12.19	.0056
H7	Left	12	10.19 ± 7.3	18.81 ± 9.2	−8.62	.0166
Total	Left	12	39.24 ± 23	93.38 ± 32	−54.15	.0007
A4	Right	12	14.58 ± 8.6	32.08 ± 8.6	−17.49	.0002
A5	Right	12	15.91 ± 6.7	32.09 ± 9.8	−16.18	.0003
A6	Right	12	13.67 ± 6.6	25.29 ± 9.5	−12.63	.0020
A7	Right	12	11.06 ± 8.6	19.45 ± 8.2	−8.38	.0080
Total	Right	12	55.22 ± 26	109.91 ± 26	−54.68	<.0001
A4/H4	Left and right	24	11.69 ± 7.9	29.86 ± 8.3	−18.17	<.0001
A5/H5	Left and right	24	13.14 ± 6.9	28.48 ± 9.7	−15.34	<.0001
A6/H6	Left and right	24	11.77 ± 7.0	24.18 ± 9.6	−12.41	<.0001
A7/H7	Left and right	24	10.63 ± 7.8	19.13 ± 8.5	−8.50	.0002
Total	Left and right	24	47.23 ± 26	101.64 ± 30	−54.42	<.0001

Abbreviation: SD, standard deviation.

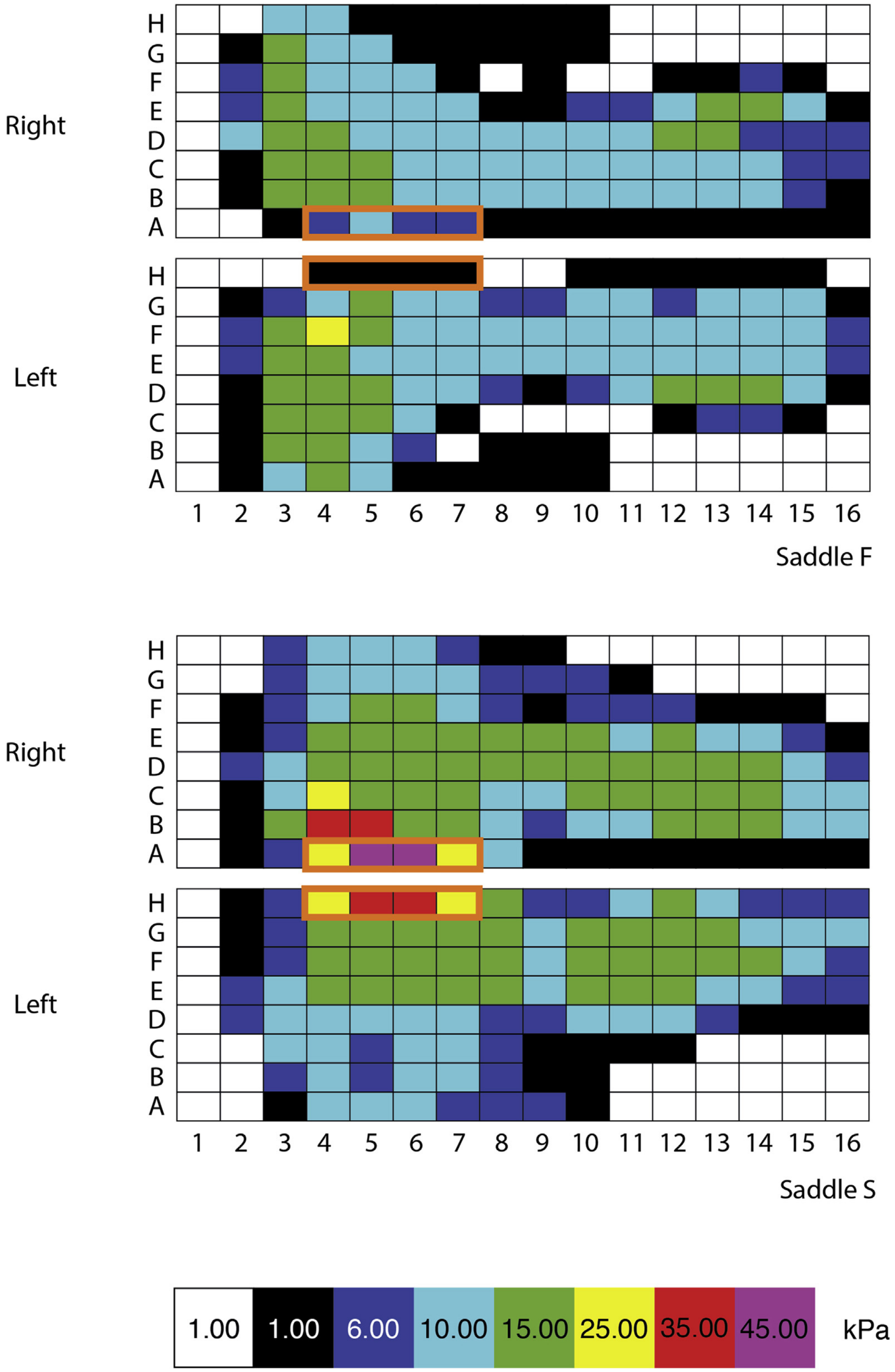

Fig. 4. Peak pressure distribution detected using a pressure mat under saddle S and saddle F at sitting trot showing high peak pressure at cells A4–A7/H4–H7 under saddle S either side of the spine, but absence of these high peak pressures and more even peak pressure distribution under saddle F. Cranial is to the left of the picture. The scale at the bottom of the picture shows the scale for peak pressure measurements at each location.

Table 4
The carpal and tarsal flexion angles of dressage horses at trot wearing their own saddle (saddle S) fitted to Society of Master Saddlers guidelines or with a saddle designed to reduce pressure in the region of T10–T13 (saddle F). There was greater carpal and tarsal flexion with saddles F than S.

Parameter	Side	No. Observations	Saddle F	Saddle S	Difference (F–S)	*P* Value
Carpal flexion angle (°) (mean ± SD)	Left	13	96.78 ± 7.9	100.31 ± 7.4	−3.53	.0011
	Right	13	94.93 ± 8.0	96.20 ± 5.1	−1.27	.4284
	Pooled	26	95.86 ± 7.9	98.25 ± 6.6	−2.40	.0123
Hock flexion angle (°) (mean ± SD)	Left	13	115.71 ± 7.5	119.95 ± 6.7	−4.23	<.0001
	Right	13	117.75 ± 7.9	122.21 ± 7.8	−4.46	.0029
	Pooled	26	116.73 ± 7.6	121.08 ± 7.2	−4.34	<.0001

Abbreviation: SD, standard deviation.

3.2.5.2.2. Comparison Between Saddle Type. Forelimb and hindlimb protraction were significantly greater with saddles F than S for left limb, right limb, and pooled measurements. With saddle F, forelimb protraction was on average approximately 13% greater, and hindlimb protraction was approximately 22.7% greater.

Carpal flexion angle was significantly smaller (i.e., more flexed) on the left and for pooled observations with saddle F. Use of saddle F was associated with an average of >3.5° more carpal flexion than with saddle S. There was significantly smaller tarsal flexion angle (i.e., more flexed) for the saddles F than S, in left, right, and pooled observations. Use of saddle F was associated with approximately 4.3° more tarsal flexion than with saddle S.

3.3. Experiment 3: Thoracolumbar Dimensions Before and After Exercise After 3 Months Using Saddle F

Thoracolumbar width before exercise was significantly greater at 3 months than in experiment 2 for all locations (Table 6). Thoracolumbar width after exercise was significantly greater than in saddles S and F after exercise in experiment 2. The ratio of width after exercise to width before exercise was significantly greater at 3 months than for saddle S at baseline but was not significantly different to the increase seen at baseline with saddle F except dorsally at T18 (Table 6).

There was no difference in body condition score and less than a 5 mm change in measurement using a weight tape for any horse between experiment 2 and experiment 3.

4. Discussion

The results of this study support the stated hypotheses. A repeatable zone of peak pressure was located axially under the saddle in the region of T10–T13 and occurred at a consistent point in the stride pattern. A saddle designed to reduce peak pressures in this region resulted in lower peak pressure at this location under the saddle and was associated with improved stride kinematics. Reduced pressure was associated with increased thoracolumbar expansion after exercise, which remained increased after using saddle F for 3 months.

Various studies have looked at pressure patterns under saddles and the effect of different widths, gaits, tree, panel flocking, or girth strap placement [18–24]. However, the pressure pattern observed under saddles specifically fitted to SMS (industry) guidelines has not previously been reported. This study aimed to reduce variability by using elite horses and riders with a high skill level, working with high quality, elite horses without lameness on a uniform arena surface, and saddles fitted following industry guidelines. However, high peak pressures were still observed under the saddle at cells A4–A7/H4–H7, in the region of T10–13. This location has considerable muscle activity related to posture and control of movement, including longissimus dorsi, which is directly involved in the control, stabilization and limitation of dynamic spinal movement [25]. It has been reported that T12 was the best place to take electromyographic recordings, suggesting that there is considerable muscle activity at this location [26]. There is increased longissimus dorsi activity in the second half of the stance phase [25], which coincides with the timing of the highest peak pressures that we detected and were also reported by Fruehwirth et al [22]. A previous study evaluating the influence of tree width on pressure distribution concluded that constriction by poor saddle fit resulted in higher pressures that increased muscle tension, reduced elasticity of the back, and could potentially alter gait [23]. It seems likely that the required degree of back movement at this

Table 5
The forelimb and hindlimb protraction of dressage horses at trot wearing their own saddle (saddle S) fitted to Society of Master Saddlers guidelines or with a saddle designed to reduce pressure in the region of T10–T13 (saddle F). There was significantly greater forelimb and hindlimb protraction with saddles F than S.

Parameter	Side	No. Observations	Saddle F	Saddle S	Difference (F–S)	*P* Value
Forelimb protraction (mean ± SD)	Left	13	25.08 ± 5.0	22.06 ± 3.2	3.02 (13.7%)	.0005
	Right	13	24.92 ± 5.1	22.06 ± 3.2	2.86 (13.0%)	.0094
	Pooled	26	25.00 ± 4.9	22.06 ± 3.2	2.94 (13.3%)	<.0001
Hindlimb protraction (mean ± SD)	Left	13	5.45 ± 1.5	4.44 ± 1.2	1.01 (22.7%)	.0262
	Right	13	5.80 ± 1.5	4.73 ± 1.4	1.07 (22.6%)	.0051
	Pooled	26	5.62 ± 1.5	4.58 ± 1.3	1.04 (22.7%)	.0003

Abbreviation: SD, standard deviation.

Table 6
Mean difference in thoracolumbar width measured using a flexicurve between experiment 3 (after being ridden in saddle F for 3 months [exp 3]) and experiment 2 (immediately before exercise [exp 2]), and the mean ratio of thoracolumbar width immediately after exercise to immediately before exercise for 10 horses from exp 2.

Measurement Location	Increase in Width Before Exercise Between Exp 2 and Exp 3 (mm)	*P* Value for Comparison Between Exp 2 and Exp 3	Ratio of After to Before Exercise in Exp 3	*P* Value for Comparison of Ratio of After to Before Exercise in Exp 3 to Saddle F Ratio in Exp 2	*P* Value for Comparison of Ratio of After to Before Exercise in Exp 3 to Saddle S Ratio in Exp 2
T8 3 cm	4.0	0.009	0.118	.678	.0003
T8 15 cm	18.2	0.007	0.158	.178	.06
T18 3 cm	26.8	0.003	0.156	.048	.005
T18 15 cm	24.8	0.023	0.102	.117	.0012

All horses increased in width in exp 3 compared with exp 2, and there was significantly greater increase in thoracolumbar width after exercise for experiment 3 compared with saddle S in exp 2.

location in this study might be improved by reduced peak pressures if this represents relief of constriction. It has been reported that increased back extension was associated with altered gait features [27]. In our study, saddle F was associated with increased thoracolumbar dimensions after exercise and improved gait features. It seems feasible that relief of muscle pressure at this location is improving posture and control of thoracolumbar movement, thus allowing improved gait features.

In trot, horses extend the back during the first part of each diagonal stance phase and flex in the second half of stance [8], but there is also rotation of the spine and thorax during motion. We found that timing of peak pressure in the stride was on the contralateral side to forelimb stance and the ipsilateral side to hindlimb stance. It has been shown that the overall pressure under a saddle has repeatable variations with time related to the stride pattern of the horse, with greater overall pressure when the ipsilateral forelimb is in the swing phase [22], which would support the timing of highest peak pressures at the more specific cells A4–A7/H4–H7 in our study. At this point, the thorax is rotating upward on the contralateral side to the forelimb in stance, as the ipsilateral hindlimb protracts, so potentially increasing pressure axially under the saddle on that side. The results of this study support saddle F having an effect of increased forelimb protraction, increased hindlimb protraction, and greater carpal and tarsal flexion. Improved gait features with saddle F might possibly relate, at least in part, to improved rotation through the thorax and improved flexion, which might be contributing to the relatively greater improvement in hindlimb compared with forelimb protraction. It is also possible that the reduced asymmetry in pressures seen in saddle F compared with saddle S may be explained by less restriction of thoracic ribcage movement.

Previous studies have suggested that various factors can influence posture, pressure under the saddle, and muscle development, including quality of work and saddle fit [5,6,15]. Increase in thoracolumbar width after exercise has been associated with good saddle fit and high quality of work [5]. All the horses in this study were being trained correctly and competing successfully at high level and were ridden the same way during the study, so it seems likely that variations in thoracolumbar width were related to saddle fit. For the horses that were subsequently ridden in saddle F for 3 months and remeasured (experiment 3), there was further improvement in thoracolumbar dimensions. The effect of progressive training during the intervening period cannot be ruled out as a contributory factor, but it is possible that the saddle design during training could also have been contributing to the improvement in posture before exercise. The degree of increase in dimensions after exercise was to a similar level as saddle F in experiment 2, but more than saddle S, suggesting that alteration in saddle design may not just be limited to an immediate short-term effect and may have longer-term consequences. However, further longitudinal studies comparing training and saddle type would be needed to confirm or understand this more completely.

Modification in saddle construction can have effects on pressure magnitude and distribution under the saddle [18,20,23,24]. Design features in saddle F included modification of tree shape, panel design, and girth strap placement. It has been reported that tree width has a significant effect on pressure on the saddle. Narrow tree shape was associated with higher pressures in the caudal part of the saddle, distributed over a smaller area, while a saddle that was much too wide was associated with increased pressures further cranially [23]. A previous study evaluating girth strap placement on saddle pressure found that a V positioning of the girth straps, with the cranial (point) strap placed further forward, led to altered pressure distribution compared with a traditional girth strap attachment, with higher pressures in the cranial part of the saddle [18]. This supports the lower pressures observed in our study, where the cranial (point) strap was attached further caudally. The design features in saddle F were done to optimize fit and alignment to the horse during exercise, using the posture and range of motion that a high-level dressage horse performs during training. The horses in this study were particularly selected as samples for this reason. For horses that do not work at this level and may be less muscled, more stiff or performing with poor posture, it is possible that the same benefits would not be obtained. However, it is also possible that use of a saddle with this design would lead to improvements in the less optimal subject, but this type of horse has not been tested in this study.

This study has limitations. Using three-dimensional motion analysis would have expanded information on limb movement beyond the two-dimensional motion analysis used. However, intrahorse variation was limited as far as possible by using a standardized straight line test with markers to ensure that the horse was perpendicular to the camera at the time of data acquisition. No measurement of thoracolumbar width was performed at T13, which would be useful to include in a future study and would be recommended to include in standard evaluation for horses undergoing saddle fitting. There was potential bias as it was not possible to blind the riders to which saddle was being used, although they were blinded to which panel was being used and the thoracolumbar and gait measurements were obtained blinded to the saddle type.

5. Conclusion

Saddles fitted to published guidelines may still have a nonideal interface with the horse. Using a saddle to reduce peak pressures in the region of T10–T13 was associated with improved limb kinematics in trot and in thoracolumbar dimensions after exercise, which was retained after 3 months.

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