The Veterinary Journal xxx (2013) xxx–xxx

Contents lists available at ScienceDirect

The Veterinary Journal

journal homepage: www.elsevier.com/locate/tvjl

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

Rachel Murray [a,*], Russell Guire [b], Mark Fisher [c], Vanessa Fairfax [d]

[a] *Animal Health Trust, Lanwades Park, Kentford, Newmarket CB8 7UU, UK*
[b] *Centaur Biomechanics, Moreton Morrell CV35 9BB, UK*
[c] *British Equestrian Federation Consultant Master Saddler, Leverington, Wisbech PE13 5BU, UK*
[d] *Fairfax Saddles Ltd, Fryers Road, Bloxwich, Walsall WS3 2XJ, UK*

ARTICLE INFO

Article history:
Accepted 21 July 2013
Available online xxxx

Keywords:
Biomechanics
Equine
Girth
Performance
Thoracic

ABSTRACT

Girths are frequently blamed for veterinary and performance problems, but research into girth/horse interaction is sparse. The study objectives were (1) to determine location of peak pressure under a range of girths, and (2) to compare horse gait between the horse's standard girth and a girth designed to avoid detected peak pressure locations. In the first part of the study, and following validation procedures, a calibrated pressure mat placed under the girth of 10 horses was used to determine the location of peak pressures. A girth was designed to avoid peak pressure locations (Girth F). In the second part, 20 elite horses/riders with no lameness or performance problem were ridden in Girth F and their standard girth (Girth S) in a double blind crossover design. Pressure mat data were acquired from under the girths. High speed video was captured and forelimb and hindlimb protraction, maximal carpal and tarsal flexion during flight were determined in trot. In standard girths, peak pressures were located over the musculature behind the elbow.

Pressure mat results revealed that the maximum forces with Girth S were 22% (left) and 14% (right) greater than Girth F, and peak pressures were 76% (left) and 98% (right) greater ($P < 0.01$ for all). On gait evaluation, Girth F was associated with 6–11% greater forelimb protraction, 10–20% greater hindlimb protraction, 4% greater carpal flexion, and 3% greater tarsal flexion than Girth S ($P < 0.01$ for all). Peak pressures were located where horses tend to develop pressure sores. Girth F reduced peak pressures under the girth, and improved limb protraction and carpal/ tarsal flexion, which may reflect improved posture and comfort.

Introduction

Girths are frequently blamed for veterinary and performance problems, but research into girth/horse interaction is sparse. It has long been accepted that girth galls (or sores) may occur when a dirty or poorly fitting girth is used or overused, and the location that is accepted as a high risk area is the skin of the axilla, caudal to the olecranon (Smythe, 1959; Rose, 1982; Fraser, 1992; Lloyd et al., 2003; Pusey et al., 2010). Muscles that lie under the girth are involved in locomotion and maintenance of posture, so excessive pressure or restriction of these muscle groups could potentially have a negative effect on movement patterns (Pilliner et al., 2002; Wyche, 2003; Wright, 2010). However, there has been no previous reported investigation into the pattern of pressure distribution under girths and whether this could be alleviated to reduce the potential for development of injury or to improve performance.

The objectives of this study were (1) to determine the sites of maximum pressure under different girths in horses in trot using a pressure mat; (2) to design a girth that avoids sites of maximal pressure during movement, and (3) to compare the maximum pressure and gait characteristics of horses wearing the designed girth with those in the same horses wearing their usual girths. It was hypothesised (1) that there are repeatable locations of maximum pressure under different girth designs; (2) that use of a girth designed to avoid locations of maximum pressure does reduce maximum pressure compared to the horse's usual girth, and (3) that use of the designed girth leads to greater stride length, carpal and tarsal flexion in trot compared to the horse's usual girth.

* Corresponding author. Tel.: +44 1638 751908.
E-mail address: rachel.murray@aht.org.uk (R. Murray).

1090-0233/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.tvjl.2013.07.028

Materials and methods

Experiment 1: Assessment of pressure distribution under frequently used girths

Ten elite competition horses (3 jumpers, 3 eventers, 4 dressage), of height (1.62–1.70 m [16–16.3 hands]) were used to evaluate pressure distribution under 15 girths: nine were standard girths (length 127–137.2 cm [50–54 inches]) and six were dressage girths (61–76.2 cm [24–30 inches]). All girths were normally used by these horses for training and competition.

A small format pressure mat (432 mm long and 108 mm wide, 32 sensors long and 8 sensors wide) (Sensor Elastisens ES-256, Novel) was positioned centrally underneath the girth, with the end of the sensors located 4 cm above the olecranon process (±2 cm) (Fig. 1). The girth was fastened until just touching the skin, the mat was zeroed then the girth was tightened symmetrically to the tension that the rider normally used, ensuring that the mat remained central. Prior to testing, repeatability of positioning and data collection was confirmed. A camera (Samsung Digital Cam VP-D371W) capturing at 50 frames/s was synchronized with the mat and the programme. The mean peak pressures for each rein were plotted against point in the stride.

Horses were warmed up in their usual routine. Readings were obtained from three straight line passes on each rein in rising trot between markers placed 10 m apart. Pressure mat data were captured using blue tooth technology and simultaneous video footage was recorded.

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

Experiment 2: Effect of girth type on pressure distribution and gait parameters

Based on the results of Part 1, a girth was designed to avoid the locations of peak pressure (Girth F). The locations of the peak pressures for all Girth S designs were plotted on a grid and a common high pressure zone towards the cranial aspect of the girth was identified. A girth was then designed to avoid the high pressure zone. The cranial border and underside of the girth was lined with high performance pressure absorbing material to improve the interface with the horse (Girth F). Pressure patterns under the girth and horse gait were compared between Girth F, and the horse's usual standard girth (Girth S).

Fig. 1. The pressure mat positioned under a horse's girth during the study.

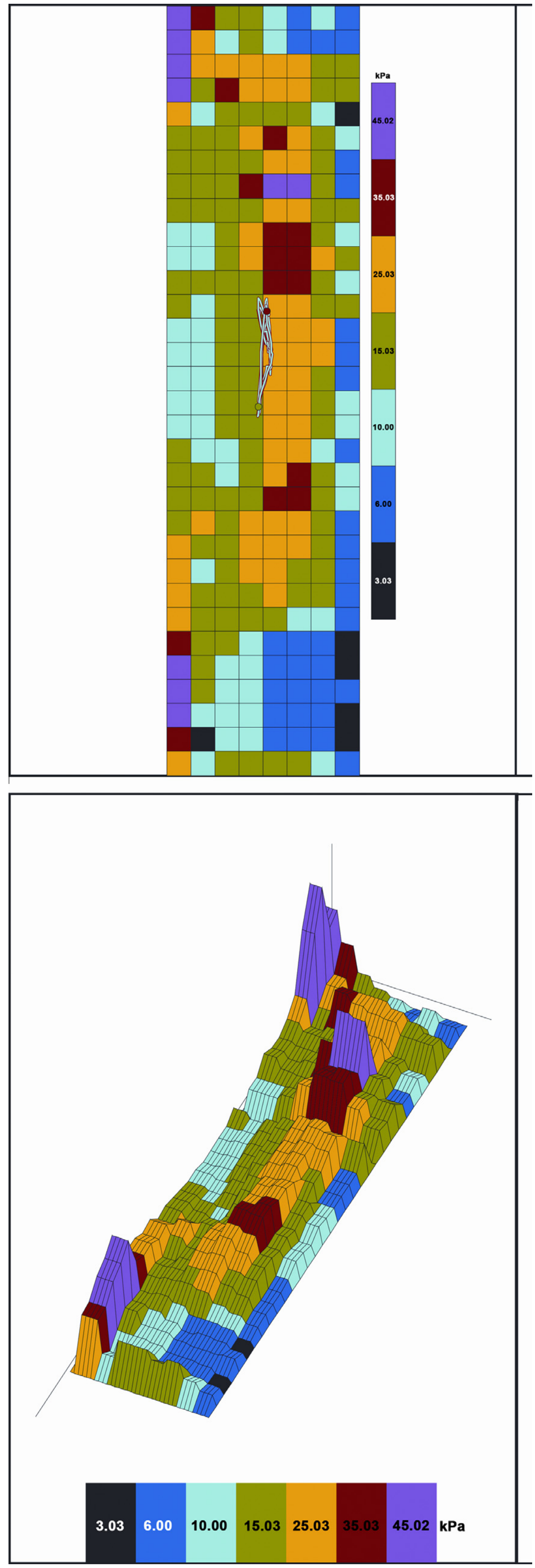

Fig. 2. Pressure distribution detected by the pressure mat located under the usual girth (Girth S) of a horse in trot illustrating the consistent pattern of peak pressure locations under the cranial edge of the girth. These areas of high peak pressure correspond to a location on the horse immediately caudal to the olecranon process of the ulna. The scale at the bottom of the picture shows the scale for peak pressure measurements at each location. Cranial is to the left of the picture.

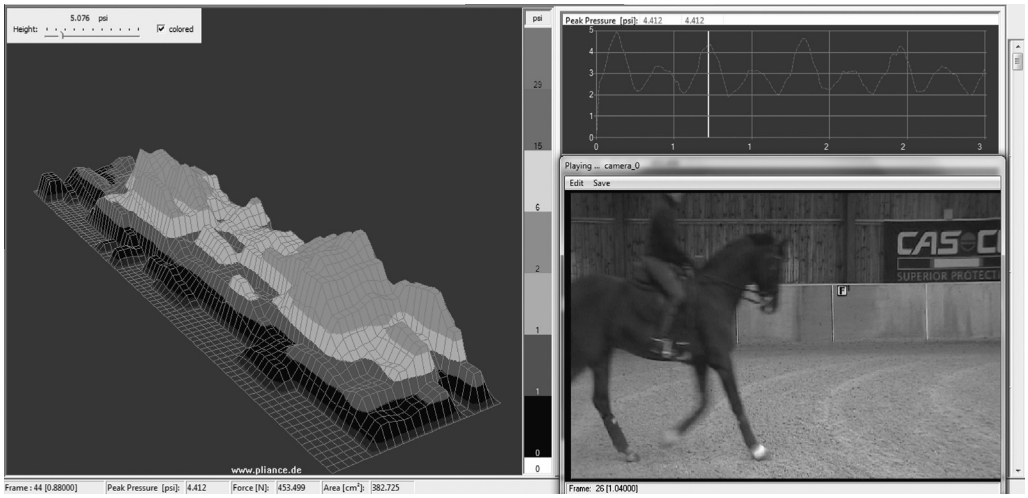

Fig. 3. Timing of peak girth pressure in relation to stride pattern: Peak pressures under the girth were observed on the side of forelimb ground contact at the onset of stance. Peak pressures are shown against time in the top right: the thick vertical white line indicates the point in the stride shown in the photograph below at peak onset of stance. The peak pressure distribution at the same point in the stride is shown in the plot to the left, with cranial positioned to the right of the picture, corresponding with the photograph.

Twenty elite horses from three disciplines (9 dressage, 9 eventing, 2 jumping) and 20 elite riders (8 male, 12 female) were used for the study. All horses included were a part of the British Equestrian Federation World Class Programme, Performance Squad so were on a regular programme of assessment by a Chartered Physiotherapist, Veterinary Surgeon and Master Farrier in the lead up to the testing, and all were deemed fit and without lameness. All riders had been regularly assessed by a Chartered Physiotherapist and were deemed fit on the date of testing.

Skin markers were placed on each horse using 3M ECE104 reflective tape. Marker locations were identified by manual palpation of anatomical landmarks identifying joint centres and segment ends. The markers were located over the atlas, scapular spine, head of humerus (cranial), 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. All horses undertook testing in their standard equipment, with only the girth altered between tests.

All horses were warmed up for 20 min prior to testing, in walk, trot and canter, and acclimatized to the testing environment during the warm up. The testing protocol was performed with the horse in Girth S and Girth F in a double blind cross-over design, with riders blinded to which girth was being used. In 10 horses Girth S was tested first and in 10 horses Girth F was tested first. After changing the girth, horses were given 20 min to acclimatize to the new girth before repeating the testing protocol.

For testing, data were collected from three passes left and three passes right in rising trot on a Gel Track surface (Martin Collins Enterprises) which had been levelled prior to testing. High speed video and pressure mat data were acquired simultaneously. 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 taken.

High speed motion capture was carried out using a Casio EX-FH25 camera, capturing at 240 Hz. The camera was placed 10 m from the testing location, parallel to the testing track with a field of vision capturing three complete stride cycles. Two 240 W halogen spot lights were used to illuminate the markers, located 10 m from the testing area. High speed video data were processed using Quintic Biomechanics. Automatic marker tracking was used to investigate limb protraction and carpal/tarsal flexion during flight. One whole stride was tracked from 20 frames prior to point of ground contact. Marker tracking was cross-checked manually: in cases where markers had been mis-tracked 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 filtered independently.

Forelimb protraction was defined as the angle between the vertical and a line from the scapular spine marker to LCL marker at maximal protraction before ground contact; hindlimb protraction as the angle between the vertical and a line from the tuber coxae marker to the LCL marker at maximal protraction before ground contact; carpal flexion as the angle between the ulna, ulnar carpal bone and metacarpal condyle markers at maximal carpal flexion during flight; tarsal flexion as the angle between the lateral condyle of the femur, talus and metatarsal condyle markers at maximal tarsal flexion during flight.

Pressure under the girth was recorded using the same pressure mat and measurement technique as in part 1. Peak pressure and maximum force were recorded.

On completion of each test, each rider graded whether there was no difference, slight difference or significant difference between Girth S or F, and if a difference was perceived, in which girth the movement of the horse was better.

Repeatability

To confirm repeatability of data acquisition and analysis, high speed video and pressure mat data were captured three times at 10 min intervals, with the saddle taken off and on in between data capture to replicate a similar environment to the study testing, and marker points were re-tracked three times. The coefficient of variance for each data point was determined and the marker points for the gait parameters at each point in the stride were overlaid graphically.

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 girth on the measured pressure mat and gait parameters within each horse. All analyses were performed using statistical analysis software (Analyse-It for Microsoft Excel version 3) with a significance level of $P < 0.05$.

Results

Repeatability

For gait parameters, there was excellent repeatability for maximum carpal and tarsal flexion ($CV < 0.001$) and good repeatability for forelimb and hindlimb protraction ($CV < 0.05$), with good agreement between repetitions for all data points in the stride. Location of maximum pressure under the girth was the same for all tests. The magnitude of peak pressure and maximum force was considered within a range which was acceptable based on the differences detected between test conditions (CV 0.06–0.013).

Experiment 1: Assessment of pressure distribution under frequently used girths

With all horses and girths, peak pressures were consistently located on the cranial edge of the girth, positioned caudal to the level of the olecranon process of the ulna (Fig. 2). The exact location of the peak pressure sensors on the mat varied in relation to the size of the horse's thorax so the peak pressure zones were closer together on the mat in the horses with a smaller thorax. All horses

Please cite this article in press as: Murray, R., et al. 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. The Veterinary Journal (2013), http://dx.doi.org/10.1016/j.tvjl.2013.07.028

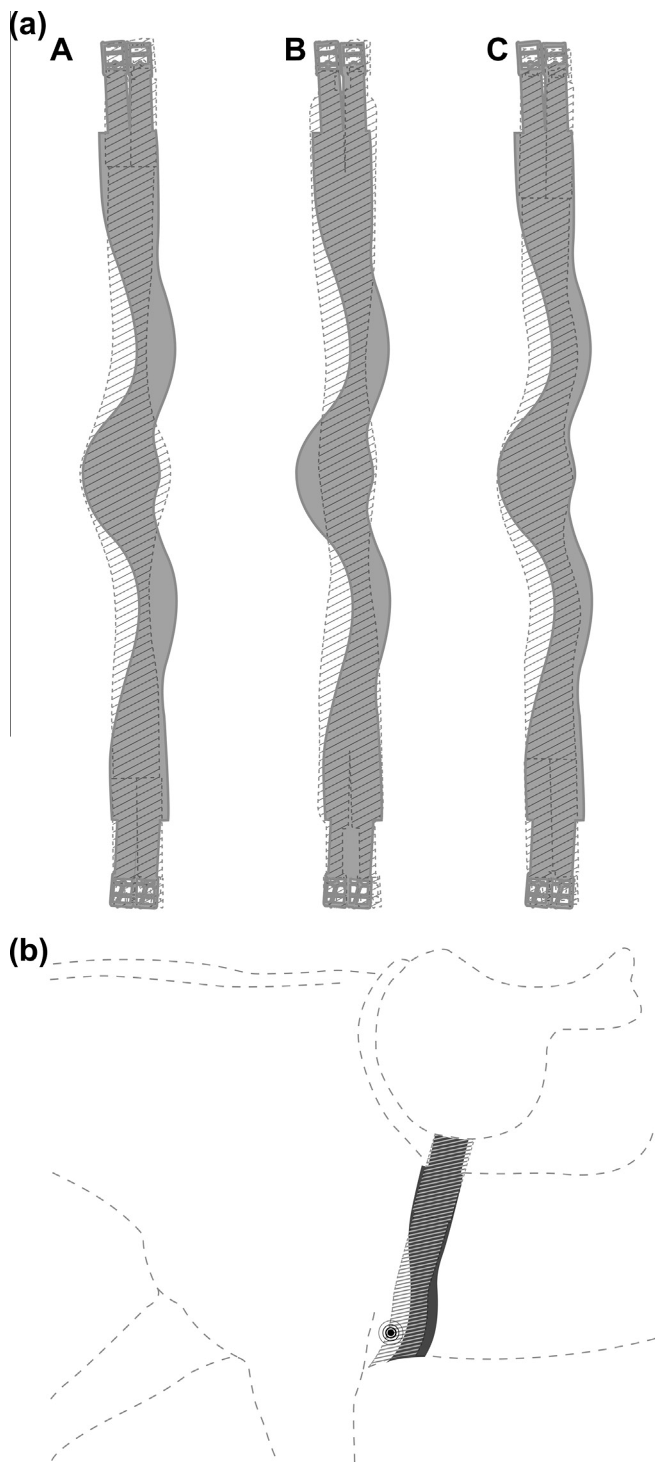

Fig. 4. Design of Girth F and various different designs of Girth S (shaded), showing how Girth F (dark grey) avoids the location of peak pressures detected on other frequently used girths. (A) Overlay of Girth F over three types of Girth; (B) position of Girth F over Girth S designs with the concentric circles denoting the area of maximal peak pressures under the girth.

had a thoracic width of 20–24 cm at the level of the olecranon processes.

The peak pressure readings occurred in every horse when the limb on the side of peak loading was in stance and the contralateral limb protracted, at the point of initial loading of the forelimb during limb retraction (Fig. 3). During each stride, the peak pressure location alternated to the side with the limb in stance.

Table 1
Pressure mat data (mean ± SD) from under the girth for 18 horses ridden in two girths (Girth F and Girth S) in a double-blind cross-over design, assessed from the left (on the left rein) and right (on the right rein) sides, indicating significantly higher peak pressure and maximum force under Girth S than Girth F.

Parameter	Side	Girth F	Girth S	Difference	*P* value
Maximum force (N)	Left	281.1 ± 143.6	343.8 ± 175.3	−62.3	0.0112
Maximum force (N)	Right	287.8 ± 143.4	327.8 ± 173.5	−40.2	0.0304
Peak pressure (kPa)	Left	31.0 ± 12.0	54.6 ± 32.5	−23.6	0.0021
Peak pressure (kPa)	Right	31.3 ± 13.9	62.1 ± 39.6	−30.8	0.0020

Experiment 2: Effect of girth type on pressure distribution and gait parameters

The design of Girth F to avoid locations of peak pressure and various designs of Girth S used in the study are shown in Fig. 4. Girth F was shaped with a considerable caudal indentation of the cranial edge of the girth overlaid by cushioning at the level of the elbow and olecranon process, over the location of peak pressures from Experiment 1.

There was no difference in speed between girth types. However, significantly lower maximum force and significantly lower peak pressure were detected with Girth F than with Girth S (Table 1, Fig. 5). Maximum forces with Girth S were 22% (left) and 14% (right) greater than Girth F, and peak pressure was 76% (left) and 98% (right) greater with Girth S than Girth F. There was no significance difference between left and right values for either maximum force or peak pressure, whichever girth was used.

Girth F was associated with significantly greater forelimb and hindlimb protraction than Girth S for both left and right side measurements (Table 2). Forelimb protraction with Girth F was between 6% and 11% greater than the Girth S. Hindlimb protraction was approximately 10% to 20% greater with Girth F. Carpal and tarsal flexion angle was significantly less with Girth F than Girth S, indicating greater degree of flexion with Girth F than Girth S. Carpal and tarsal flexion angles with Girth F were approximately 4% and 3% less than Girth S, respectively, indicating greater degree of flexion with Girth F than Girth S.

Twenty out of 22 riders graded the two girths as being significantly different, with Girth F associated with improved movement while two riders graded the girths as not different.

Discussion

The results of this study support the stated hypotheses. To the authors' knowledge, this is the first study investigating pressure patterns under a girth during the stride, or the response of the horse's gait to use of different girth designs. Repeatable locations and timings of maximum pressure were detected under different girth designs. Using a girth designed to avoid locations of maximum pressure led to lower maximum pressure compared to the horse's usual girth, and was associated with greater stride length, carpal and tarsal flexion in trot compared to the horse's usual girth.

The location of peak pressure detected in this study explains the clinically reported location of girth galls (sores) near the cranial aspect of the girth in the axillary region, which has been attributed to pressure or friction at this location. The magnitude of peak pressures detected appears to be similar to or larger than that observed under some saddles (Belock et al., 2012), and the peak pressures observed under Girth S are of a magnitude associated with clinical

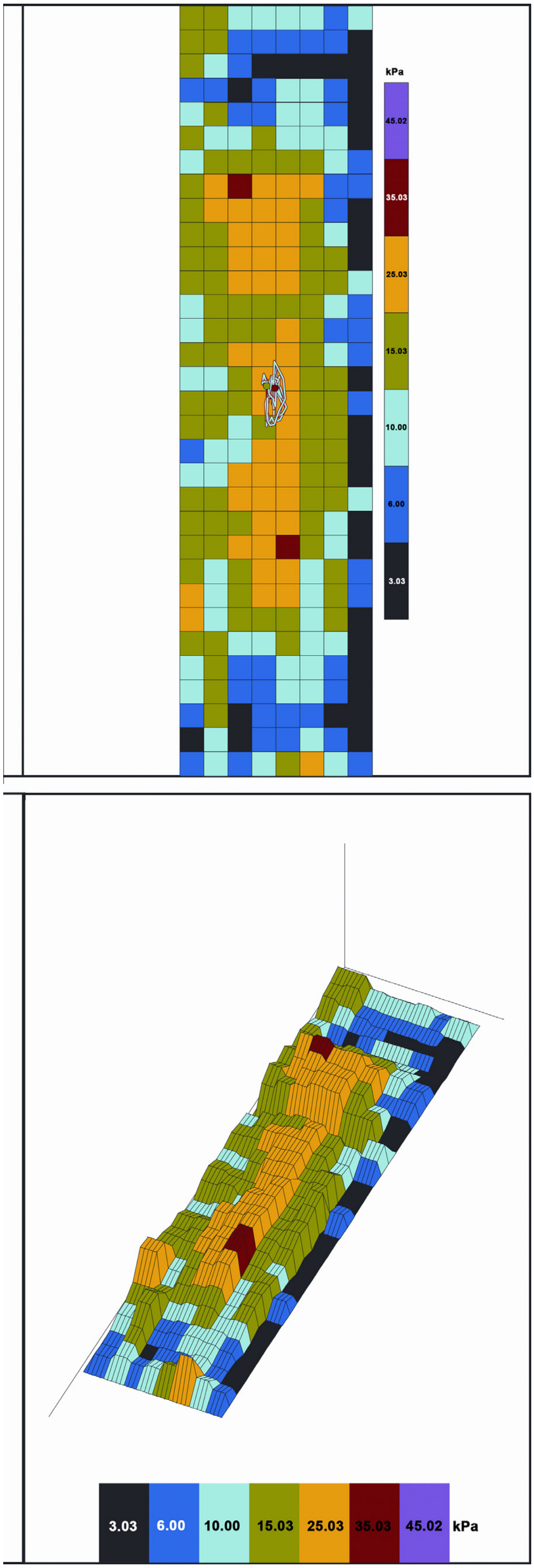

Fig. 5. Pressure distribution on a pressure mat located under Girth F of the same horse in Fig. 2 in trot illustrating the absence of high peak pressure locations underneath the cranial edge of the girth. The scale at the bottom of the picture shows the scale for peak pressure measurements at each location. Cranial is to the left of the picture.

Table 2
Gait parameters (mean ± SD) during flight for 20 horses ridden in two girths (Girth F and Girth S) in a double-blind cross-over design assessed from the left (on the left rein) and right (on the right rein) sides.

Parameter	Side	Girth F	Girth S	Difference	*P* value
Carpal flexion angle (°)	Left	92.6 ± 12.4	96.4 ± 12.0	−3.8 (4.1%)	0.03
Carpal flexion angle (°)	Right	92.7 ± 12.6	96.3 ± 12.6	−3.6 (3.9%)	0.01
Tarsal flexion angle (°)	Left	113.4 ± 7.4	116.9 ± 7.7	−3.5 (3%)	<0.0001
Tarsal flexion angle (°)	Right	113.6 ± 8.0	117.0 ± 8.6	−3.4 (3.0%)	<0.0001
Forelimb protraction (°)	Left	23.7 ± 4.2	21.5 ± 3.3	2.3 (10.7%)	<0.0001
Forelimb protraction (°)	Right	24.0 ± 4.2	22.6 ± 3.6	1.5 (6.6%)	0.007
Hindlimb protraction (°)	Left	7.5 ± 6.8	6.3 ± 6.3	1.2 (19.5%)	<0.0001
Hindlimb protraction (°)	Right	7.4 ± 6.7	6.8 ± 6.6	0.7 (10.3%)	0.005

signs of back pain when detected under saddles (Nyikos et al., 2005). Pain in this region can be associated with resentment during tightening of the girth or riding. It is therefore useful for the veterinary surgeon involved in investigating these problems to be aware of the potential to reduce peak pressure and location of pressure by altering girth design.

Previous investigation into girth–horse interaction has been limited to relationship with respiration, effect on racehorse 'run to fatigue' times on a treadmill, and effect on saddle pressure of moving the girth straps (Bowers and Slocombe, 1999, 2000, 2005; de Cocq et al., 2004; Hoffman et al., 2005; Byström et al., 2010; Wright, 2010). A relationship between increased girth tension and reduced run to fatigue times indicated that high girth tensions were having an influence on locomotion, and this was initially attributed to restriction of respiratory function (Bowers and Slocombe, 1999).

It was originally hypothesised that girth tension would influence respiration through limiting thoracic excursion (Bowers and Slocombe, 1999). However, more recent work has shown a lack of relationship between girth tension and respiratory function, although there is a potential relationship between girth tension and effect on thoracic dimensions (Bowers et al., 2005; Hoffman et al., 2005). The reason for reduced time to fatigue with increased girth tension or different girth materials is not clear, but it is possible that this is related to pressure on the muscles of the thoracic sling, resulting in restricted locomotor muscle contraction or extension (Colborne et al., 2008; Wright, 2010). Increasing girth tension could reduce limb protraction/retraction and consequently the effectiveness of the biceps catapult mechanism (Wilson et al., 2003) thus increasing the need for muscular input and reducing the time to fatigue. This biceps catapult mechanism may be important in the galloping racehorse but at slow speeds it is less effective. Consequently, the sports horse has a greater reliance on muscle activation for energy generation (Goff and Stubbs, 2007) which may mean that effects of girth pressure are even more apparent.

Peak girth pressure was seen at onset of stance in the forelimb (Fig. 3). At this point in the stride the proximal limb and trunk muscles have to modulate several actions/movements. The adductors/abductors are responsible for limb placement. Thoracic swing must be moderated and contraction of muscles required to bring the trunk forward over the limb must also be initiated. The horse can modulate stance forces experienced by the limb by altering limb compliance (Wilson et al., 2001), but it is likely to be an active proprioceptive mechanism based on sensory feedback on a stride by stride basis so is likely to require muscle activation just before hoof ground interaction (Harrison et al., 2012). This suggests that at the point of peak girth pressure the musculature directly under the girth, and that linked to it, are carrying out multiple complex roles, potentially making changes in pressure influential. By the point of mid-stance, when the limb is vertical at peak loading and the contralateral limb is parallel, the load will be taken through the osseous structures with fewer requirements for muscle tone to stabilise the limb.

Standard girths lie over the junction of various extrinsic muscles of the forelimb, involved in retraction and movement of the forelimb (pectorals, thoracic serratus ventralis), and flexion of thoracic, lumbar, sacral regions (rectus abdominis), and therefore protraction of the hindlimb (Payne et al., 2004; Colborne et al., 2008) as well as the overlying cutaneous trunci muscle (Van Iwaarden et al., 2012). These muscles need room to contract, but becoming shorter and thicker may be difficult in conditions of high pressure under a girth. Relief of pressure on the girth muscles is obviously not affecting the primary protractor muscles of the forelimb (e.g. biceps, omotransversarius) but a reduction in pressure may facilitate greater efficiency of the thoracic serratus ventralis and pectorals, which are recruited during forelimb protraction. This could aid the primary protractors in their role, resulting in the greater forelimb protraction observed in this study.

The thoracic serratus ventralis and pectorals are also important in support and elevation of the thorax. Together with the rectus abdominis and external abdominal oblique muscles, also situated in the girth region, they lift the abdomen and enable flexion through the thoracolumbar and lumbosacral regions (Denoix and Pailloux, 2001; Payne et al., 2004; Colborne et al., 2008). Flexion of the thoracolumbar/lumbosacral region is important for posture, so allowing protraction of the hindlimb (Denoix and Pailloux, 2001). This mechanism, in conjunction with the oblique muscles producing lateral back flexion, and lateral thoracic movement, may allow for greater hindlimb protraction under conditions of lower girth pressure. Based on the significant difference in limb movement between different girth designs, it is recommended that girth design should potentially be considered by the veterinary surgeon during evaluation of poor performance.

This study has limitations. Using 3-dimensional (3-D) motion analysis would have expanded with information on limb movement over the 2-D motion analysis used. However, intra-horse variation was limited as far as possible by using a standardised straight line test with markers to ensure that the horse was perpendicular to the camera at the time of data acquisition.

Conclusions

Peak pressures were located where horses are reported to develop pressure sores. Girth F reduced peak pressures under the girth, and improved limb protraction and carpal/tarsal flexion compared to the horse's usual girth, which may reflect improved posture and comfort.

Conflict of interest statement

Vanessa Fairfax is employed by Fairfax Saddles Ltd. None of the other authors of this paper has a financial or personal relationship with other people or organizations that could inappropriately influence or bias the content of the paper.

Acknowledgements

The authors are grateful to the riders involved with the study, to Vicki Walker and Carolyne Tranquille (Animal Health Trust) for advice on the manuscript, and for funding support from UK Sport lottery funding for the BEF World Class Programme and Fairfax Saddles Ltd.

References

Belock, B., Kaiser, L.J., Lavagnino, M., Clayton, H.M., 2012. Comparison of pressure distribution under a conventional saddle and a treeless saddle at sitting trot. The Veterinary Journal 193, 87–91.

Bowers, J.R., Slocombe, R.F., 1999. Influence of girth strap tensions on athletic performance of racehorses. Equine Veterinary Journal Suppl. 30, 52–56.

Bowers, J., Slocombe, R., 2000. Tensions used on girths on Thoroughbred racehorses. Australian Veterinary Journal 78, 567–569.

Bowers, J., Slocombe, R.F., 2005. Comparison of girth materials, girth tensions and their effects on performance in racehorses. Australian Veterinary Journal 83, 68–74.

Bowers, J., Slocombe, R.F., Sides, R.H., Bayly, W.M., Kingston, J.K., 2005. Interaction of saddle girth construction and tension on respiratory mechanics and gas exchange during supramaximal treadmill exercise in horses. Australian Veterinary Journal 83, 62–67.

Byström, A., Stalfelt, A., Egenvall, A., Von Peinen, K., Morgan, K., Roepstorff, L., 2010. Influence of girth strap placement and panel flocking material on the saddle pressure pattern during riding of horses. Equine Veterinary Journal Suppl. 38, 502–509.

Colborne, G.R., Allen, R.J., Wilson, R.J.R., Marlin, D.J., Franklin, S.H., 2008. Thoracic geometry changes during equine locomotion. Equine and Comparative Exercise Physiology 3, 53–59.

de Cocq, P., van Weeren, P.R., Back, W., 2004. Effects of girth, saddle and weight on movements of the horse. Equine Veterinary Journal 36, 758–763.

Denoix, J.M., Pailloux, J.P., 2001. Physical Therapy and Massage for the Horse, Second Ed. Manson Publishing, London, UK.

Fraser, A.F., 1992. The Behaviour and Welfare of the Horse, Second Ed. CAB International, Wallingford, UK, p. 115.

Goff, L., Stubbs, N., 2007. Applied animal biomechanics. In: McGowan, C.M., Goff, L., Stubbs, N. (Eds.), Animal Physiotherapy Assessment Treatment and Rehabilitation of Animals. Blackwell Publishing, Oxford, UK, pp. 45–51.

Harrison, S.M., Whitton, R.C., King, M., Haussler, K.K., Kawcak, C.E., Stover, S.M., Pandy, M.G., 2012. Forelimb muscle activity during equine locomotion. Journal of Experimental Biology 215, 2980–2991.

Hoffman, A.M., Swanson, L.G., Bruns, S.J., Kuehn, H., Bedenice, D., 2005. Effects of tension of the girth strap on respiratory system mechanics in horses at rest and during hyperpnea induced by administration of lobeline hydrochloride. American Journal Veterinary Research 66, 1167–1174.

Lloyd, D., Littlewood, J., Craig, M., Thomsett, L.R., 2003. Practical Equine Dermatology. Blackwell Science, Oxford, UK, p. 57.

Nyikos, S., Werner, D., Muller, J.A., Buess, C., Keel, R., Kalpen, A., Vontobel, H.D., von Plocki, K.A., Auer, J.A., von Rechenberg, B., 2005. Measurements of saddle pressure in conjunction with back problems in horses. Pferdeheilkunde 21, 187–198.

Payne, R.C., Veenman, P., Wilson, A.M., 2004. The role of the extrinsic thoracic limb muscles in equine locomotion. Journal of Anatomy 205, 479–490.

Pilliner, S., Elmhurst, S., Davies, Z., 2002. The Horse in Motion. Blackwell Science Ltd., Oxford, UK.

Pusey, A., Brooks, J., Jenks, A., 2010. Osteopathy and the Treatment of Horses. Wiley-Blackwell, Oxford, UK, p. 86.

Rose, M., 1982. The Horsemaster's Notebook. Harrap Ltd., London, UK, p. 185.

Smythe, R.H., 1959. The Examination of Animals for Soundness. Charles C Thomas, Springfield, Illinois, USA, p. 42.

Van Iwaarden, A., Stubbs, N.C., Clayton, J.M., 2012. Topographical anatomy of the equine m. cutaneous trunci in relation to the position of the saddle and girth. Equine Veterinary Science 32, 519–524.

Wilson, A.M., McGuigan, M.P., Su, A., van den Bogert, A.J., 2001. Horses damp the spring in their step. Nature 414, 895–899.

Wilson, A.M., Watson, J.C., Lichtwark, G.A., 2003. Biomechanics: A catapult for rapid limb protraction. Nature 421, 36.

Wright, S., 2010. Girth tensions and their variability while standing and during exercise. Comparative Exercise Physiology 7, 141–148.

Wyche, S., 2003. The Horse's Muscles in Motion. The Crowood Press Ltd., Marlborough, UK.