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Functional anatomy of the caudal thoracolumbar and lumbosacral spine in the horse

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Summary

Reasons for performing study: **Research in spinal biomechanics and functional anatomy has advanced back pain research in man. Yet, despite the performance limiting nature of back pain in horses, there are few data for the equine spine.**

Objectives: **To describe aspects of functional anatomy of the equine thoracolumbar and lumbosacral (LS) spine and potential effects on performance.**

Methods: **The first study investigated variations in LS vertebral formula by *post mortem* examination of 120 horses. Midline vertebral transection was carried out on 65 Thoroughbred (TB), 24 Standardbred (SB) and 31 other breeds. The second study investigated morphology and biomechanics of the deep stabilising epaxial muscles of 13 horses using MRI (n = 3), anatomical dissection (n = 11) and biomechanical analysis (n = 6). The spinous process angular orientation relative to the vertebral body, was analysed at vertebrae T13, T18, L3, L5, L6 and S1.**

Results: **LS variations were found in 33.3% of the total group, 40.0% TB and 45.2% others, but 0% SB. Sacralisation of lumbar vertebra (L) 6 with LS motion between L5 and L6 occurred in 32.3% TB and 29.0% others. Five segmental *multifidus* fascicles were identified originating from spinous processes and vertebral laminae running craniocaudally onto the mammillary processes and lateral border of the sacrum, crossing between 1–5 intervertebral discs. *Sacrocaudalis dorsalis* (SCD) *lateralis* muscle was an extension of *multifidus* from L4, L5 and L6 depending on the vertebral formula whereas SCD medialis *mm* originated from S3. Both inserted on caudal vertebrae. Based on the location and direction of fibres, the principal action of the deep epaxial muscles was dorsoventral sagittal rotation. This action was dependent on vertebral spinous process/body orientation. We hypothesise that equine *multifidus* and SCD *lateralis* muscles act as caudal sagittal rotators of their vertebra of origin, as is the case in man, allowing dynamic stabilisation during dorsoventral motion.**

Conclusion: **Equine *multifidus* anatomy and function are comparable to that of man. The high prevalence of anatomical variations in the LS spine may affect maximal dorsoventral motion, the stability of the LS joint and, therefore, have consequences for athletic performance. Further studies of these structures are warranted in appropriately selected poorly performing horses.**

Introduction

Equine thoracolumbar (TL) and lumbosacral (LS) back pain and associated epaxial and hypaxial neuromuscular dysfunction is a significant performance limiting problem in horses (Jeffcott 1975, 1980, 1999; Denoix 1998; Haussler 1999). Problems are frequently recurrent (Denoix 1998) and reports of the prevalence range 0.9–94%, depending on the speciality and type of practice surveyed (Jeffcott 1980). Back pain syndromes are often insidious and difficult to diagnose with variable clinical manifestations from overt lameness or pain on palpation of the TL/LS region to subtle gait alterations or behavioural changes. The predominant feature identified is a substantial loss of performance (Jeffcott 1980, 1999; Jeffcott and Dalin 1982; Denoix 1998, 1999; Haussler 1999). A thorough understanding of equine spinal biomechanics and functional anatomy is required to enable advancement of back pain diagnosis and treatment in the horse (Gellman 1998; Denoix 1999).

Morphological developmental variations in the TL/LS vertebral formula have been widely reported (Rooney 1969; Getty *et al.* 1975; Jeffcott 1979; Townsend 1987; Haussler *et al.* 1997). A study of 36 racehorses (Haussler *et al.* 1997) reported only 61% having the 'normal' vertebral formula of cervical (C) 7, thoracic (T) 18, lumbar (L) 6, sacral (S) 5 and caudal vertebrae 15–21. 89% had combined LS number of 11 vertebrae with variability in the regional number due to transitional vertebrae in the TL (22%) and sacrocaudal (36%; fusion of caudal vertebrae) regions. However, the study was limited to Thoroughbreds (TB), and may not be extrapolated to other breeds. Comprehensive investigation of the vertebral anatomy and anatomical variation is required.

The LS junction is where maximal intervertebral motion in the TL/LS spine occurs. Kinematic studies have shown dorsoventral motion (sagittal plane) of ± 9–32°, measured from L5 to S1 inclusive (Denoix 1987, 1999). The LS joint's relatively large mobility is reportedly due to a number of anatomical features including increased thickness and decreased height of the intervertebral disc (Thoulon 1991; Denoix 1999), the wide divergence of the dorsal spinous processes, poorly developed interspinous ligament and absence of supraspinous ligament (Jeffcott and Dalin 1980) and vertical orientation of the articular facets (Townsend and Leach 1984). The divergence of the spinous processes generally takes place between L6 and S1, but may occur between L5 and L6 (Haussler *et al.* 1997; Denoix 1998, 1999). However, quantitative spinous process orientation relative to the vertebral body or relationship with breed has not been reported. The divergence of the spinous processes between L5–S1 may impact spinal mobility at the point of greatest dorsoventral motion

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and, therefore, affect performance and development of pathology in the LS region.

Few studies have investigated the control of intervertebral mobility in the horse. Calculation of the instantaneous centre of rotation (ICR) of the TL/LS intervertebral joint complexes or motion segments in equine cadavers has revealed that in the region of maximal dorsoventral motion (L5–S1) the ICR occurs at the LS as reported for the human LS complex (Gonon *et al.* 1984; Denoix 1999). Due to ICR location, LS dorsoventral motion is suggested to be an assimilated rotation around the centre of the more caudal vertebral body as with man (Panjabi *et al.* 1989; Denoix 1999). LS dorsoventral motion is guided by intervertebral translation in the lateral part of the left and right intertransverse joints due to the cranial orientation of the L6–S1 transverse process (Denoix 1999). The vertebral body displacement is a result of coupled and accessory intervertebral motion including translation and shearing movements within the intervertebral disc and greater tensile and compressive strain due to the thickness of the disc (Denoix 1987).

Lumbosacral intervertebral motion has been extensively investigated in man using biomechanics and neuromotor control research in normal and lumbar back pain subjects (Panjabi *et al.* 1989, 1992; Hides *et al.* 1992, 1994, 1996; Moseley *et al.* 2002; Hodges 2003; Lee, 2004). In human (Panjabi *et al.* 1989, Panjabi 1992; Hodges and Richardson1996; Hides and Richardson 2001; Hodges *et al.* 2001) and porcine (Kaigle *et al.* 1995, 1998; Hodges 2003) studies, the activity of the deep stabilising muscles of the vertebral column and pelvis have been shown to affect motion and stiffness of the intervertebral segments of the spine and pelvis. A key muscle group is the *multifidus mm* with dysfunction and atrophy of these muscles closely linked with TL/LS pathology in human back pain (Hides *et al.* 1994, 1996; Moseley *et al.* 2002; Lee 2004). Further, poor dynamic control of these muscles has been shown to be a predictor for lower back pain in man (Cholewicki *et al.* 2005).

Unfortunately, compared to human research there is limited neuromotor control data for the equine vertebral column and the role of muscle in dynamic control of stability is virtually unknown. Equine electromyography studies have concentrated on the large trunk and epaxial muscles only, such as *longissimus dorsi* in relation trotting on a treadmill (Peham *et al.* 2001; Robert *et al.* 2001; Licka *et al.* 2004). However, human work indicates that these muscles are not sufficient to maintain stability and control of the spine and contribution from the deeper segmental muscles is essential (Bergmark 1989; Cholewicki *et al.* 1997).

In man, *multifidus* muscle provides a critical contribution to stability in the thoracic, lumbar and sacral regions via its 3 distinct segmental fascicles (Bogduk and Twomey 1987; Panjabi *et al.* 1989; Hides *et al.* 1992; Kaigle 1995; Moseley *et al.* 2002). *Multifidus* action during rotation counteracts the flexion moment of the abdominal muscles, which are the primary muscles that generate axial rotation of the spine (Bogduk and Twomey 1987). Hence, the activity of the *multifidus mm* has been shown to increase intervertebral stiffness at L4–5 in multiple directions due to the principal agonist muscles, the abdominal oblique muscles simultaneously flexing the lumbar spine (Wilke *et al.* 1995). Kaigle *et al.* (1995, 1998) reported that electrical stimulation of *multifidus* improves the quality of control of intervertebral motion around the neutral position during movement in the sagittal and frontal planes. We hypothesise that the *multifidus* may provide a similar role in control of intervertebral stability in horses if there is a similarity in muscle morphology and architecture in the TL/LS region compared to man.

The role the equine *multifidus* and *sacrocaudalis* (SCD) muscles in vertebral stability remains unclear. The limited literature available is inconsistent in the description of the anatomical arrangement and functional relationship of the intrinsic epaxial muscle (Getty *et al.* 1975; Haussler 1999; Nickel 1986; Budras *et al.* 2001). The potential contribution of these muscles, particularly *multifidus* muscle, is dependent on detailing the vertebral anatomy, muscle morphology and variations (such as alignment of the spinous processes which provides attachment for the spinal muscles). This paper describes data from a series of studies that investigated the morphology, anatomical variations and vertebral orientation of the TL/LS vertebral column and the anatomy and biomechanics of the 2 epaxial muscles; *multifidus* and SCD.

Materials and methods

Studies were approved by the Institutional Animal Ethics Committee.

Study 1

Horse cadavers (n = 120) were examined to identify variations in vertebral formula. Horses were examined at an abattoir (n = 114; 65 TB, 24 Standardbred [SB] and 31 other breeds). Horse breed and age was recorded prior to slaughter. A midline vertebral transection was performed and the vertebral formulae (C, T, L and S) analysed and recorded for each horse. A further 6 horses were examined during dissection for anatomical studies (3 TB, 3 SB.) However, only the T, L and S vertebral formulae were analysed and recorded in these 6 cadavers. Observations were made of the site of divergence of the LS spinous processes. The level of spinous process divergence and maximal dorsoventral motion was identified by the presence of a bulk of muscle fibres between spinous processes (*m. interspinalis*). The presence of transitional vertebrae, lumbar sacralisation and the number of intervertebral discs were also noted.

Study 2

Magnetic resonance imaging (MRI): Images were made of the LS region in 3 cadavers (1 TB, 2 SB) to identify gross anatomy and guide the detailed dissection and biomechanical analysis. Cadavers were dissected grossly to provide a spinal block from T11 to caudal vertebra 3 with a cross sectional area of 40 cm^2. T13 was identified and marked and all epaxial and hypaxial musculature in the block of tissue were left intact. Dorsally orientated spinal sections were imaged at 1 cm intervals in axial, coronal and sagittal slices from T13 to caudal vertebra 3. MRI data were acquired on a Bruker AVANCE spectrometer interfaced to an Oxford 2T whole body magnet. Spin echo images were acquired on the body coil with the following parameters: Field-of-view = 400 x 400 mm, slice thickness = 10 mm, slice separation = 0 mm, number of slices = 30, slice orientation = axial, TR = 1000 msecs, TE = 17 msecs, image matrix 512 x 512, spectral width = 100 kHz, number of averages = 2, total experiment time = 10 min. After acquisition of a series of slices the bed was moved 260 mm and the next series acquired. Four series of images were acquired.

Anatomical dissection: Detailed dissection of the vertebral column and deep epaxial muscles in the TL and sacral spine in 11 cadavers (age 2–30 years; 6 TB, 3 SB, 2 others) was performed using procedures adapted from Macintosh and Bogduk (1986a,b). In 1 cadaver, cross-sectional slices T13, T18, L3, L4, L5, L6, S1 and S3 with muscles kept intact were prepared using a band saw. These sections were examined to identify the fascial divisions between multifidus, SCD complex and dorsolateral epaxial musculature for comparison MRI.

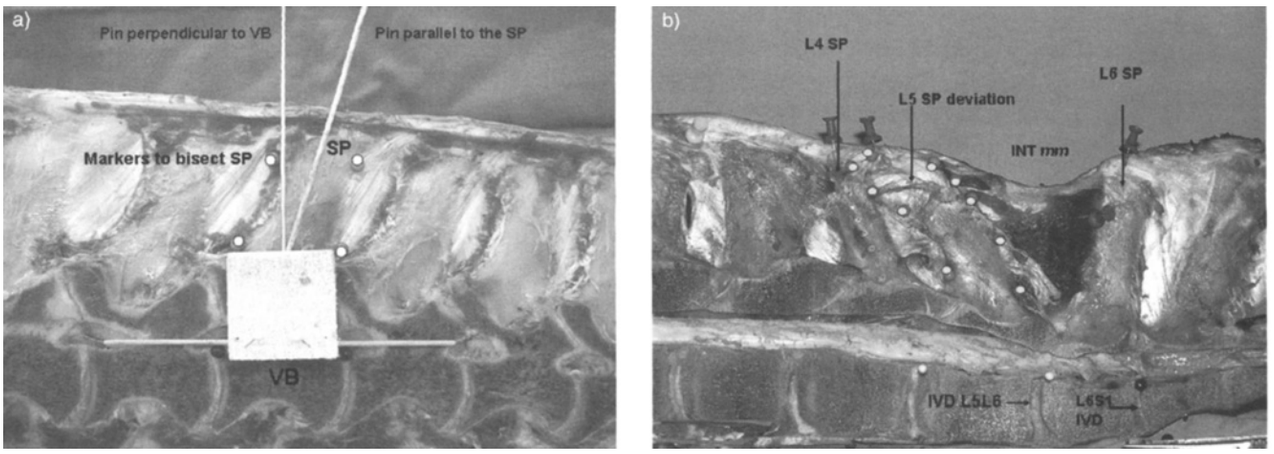

Fig 1: Measurement technique for measuring the spinous process (SP) orientation angle relative to the vertebral body (VB) is demonstrated. a) One pin is placed perpendicular to the horizontal orientation of the VB. The second pin is aligned parallel to the SP such that it bisected the mid point between markers on the caudal and cranial aspects of the spinous process at points along the length of the spinous process from the lamina to the dorsal tip. b) Showing the L5-L6 lumbosacral vertebral formula in relation to the SP orientation angle, interspinalis *muscle and number of intervertebral discs (IVD).*

The *multifidus*/SCD *mm* complex was isolated by careful resection of the large superficial epaxial and hypaxial musculature and disarticulation of the sacroiliac joint to remove the ilium. The distinct fascia covering over *multifidus* was removed so that overall appearance of the intact muscle complex could be inspected. Two approaches were then used to determine the pattern, orientation and attachments of the fascicles. In 5 horses, individual *multifidus* bundles of fascicles were detached from the T13 spinous process and *lamina* and the attachments identified. Once the bundles had been resected, the procedure was replicated for fascicles attaching to successive thoracic, lumbar and sacral vertebrae until all fibres of the muscle complex had been removed. In 6 horses, the individual *multifidus* and SCD fascicles were identified by locating the cleavage planes with the caudal attachments. Fascicles were then detached, mobilised and traced to their cranial attachments. In both samples, the left and right sides were dissected and recorded using digital video (Sony digital, 3CCD megapixel camera) and still photography (Olympus 3.2 megapixel).

Biomechanics: Spinous process orientation relative to the vertebral body was quantified in 6 cadavers (4 TB, 2 SB). Soft tissues other than *multifidus* and SCD *mm* were removed and the entire length of the right (n = 3) or left (n = 3) vertebral column. A band saw was used to transect the specimen sagittally from T9-caudal vertebra 1 along the line of the medial *lamina* adjacent to the spinous processes. This procedure removed the facet joints, leaving the spinous processes intact with the longitudinally transected vertebral body in full view. LS variations using the presence of the *interspinalis mm* and intervertebral discs were documented.

To quantify the orientation of the spinous processes at T13, T18, L3, L4, L5, L6 and S1, the caudal aspect of the dorsal and ventral edges of the vertebral body were identified and marked with pins. A pin running perpendicular to this line was extended vertically (Fig 1a, b). Second, a steel pin, representing the spinous process orientation was aligned such that it bisected the mid-point between markers on the caudal and cranial aspects of the spinous process at points along the length of the spinous process from the lamina to the dorsal tip. Digital photographic images (Olympus 3.2 megapixel) were taken in each region in a horizontal plane to the vertebral body. A metric ruler was placed on the dorsal aspect of the spinous process. Each spinous process angle was measured using image analysis software (Image J, version 1.32j, NIH, USA). Evaluation of the reliability of the spinous processes/vertebral body angle methodology was determined at 1 level (T13) in the 6 horses with 2 repeated measures on different days.

Data analysis

Data are presented descriptively with the vertebral formula calculated and expressed as a percentage of the total number of horses and breed group. For the reliability analysis for the measurement of the angle of the spinous process, the intraclass correlation coefficient (ICC [2,1]) and s.e. of measurement were calculated. Mean ± s.d. were calculated in the 2 vertebral formulae groups for all levels and *t* tests for independent samples were used to determine if there was a significant difference at any level between the 2 groups. Significance was set at $P<0.05$.

Results

Study 1

The conventional C7, T18 vertebral formula was found in all horses examined (n = 114). However, the L6, S5 formula with L6-S1 as the maximal dorsoventral motion, was only found in 67 % (80/120) horses. By breed, the expected LS formula was found in; 60% of TB (39/120), 100% SB (24/120) and 55% others (17/120) (Table 1).

LS variations were found in found in 33% of horses (40/120). By breed; 40% (26/65) TB, 0% SB, 45% (14/31) others. 8% (10/120) horses were identified with 5 lumbar vertebrae but the normal 5 sacral formula, with max dorsoventral motion L5-S1. By breed; 8% (5/65) TB, 0% SB and 16% (5/31) others. 25% (30/120) of horses had the conventional L6-S5 formula but a variation of LS with maximal dorsoventral motion at the L5-L6 intervertebral segment; 32% (21/65) TB, 0% SB, 29% (9/31) OTs. This was apparent as a spinous process/vertebral orientation divergence of L5 cranially and L6 caudally, and *interspinalis mm* (muscles) between L5 and L6 (Figure 1b).

This variation had two subsets: 1) 19% (23/120) of horses; 24% (16/65) TB, 0% SB and 23% (7/31) others had L5-L6 divergence with *m. interspinalis* present between L5 and L6 only, and various stages of L6-S1 intervertebral disc sacralisation characteristic evident; 2) 6% (7/120) horses; 8% (5/65) TB, 0% SB and 6% (2/31) others, had a more normalised LS intervertebral

disc, with L6 acting as a transitional vertebra. The striking feature in this sub-population was the presence of a less developed interspinalis m between L6-S1 as well as between L5 and L6.

Study 2

The representative MRI image taken at S1 (Fig 2) shows the cross sectional arrangement of the *multifidus*. Of note, was the presence of adipose tissue between the spinous processes, *lamina* and lateral sacrum and the *multifidus*/SCD complex, and in close proximity to the facet and sacroiliac joint. A bursa was found in all horses at variable sites on the dorsocauldal tip of the cranially directed spinous process (L4-L6), depending on the level of divergence of the spinous processes. The bursa was located in association with the SCD lateralis muscle attachments. On MRI and gross inspection the intact *multifidus*/SCD complex appeared homogenous beneath its delineating fascial encasement, comparable to the human lumbar *multifidus* (Macintosh and Bogduk 1986a,b).

In the TL/LS regions there were 5 distinct segmental bands of *multifidus mm* fascicles (cleavage plane). Each band extended caudolaterally from midline and emanated from 1 spinous process and *lamina* (Fig 3a). The fascicles were multipennate with a fleshy body and tendinous portion both running the length of the muscle. Fascicles were confluent with one another cranially arising from the tip of the spinous process to the vertebral lamina, but distinct with independent attachments caudally. The most dorsal fascicle of *multifidus* overlaid the others and crossed 2–4 intervertebral discs, arising from the caudal edge and lateral surface of the spinous process. A fleshy portion crossed 4 intervertebral discs. The remaining fascicles crossed 4, 3 and 2 intervertebral discs, from the tendinous insertion alone on the dorsocaudal aspect of the spinous process to the lamina. The deepest and shortest fascicle only crossed 1 intervertebral disc and arose from the vertebral *lamina* (Fig 3a).

Fascicles of SCD *lateralis* appeared to have the same morphology as the *multifidii* muscles, replicating and replacing the most lateral of the multifidus fascicles commencing at L4, L5, and L6 depending on LS variations (Fig 3b). The tendinous portion of the muscle bundle originated from the dorsal aspect of L4, L5 or L6, blending with the TL fascia and the supraspinous ligament in this region. In 7 cases a bursa in this tendinous portion over L5 or L6 dorsal spinous process was noted. Deeper fibres of SCD lateralis also followed the same pattern as *multifidus* attaching to the lateral border of L5 or L6 and the lateral border and *lamina* of the sacrum. Fascicles of SCD *lateralis* continued beyond the sacrum following similar morphology along the caudal vertebrae. SCD *medialis* attached from S3 in a similar pattern to the *multifidus* fascicles elsewhere, attaching to the lateral border of the sacrum and extending caudally to the caudal vertebrae (Fig 3b). Visually, the cross-sectional area of the *multifidii* and SCD *lateralis* bundles were much larger at the LS junction. This gradual increase in size continued caudally with SCD medialis from S3 caudally.

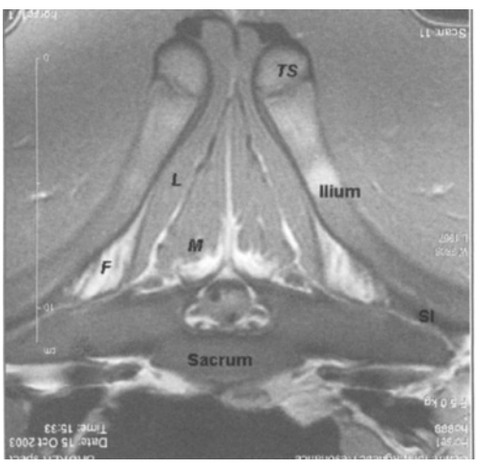

Fig 2: Magnetic resonance image (MRI) at the first sacral vertebrae, demonstrating the vertebral body and process, ilium and associated musculature: Multifidus *(M),* longissimus *(L). The image is inverted for easier interpretation as the equine was imaged lying dorsally. Note: also clearly visible in this image is the sacroiliac joint (SI), associated adipose tissue (F), and the discrepancy in size of the musculature from left to right of* multifidus *and* longissimus.

TABLE 1: Vertebral formulae for 120 horses; 65 Thoroughbreds (TB), 24 Standardbreds (SB), 31 other or unbranded horses

Vertebral Formulae DV Site INT *mm*	% of TOTAL	% of TB	% of SB	% of other horses
L6, S5 DV: L6S1 INT: L6S1	67% (80/120)	60% (39/65)	100% (24/24)	55% (17/31)
L5, S5 DV: L5S1 INT: L5S1	8% (10/120)	8% (5/65)	0%	16% (5/31)
L6, S5 DV: L5L6 INT: L5L6	19% (23/120)	25% (16/65)	0%	23% (7/31)
L6, S5 DV: L5L6 INT: L5L6S1	6% (7/120)	8% (5/65)	0%	6% (2/31)
Total L6S1 DV: L5L6	25% (30/120)	32% (21/65)	0%	29% (9/31)
Total L5 L6 S1 Variations	33% (40/120)	40% (26/65)	0%	46% (14/31)

Key: Lumbar vertebrae (L); sacral vertebrae (S) *interspinalis* muscle (INT. *mm*); vertebral region of maximal dorsoventral motion (DV). Values are expressed as a percentage of the total group and numerically.

The *interspinalis* muscle was present in the region of maximal dorsoventral motion i.e. the level of divergence of the spinous process and maximal dorsoventral motion, but not elsewhere in the thoracolumbar spine. Adipose tissue of variable size (individual to the horse and vertebral level) separated the *multifidus*, SCD *lateralis* and SCD *medialis* muscles from the bone and the *interspinalis* muscle (Fig 2).

The reliability for measurement of the angle of the spinous process was very good, with an ICC [2,1] of 0.99. The s.e. of the measurement was 0.41° and the smallest detectable difference of 1.1°.

The mechanical function (moment arm and force vector) of the *multifidus* muscle fascicles were affected by the orientation of the spinous process relative to the vertebral body. Based on variations in vertebral formula and the location of *m. interspinalis*, horses were allocated into; L6–S1 (n = 3) formula or L5–L6 formula (n = 3) groups. This variation in level of the divergence of the spinous processes was associated with significant changes in the angle of the spinous process of L6 relative to the vertebral body and varied

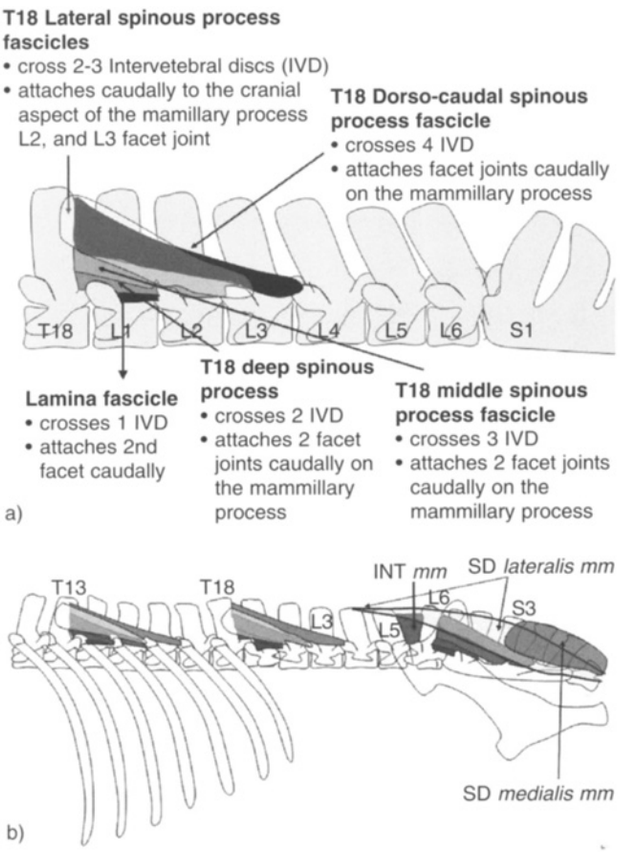

Fig 3: Multifidus *morphology and pattern demonstrated from Thoracic (T) T18. (a) The fibres from the* lamina *of T18 intervertebral disc (IVD.1) insert into the mammillary process of the vertebra 1 level caudad; Lumbar (L1). The fibres form the lateral surface of the spinous process insert into the mammillary process of the vertebrae 2 (SP.2.IVD); L2 and 3 (SP.IVD); L3, levels caudad. The fascicles form the caudal spinous process insert into the mammillary processes of the vertebrae 2 (IVD.2); L2, 3 (IVD3); L3, and 4 (IVD.4); L4 levels below. The pattern becomes progressively modified below the 3rd lumbar vertebra as the sacrum lacks a mammillary process with the caudal fascicles exhibiting a more broad dorsal attachment onto the lateral sacral surface. (b) The* sacrocaudalis dorsalis lateralis *(SCD) muscles* (mm) *attach from lumbar L4 and SCD* medialis mm *from S3. The vertebral formula in this example with* interspinalis mm *only evident here between L5 and L6.*

significantly between the 2 groups (P<0.001). Within each group, there was a large degree of variability in angle but not direction (cranial or caudal) from T13–L5. Mean values in the L6–S1 group compared to the L5–L6 group ranged as follows; T13 (-18.9 to -23.6°); T18 (23.3–12.9°); L3 (14.8–7.3°); L5 (9.1 to -24.9°); L6 (9.1 to -11.6) due to L6 divergence; S1 (-16.3–30.7). See Table 2, and Figures 4 and 5)

Discussion

This is the first comprehensive study of the anatomy of the deep epaxial muscles in the equine spine and the first comparison of anatomical variation in spinal anatomy between horse breeds. The high prevalence of anatomical variations in the TL/LS vertebral formula, spinous process divergence and or transitional lumbar vertebrae especially in TB horses was dramatic and could potentially have effects on performance. Although no evidence currently exists relating morphological variations, joint range of motion and performance, the variations noted may alter maximal functional dorsoventral LS motion. Morphological variability in the region of maximal motion of the thoracic and LS spine may result in either increased or decreased motion and therefore directly impact on performance or potentially the pathogenesis of equine back pain.

The overall variability in the current study (40% of TB group) was comparable to a study in 36 TB horses (Haussler *et al.* 1997) where 39% had L5-S1 variation. In the current study, no variations existed in the thoracic spine of TB horses, 8% had only 5 lumbar vertebrae and 32% had the maximal dorsoventral motion at L5-L6 with varying degrees of sacralisation of L6 (LS transitional vertebrae). Comparatively, Haussler *et al.* (1997) found transitional vertebrae in the TL (22%) and sacrocaudal (36%; fusion of caudal) regions along with variations of lumbar sacralisation. The other breeds also had a high prevalence of LS variation, however they consisted of all unbranded horses, which may have biased these data towards the TB population, as there are many unbranded TB types in the Australian horse population. The Standardbreds had 100% conventional vertebral formula which indicates a breed difference in expected LS vertebral formula.

The high prevalence of L5–L6 spinal variations may have an effect on the mobility in the LS region that may lead to altered function, performance and pathology. At present it is uncertain that these variations alter the biomechanics of the LS region but *multifidus* orientation (force vectors) relative to the variable LS spinous process angles may alter the proposed function of *multifidus*. In horses with divergence between the spinous process of L5-L6, multifidus may play a greater role in LS stability because maximal dorsoventral motion occurs both at L5-L6 and L6-S1 (Denoix 1998). The role of the SCD complex in the LS region is also unclear. The presence of a bursa associated with the long tendinous cranial attachments of SCD *lateralis* in the majority of horses suggests considerable motion and forces imparted on the spinous processes. This is also supported by the increased bulk of muscle in the region. Further research to determine the functional significance of these vertebral variations and anomalies and their relationship to stability muscles in horses with and without back pain is warranted.

The *multifidus* muscle in the horse is comparable to that in man, comprising a series of overlapping fascicles grouped into bands from each vertebrae running cranio-caudally in their attachments (Bogduk and Twomey 1987). *Multifidus* comprised a series of musculotendinous units, although the fascicles are not all

TABLE 2: Spinous process (SP) orientation angle (°) relative to the vertebral body. Positive angles = SP angling cranially, negative angles = SP angling caudally. Horses 3, 5, and 6 have a L6-S1 vertebral formula, with divergence (L6 cranially, S1 caudally) of the spinous processes occurring at L6. Horses 1, 2, and 4 have a L5-L6 vertebral formula with divergence occurring at L5 (L5 cranially, L6 caudally). Angles were analysed at the; T13, 18, L3, 4 , 5 and 6 and S1

	T13	T18	L3	L4	L5	L6	S1
L6S1							
Horse							
3	-26.1	10	4.5	4.9	12.5	13.2	-17.40
5	-13.7	35.6	24.6	9.7	5.4	6.7	-18.20
6	-16.9	24.3	15.2	17.9	12.2	7.4	-13.50
Mean	-18.9	23.3	14.77	10.83	10.03	9.1	-16.37
SD	6.43	12.83	10.06	6.57	4.02	3.57	2.514
L5L6							
Horse							
1	-21.8	13.3	4.04	16.8	17.98	-9.29	-43.00
2	-25	7.3	16.3	26.5	40.2	-13.50	-30.30
4	-24.1	18.1	1.6	2.8	16.7	-12.10	-19.00
Mean	-23.63	12.9	7.31	15.37	24.96	-11.63	-30.77
SD	1.65	5.41	7.87	11.91	13.21	2.14	12.01

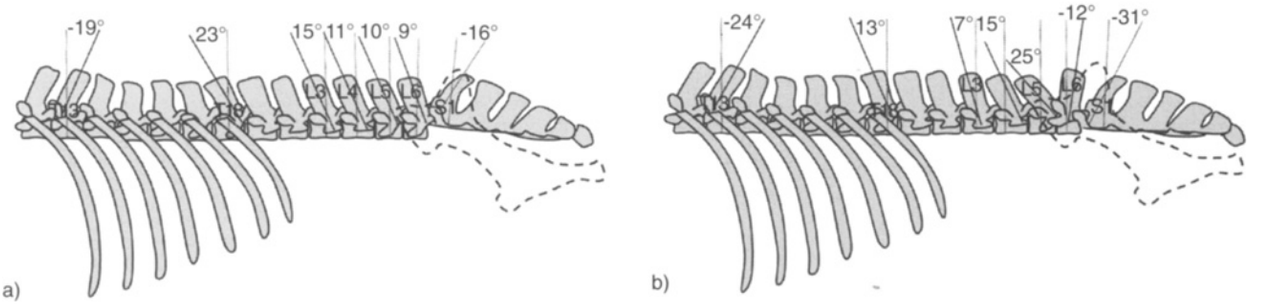

Fig 4: Models of the mean spinous process angles of orientation relative to the vertebral body. (a) Horses with the lumbosacral vertebral formula Lumbar (L) L6–Sacrum(S) 1, where the angles of divergence occurred at L6 orientated cranially and S1 caudally. (b) Horses with the lumbosacral vertebral formula Lumbar (L) L5–L6, where the angles of divergence occurred at L5 orientated cranially and L6 caudally. Mean angles are represented but the exact orientation of the vertebral level thoracic (T) 13, T18, L3, L4, L5, L6 and S1.

short as described by Haussler (1999) but variable in length as they span 1–4 adjacent vertebral segments. Fascicles originate from the spinous processes and vertebral *lamina* and insert onto the articular and mammillary processes rather than the opposite (Nickel 1986; Haussler 1999), with no attachment onto the transverse process as stated by Haussler (1999).

There are some major differences between horse and man in the LS region. SCD with its attachment to the tail is not present in man. This muscle has potential significance for control of the spine as it crosses the level of divergence of the spinous processes with large amplitude of dorsoventral motion, and is related to the sacroiliac joints which have a vastly different skeletal morphology to that of man (Getty *et al.* 1975; Nickel 1986). The morphology of both SCD *lateralis* and SCD *medialis* mirrors that of the other *multifidus* fascicles, although the SCD fascicles are larger and longer, extending to the caudal vertebrae. SCD *lateralis* was an extension of the *multifidus* (Getty *et al.* 1975), originating from L4–6. Nickel (1986) and Evans (1993) contradict this by describing SCD *medialis* as an extension of *multifidus*, which may also be correct although SCD *medialis* originates from S3. Nickel (1986) reported that SCD *lateralis* was an extension of *m. longissimus* although the present study refutes this. Unlike the human data (Bogduk and Twomey 1987), equine *multifidus* did not appear to have attachments to the *longissimus* via tendinous slips, instead it is encased in a separate fascia. In the equine sacral region the multifidus mm attaches broadly to the dorsal surface of the sacrum, but has no attachment to the ilium. *Multifidus* is separated from the ilium by a direct muscle attachment of muscle fibres from the *longissimus* and *iliocostalis* muscle that attach to the ilium.

There are several muscles that control flexibility and stability in the equine spine along with the more superficial epaxial *mm* (*iliocostalis* and *longissimus*) that extend the spine (Valberg 1999; Getty *et al.* 1975; Nickel 1986; Budras *et al.* 2001; Peham *et al.* 2001). It has been suggested that the deeper muscles, such as *multifidus*, may have a significant role in segmental stabilisation, proprioception and postural control (Haussler 1999). Nickel (1986) suggests that the SCD may contribute stability to the lumbar, sacral and caudal vertebrae. Although Evans (1993) and Getty (1975) suggest that the function of SCD is limited to elevation and lateral flexion of the tail. In the lumbar region in man, *multifidus* contributes to intervertebral stability accounting for 66% of the increase in stiffness imparted by muscular action (Wilke *et al.* 1995). The deepest fascicles crossing 1 intervertebral disc, play an integral role in controlling inter-segmental translation. In man, the deep fibres of *multifidus* have been shown to be active in an anticipatory manner before predictable challenges to stability of the spine (Moseley *et al.* 2002) similar to *m. transversus abdominis* in asymptomatic individuals (Hodges and Richardson 1996). In contrast, the superficial fibres of *multifidus*, which cross up to 4 IVD, while influencing intervertebral stability, also have a greater extensor moment and control the orientation of the spine (Macintosh and Bogduk 1986 a,b; Moseley *et al.* 2002).

There are biomechanical similarities between the present data and the results of human studies (Macintosh and Bogduk 1986b). Spinal rotation is primarily produced by the oblique abdominal muscles. Due to their orientation they also indirectly flex the lumbar spine (Macintosh and Bogduk 1986b). *Multifidus* fascicles act at right angles to spinous processes (2 vectors) (Bogduk and Twomey 1987). Therefore, the proposed action of the *multifidus* is in producing an anti-flexor (extension moment) torque needed to balance unwanted flexion. In the horse, the passive stiffness of the spine is high, due to the semi-rigid anatomy of most of the lumbar spine (Jeffcott and Dalin 1980). Therefore, the requirement for muscular control of the equine lumbar spine is limited over much of its length. However, as most motion is localised at the level of divergence of the spinous processes, the requirement for control at this level is high. Therefore, as with the human situation, it may be hypothesised that the equine *multifidus* and SCD act as caudal sagittal rotators of their vertebra of origin with the length of the spinous process giving the muscle considerable mechanical advantage (Macintosh and Bogduk 1996b).

In man and pigs, *multifidus mm* plays a key role in stability (Bogduk and Twomey 1987; Panjabi *et al.* 1989; Hides *et al.*

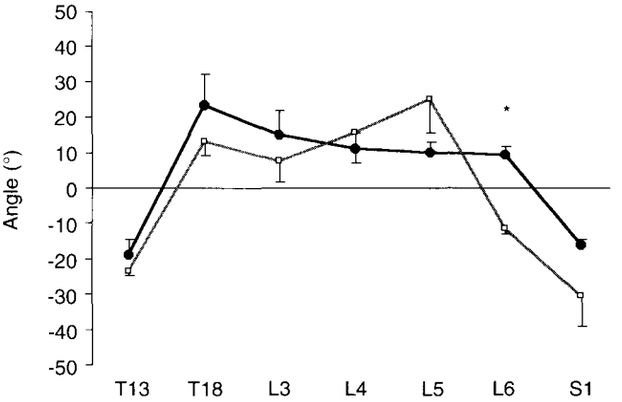

Fig 5: Mean ± s.d. spinous process angles (°) of orientation relative to the vertebral body at vertebral level T13, T18, L3, L4, L5, L6 and S1. Key: Closed circles represent divergence occurring L6–S1. Open squares represent divergence occurring L5–L6. Asterisk represents significant difference between groups (P<0.05).

1994; Kaigle 1995; Moseley *et al.* 2002). In man, spinal disease and dysfunction are accompanied by changes in the *multifidus mm* such as atrophy (Hides *et al.* 1994, 1996, 2001), decreased functional activation patterns (Ng *et al.* 2002), a loss of its preparatory stabilisation or functional protective role (Moseley *et al.* 2002). These changes have been suggested to predispose an individual to a higher incidence of recurrent back pain (Kaigle *et al.* 1995; Wilke *et al.* 1995; Bogduk and Twomey 1987; Hides *et al.* 1994, 1996; Moseley *et al.* 2002).

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