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Rural Industries Research and Development Corporation

Back Pain in Horses

Epaxial Musculature

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Foreword

Back pain and diseases of the spine and pelvis are significant problems in all types of equine performance causing poor performance, lost training days and wastage. As a result, back pain represents a considerable economic and welfare issue for the equine performance industries.

Research to date has been led by the veterinary profession with a focus on pathoanatomical problems underlying back pain. However, advances in human back pain have been led by physiotherapy research. This has focussed on the neuromotor control model and the associated dysfunction especially of the epaxial or deep back muscles that occurs as a result of back pain from different forms of pathology.

Therefore, the overall aim was to increase the knowledge of back pain in horses by investigating this multifacted problem by studying how pathology of the back itself or other parts of the musculoskeletal system is reflected in the epaxial muscles. Also, the researcher aimed to determine the relationship between atrophy or dysfunction of these muscles and pain and/or poor athletic performance. In order to do this the project had three broad objectives: first, to describe the anatomy, biomechanics and function of the equine epaxial muscles; second, to demonstrate that ultrasonography could reliably measure the dimensions of the equine epaxial muscles; and third, to objectively measure the response of equine epaxial muscles to back pain syndromes using ultrasonography.

The results of this project have shown that the anatomy and function of the equine epaxial muscles are comparable to that of humans thereby justifying a similar approach to investigating back pain in horses as in humans. Ultrasonography was found to be a repeatable and reliable tool for measurement of the equine epaxial muscle size. When examined in clinical cases of equine back pathology, there was a clear effect on the epaxial muscle size at the level of and close to areas of significant injury or pathology. While ultrasonographic examinations were primarily focused on epaxial muscle size, it was found that bony pathology was also detectable using this non-invasive tool.

In conclusion, use of a novel approach to equine back pain, borrowing from the human neuromotor control model, has advanced the knowledge of the equine back, its function and the epaxial muscle response to pathology of the spine and pelvis. Ultrasonography of the epaxial muscles is a valuable non-invasive tool that will help detect back pain and associated pathology in horses. This information will be valuable to veterinarians and physiotherapists managing back pain and poor performance syndromes in athletic horses and will lead onto future work on the effect of physiotherapeutic intervention on the recovery of epaxial muscle function following back pain.

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Managing Director
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Acknowledgments

Abbreviations

C	cervical (vertebrae)
Ca	caudal (vertebrae)
CSA	Cross sectional area
CT	Computed tomography
CV	coefficient of variation
DJD	degenerative joint disease
DSIL	Dorsal sacroiliac ligament
DSP	dorsal spinous process(es)
EIPH	exercise induced pulmonary haemorrhage
L	Lumbar (vertebrae)
LS	Lumbosacral
m	muscle
mm	muscles
MRI	Magnetic resonance imaging
S	sacral (vertebrae)
SB	Standardbred
SDFT	superficial digital flexor tendon
SIJ	sacroiliac joint
SID	sacroiliac disease or dysfunction
SD	standard deviation
T	Thoracic (vertebrae)
TB	Thoroughbred
TL	Thoracolumbar

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Background
Back pain and diseases of the spine and pelvis are significant problems in all types of performance horses, potentially causing poor performance, lost training days and wastage. As a result, back pain represents a considerable economic and welfare issue for the equine performance industries.

Evaluation of back problems in performance horses is an important part of physiotherapy and veterinary practice. Yet back pain syndromes are insidious and difficult to diagnose due to the variability of presenting signs ranging from overt lameness or pain on palpation of the back to subtle gait alterations or even behavioural changes. Complicating matters further, multiple problems often coexist, particularly lameness and back pain

Research to date has been led by the veterinary profession with a focus on pathoanatomical problems underlying back pain. However, advances in human back pain have been led by physiotherapy research. Physiotherapy research has focussed on the neuromotor control model[1] and the associated dysfunction, especially of the epaxial or deep back muscles that occurs as a result of back pain from different forms of pathology.

Aim
The overall aim was to increase the knowledge of back pain in horses by using this novel approach. Specifically; how pathology of the back itself or other parts of the musculoskeletal system is reflected in the epaxial muscles and to determine the relationship between atrophy or dysfunction of these muscles and pain and/or poor athletic performance.

Objectives
In order to do this we divided the research into three phases with the following objectives:
> Phase I: To describe the anatomy, biomechanics and function of the equine epaxial muscles.
> Phase II: To reliably measure the equine epaxial muscles using ultrasonography.
> Phase III: To objectively measure the response of equine epaxial muscles to back pain syndromes using ultrasonography.

Key findings
The results of this project have shown that the anatomy and function of the equine epaxial muscles are comparable to that of humans. A difference, however, is the equine spinal anatomy and its variations, especially in the lumbosacral region, with the variations occurring in about a third of Thoroughbred horses, and but none of the Standardbreds. These variations could have a major effect on stability of the lumbosacral joint and affect performance through altered mobility and or a predisposition to pathology during an athletic career. Ultrasonography was found to be a repeatable and reliable tool for measurement of the equine epaxial muscles and when examined in clinical cases of equine back pathology, there was a clear reduction of the epaxial muscle size at the level of and close to areas of significant injury or pathology. While ultrasonography was focused on epaxial muscle size, it was found that bony pathology was also detectable using this non-invasive tool. Another finding of particular interest was the high prevalence of serious back pathology in horses at the end of their athletic careers, justifying the importance of new, and more sensitive methods to detect such pathology.

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[1] For more information on the neuromotor control model in human or equine back pain please see link to paper McGowan CM, Stubbs NC, Jull GA. Equine physiotherapy: a comparative view of the science underlying the profession. Equine Vet J. 2007 Jan; 39(1):90-4.

Conclusions and recommendations

In conclusion, use of a novel approach to equine back pain, using the human neuromotor control model, has advanced knowledge of the equine back, its function and the epaxial muscle response to back pathology. Ultrasonography of the epaxial muscles is a valuable non-invasive tool that will help detect back pain and associated pathology in horses. This information will be valuable to veterinarians and physiotherapists managing back pain and poor performance syndromes in athletic horses and will lead onto future work on the effect of physiotherapeutic intervention on the recovery of epaxial muscle function following back pain.

Introduction

Back pain and diseases of the spine are significant problems in equine sports and veterinary medicine (Peham et al., 2001). The predominant feature identified is a substantial loss of performance (Jeffcott, 1980, 1999; Jeffcott et al., 1982; Denoix, 1998, 1999; Haussler, 1999a). As a result, evaluation of back problems is an important part of physiotherapy and veterinary practice (Jeffcott, 1980; Jeffcott et al., 1982; Denoix, 1998; Gellman, 1998). Yet, back pain syndromes are insidious and difficult to diagnose. Presenting signs may vary from overt lameness or pain on palpation of the back to subtle gait alterations or even behavioural changes. Diagnosis currently relies on a long process of elimination due to the inherent difficulty in using diagnostic equipment in the equine vertebral column (Jeffcott, 1980; Jeffcott et al., 1982; Denoix, 1998, 1999; Gellman, 1998).

In veterinary medicine, the focus on back pain has been on the underlying skeletal and ligamentous pathology or a *pathoanatomical model*. Yet in humans, the focus encompasses *neuromotor control* and the muscular system (Hodges, 2003; Lee, 2004). Numerous studies in humans and pigs have shown that the deep epaxial muscles, especially the *multifidus mm*, play a key role in spinal function and dysfunction The ability to assess the size and function of the multifidus muscles (mm) using ultrasonography has been a valuable guide to assessment, management and prevention of recurrence of back pain in man. Atrophy and dysfunction of *multifidus mm* occurs as a result of back pain and may predispose to recurrence of back pain (Hides et al., 2001; Hodges, 2003). For this reason, assessment and treatment based on this model have been developed for human back pain sufferers.

Stability of the vertebral column and role of *multifidus mm* in man

Dynamic spinal stability is known to be an important contributor to the pathogenesis of back pain in man. Loss of control of a spinal segment's stability allows more movement during activities, and is described as the loss of control of, or increased size of the segment's "neutral zone". This loss of neutral zone is associated with a predisposition to disc disease and spinal injury as well as allowing more movement across joint surfaces predisposing to degenerative changes. (Panjabi, 1992). The *multifidus mm* plays a key role in the stability of the lumbar spine in man (Moseley et al., 2002). It provides segmental stabilisation of flexion torques during rotation, acting as bilateral stabiliser in rotation (Bogduk and Twomey, 1987; Panjabi et al., 1989). Superficial fibres contribute to the control of spinal orientation and deep fibres have an integral role in controlling inter-segmental and shear forces. Fascicles act at right angles to spinous processes (2 vectors) exerting a rocking component into extension where they "control flexion" i.e. *multifidus mm* acts as a posterior sagittal rotator. Pure lumbar spinal rotation is an indirect motion due to the principal agonist muscles, the oblique abdominal muscles, simultaneously flexing the lumbar spine. Hence the role of *multifidus mm* is to balance unwanted flexion during rotation and stabilising axial rotation, maintaining the spinal segment's neutral zone (Bogduk and Twomey, 1987).

When compared to other muscles in close proximity to the last lumbar vertebrae in man (L4-L5), *multifidus mm* contributed 2/3 of the increase in stiffness imparted by muscular action (Wilke et al., 1995). *In vivo* studies in pigs confirmed *multifidus mm* as a major stabiliser of the lumbar spine (Kaigle, 1995). What is also important is the recruitment of *multifidus mm* where deep fibres have been shown to be preparatory in nature (switch on in anticipation of movement) similar to *transverse abdominus mm* in the asymptomatic subject (Hodges and Richardson, 1996). This means that the *multifidus mm* function is important in the protection of the production of abnormal rotation or shear forces in the vertebral column.

In back pain patients, *multifidus mm* has been shown to be both reduced in size, segmentally (Hides et al., 1994), and also have altered functional activation patterns. EMG studies showed that there was decreased activation of *multifidus mm* at the initial period of axial rotational exertion - also at low levels of exertion (Ng et al., 2002) – i.e. it loses the preparatory stabilisation or protective function present in the normal patient and predisposes the patient with back pain to recurrence. Rantanen et al.

(1993) found that subjects with back pain with *multifidus mm* pathology had a poor outcome post disc surgery at five year follow up. Compared with the positive outcome group, on biopsy *multifidus mm* in these patients was shown to have undergone pathological changes; "moth eaten appearance" possibly in relation to type 1 fibres, decreased fibre diameter size of type 2 fibres, a more loose adipose connective tissue, with denervation in the deep part of the *multifidus mm*.

It has been demonstrated that restoration of *multifidus mm* function and bulk is an important factor in the prevention of recurrence of back pain in people with acute back injuries (Hides et al., 1996). The recovery of *multifidus mm* has been shown not to be automatic in people, so that despite apparent recovery or resolution of pain following an episode of acute back pain, the dysfunction of *multifidus mm* persists (Hides et al., 1996). Specific physiotherapeutic intervention in people with *multifidus mm* dysfunction following an episode of acute back pain reduced the rate of recurrence of injury to 30% in physiotherapy intervention group compared with controls 84% (Hides et al., 2001).

We hypothesise that if *multifidus mm* in horses is shown to have the same role as in man, similar physiotherapeutic strategies of strengthening and recruiting this muscle can be developed for the treatment and rehabilitation of back pain in horses as have been in humans.

Back pain in humans and horses

Low back pain in the human general population is extremely common with a reported 60 – 80% incidence of recurrence in the first year following the first episode of acute lumbar pain and 22 – 62% in years the following four years (Liebensm, 1996). Back pain is also common and frequently recurrent in horses (Jeffcott 1980) with the literature reporting a variable prevalence of back pain in horses from general veterinary practice (0.9%), Thoroughbred racehorse practice (2%), veterinary school referrals (5%), mixed equine practice (dressage, showjumpers, eventing) (13%), spinal research clinic (47%), to equine chiropractic clinic (94%) (Haussler, 1999a). Bailey et al. (1997) documented that Sydney race horse trainers reported back problems as one of the most common injuries preventing training and racing. Similarly in horses, of 190 horses with chronic back problems, 57% recovered completely, 17% showed no improvement and 38% had a recurrence or continuation of signs of low back pain (Jeffcott, 1979).

Equine back pain can result from a wide variety of different pathological processes. In a review of 443 cases of equine back pain, the major identified pathological lesions associated with thoracolumbar pain were vertebral lesions (39%), soft tissue injuries (25%), sacroiliac strain (13%) and non-thoracolumbar lesions (13%). Vertebral lesions were predominantly overriding dorsal spinous processes, while soft tissue lesions were predominantly in the *longissimus dorsi m*uscles and supraspinous ligament in the caudal withers and cranial lumbar regions. Crowding and overriding dorsal spinous processes were most common beneath the saddle at T12 to T17, and most prevalent in young adult to middle aged horses used for jumping or dressage and in Thoroughbreds with short backs (Jeffcott, 1980).

Spinal muscular dysfunctions in horses with back pain are frequently secondary to underlying bone pathology but may also be due to pathology of the muscles themselves, or of a generalised muscle disorder (Valberg, 1999, Quiroz-Rothe et al., 2002). Spine and peripheral joint disease with pain can cause reflex inhibition of motor neurones, resulting in weakness and atrophy of associated muscles (Young, 1993). Local muscle damage attributed to a poorly fitting saddle, for example, can also cause atrophy of the epaxial muscles (Gellman, 1998; Harman, 1999). In a survey of 443 cases referred with thoraco-lumbar disorders, 23.37% had evidence of epaxial muscle pain (Jeffcott, 1980).

Anatomy of the equine epaxial musculature

The *longissimus dorsi m.* is the most superficial of the epaxial muscles and therefore atrophy is most visible. Signs of reduced epaxial muscle bulk are increased prominence of the vertebral spinous processes and dipping away of the profile lateral to the spine (Harman, 1999). The *multifidus mm* are deep and medial to the *longissimus dorsi m.* and not assessable by visual examination. Therefore it is not possible to determine if wasting is due to the *longissimus dorsi m.* or the *multifidus mm* by eye alone. In the horse, *multifidus mm* is described as originating from the transverse processes of the thoracic, lumbar and sacral vertebrae and having insertions into the spinous processes of S1-2, L1-6 and T1-18, receiving innervation from the dorsal branches of the thoracic and lumbar nerves (Budras et al., 2001).

Numerous skeletal muscles provide stability and flexibility in the spine (Valberg 1999). However, the role of the *multifidus* and related muscles (especially *sacrocaudalis dorsalis m*) in the horse has been unclear. The large epaxial muscles (*m. longissimus dorsi, m. iliocostalis* and *m. middle gluteal*) tend to produce gross spinal extension and global spinal "stiffness" rather than dynamic" intersegmental stability", and the ventral muscles (iliopsoas minor/major and the abdominal complex) flex the spine. It has been suggested that the deeper muscles such as *multifidus mm* may produce segmental stabilization in the horse (Haussler, 1999b), with Nickel (1986) suggesting that the tail muscles may contribute to spinal stability of the lumbar, sacral and caudal vertebrae.

In textbooks and the limited literature available there seems to be some discrepancy and lack of data as to the exact anatomical arrangement and functional relationship and role of the *sacrocaudalis dorsalis m* to *multifidus mm* and other epaxial muscles in the horse. *Sacrocaudalis dorsalis m* is described as "extensions of the lumbar epaxial muscles predominantly the longissimus and multifidus muscles" (Getty, 1975; Nickel et al., 1986; Evans, 1993) with *sacrocaudalis dorsalis medialis m* being an extension of multifidus (Nickel et al., 1986; Evans, 1993). However, Getty (1975) suggests that the action of the *sacrocaudalis dorsalis m* being elevation and lateral flexion of the tail (Getty, 1975) and that *sacrocaudalis dorsalis lateralis m* is an extension of the multifidus muscle. Since the anatomical arrangement is so vital to the biomechanical function of a muscle, clearly research on describing the detailed anatomy of the *multifidus mm* and the *sacrocaudalis dorsalis m* are warranted.

Ultrasound Imaging of *Multifidus*

Monitoring muscle size is important in human physiotherapy practice as repeated measurements can show changes that represent the effectiveness of the treatment implemented. Real-time ultrasound imaging can be used to provide an immediate image of the structures beneath the probe and complete cross-sections of muscle can be obtained (Stokes and Young, 1986). Ultrasound imaging can be used to measure muscle cross-sectional area (CSA), therefore it may be able to provide a method of direct assessment of epaxial muscle atrophy or hypertrophy and its response to therapy. Despite the quality of more advanced techniques like magnetic resonance imaging (MRI) and computed tomography (CT), no significant differences in the cross-sectional area of the *multifidus mm* were found when compared to those obtained by ultrasound imaging (Hides et al., 1995).

Ultrasound imaging may therefore be a useful tool in the assessment of the efficacy of physiotherapy on the muscular system (Hides et al., 1995). Intra-operator reliability has been demonstrated for the use of ultrasound imaging to measure the *anterior tibial m*, *quadriceps mm* and *multifidus mm* in humans (Hides et al., 1992; Martinson and Stokes, 1991; Stokes and Young, 1986). Ultrasound imaging has further been used to examine the effect of lumbar back pain on the *multifidus mm* in humans where there was significant reduction in cross-sectional area of *multifidus mm* on the symptomatic side of the spine, showing a relationship between pain and muscle atrophy (Hides et al., 1994). Despite the use of ultrasonography in the measurement of muscle size in humans, there are no reports of its validation in horses.

The clinical significance of being able to measure the size of the *multifidus mm* is to be able to quantify atrophy present and thus the dysfunction that exists in the spine. This can be used both as a diagnostic tool, and as an indicator of the risk of recurrence. If the presence of *multifidus mm* atrophy can lead to degenerative effects in the human spine (Hides et al., 1996) then it could be speculated that *multifidus mm* atrophy may allow the pre-cursor to degenerative changes. Further, it has been shown that restoration of *multifidus mm* function and bulk is an important factor in the prevention of recurrence of back pain in people with acute back injuries (Hides et al., 1996). Thus, the ability to assess the size and function of *multifidus mm* in man has been a valuable guide to assessment, management and prevention of recurrence of back pain.

The development of similar techniques in horses is warranted, and utilisation of the techniques will be valuable in developing suitable assessment and management strategies in horses suffering from back pain syndromes. The speculation that *multifidus mm* or epaxial muscle atrophy is present in both primary and secondary back pain in the horse, as it is in man, provides a rationale for investigation of ultrasonography for as an aid to diagnosis of equine back pain. Further, if atrophy is a consistent finding, the response to therapy could be quantitated allowing rational evidence-based selection of treatment techniques in horses with back pain.

Generalised secondary atrophy of the epaxial muscles, especially *longissimus dorsi mm* and *middle gluteal mm* which are located on the dorsal aspect of the equine vertebral column has been reported in horses with back pain (Jeffcott et al., 1982; Quiroz-Rothe et al., 2002) from which is can be suggested that similar changes occur in equine epaxial muscles as has been found in humans. However, there has been no research to support a neuromotor and muscular control theory of back pain in horses. We have proposed that the human neuromotor control approach can be applied to the horse and utilisation of ultrasonography in measuring epaxial muscle size, especially *multifidus mm*, will be valuable in developing suitable assessment and management strategies in horses suffering from back pain syndromes. Specifically; the aims of this project were to determine how pathology of the back itself or other parts of the musculoskeletal system is reflected in the epaxial muscles and to determine the relationship between atrophy or dysfunction of these muscles and pain and/or poor athletic performance.

Objectives

Our original stated objectives were as follows:
- to objectively measure the equine epaxial muscles
- to objectively measure the response of equine epaxial muscles to back pain syndromes
- to correlate clinical signs, ultrasonography, algometry and EMG analysis in affected horses
- to develop ultrasonography as a non-invasive tool for diagnosis of muscular dysfunction associated with back pain in horses
- to develop ultrasonography as a non-invasive tool for monitoring response to therapy of back pain in horses.

In order to address these objectives we divided the research into three methodological phases with the following objectives:

- Phase I: To describe the anatomy, biomechanics and function of the equine epaxial muscles
  Hypothesis: the equine multifidus and sacrocaudalis dorsalis mm have similar morphology, biomechanics and function to man and the pig, acting as a dynamic stabiliser of spine and having a key role in equine back pain

- Phase II: To reliably measure the equine epaxial muscles using ultrasonography
  Hypothesis: That ultrasonography of the equine epaxial muscles (multifidus mm and longissimus dorsi m) is a reliable method to determine muscle size, and variations with pathology

- Phase III: To objectively measure the response of equine epaxial muscles to back pain syndromes using ultrasonography
  Hypothesis: That clinical signs of back pain detected on clinical examination and diagnostic imaging will be correlated with the underlying pathology detected at post mortem.

Methodology

Studies were approved by the Institutional Animal Ethics Committee.

Phase I: Functional anatomy of the caudal thoracolumbar and lumbosacral spine in the horse[2]

This phase was originally planned to be the second phase, but on a review of the literature it became apparent that the anatomy of the equine *multifidus mm* and its caudal extensions (especially *sacrocaudalis dorsalis m*) in the horse were not well described and conflicting reports existed. Ultrasonography relies on accurate anatomical descriptions of the area being imaged, so this phase of the project was completed first. Further, following the initial anatomical dissections, it was noted that there was considerable variation in the vertebral formula of each horse, leading us to expand this section of the project.

Vertebral formula variation

120 horse cadavers were examined to identify variations in vertebral formula. There were 65 Thoroughbreds, 24 Standardbreds and 31 other breeds. A midline vertebral transection was performed and the vertebral formulae (number of cervical, thoracic, lumbar and sacral vertebrae present) were analysed and recorded for each horse. Observations were made of the site of divergence of the lumbosacral 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.

Magnetic resonance imaging (MRI)

Images were made of the lumbosacral region in 3 cadavers (1 Thoroughbred, 2 Standardbred) to identify gross anatomy and guide the detailed dissection and biomechanical analysis. Cadavers were grossly dissected to provide a spinal block from T11 to caudal vertebra 3 with a cross sectional area of 40 cm^2. 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 limits: Field-of-view = 400 X 400 mm, slice thickness = 10 mm, slice separation = 0 mm, number of slices = 30, slice orientation = axial, TR=1000 ms, TE=17 ms, image matrix 512 X 512, spectral width = 1 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 thoracolumbar and sacral spine in 11cadavers (2 to 30 years) (6 Thoroughbred, 3 Standardbred, 2 others) was performed using procedures adapted from Macintosh and Bogduk (1986 a, 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, sacrocadualis caudalis complex and dorsolateral epaxial musculature for comparison MRI.

The *multifidus – sacrocadualis caudalis 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

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were detached from the T13 spinous process and lamina and the attachments were 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 sacrocadualis caudalis 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 camera).

Biomechanics
Spinous process orientation relative to the vertebral body was quantified in 6 cadavers (4 Thoroughbred, 2 Standardbred). Soft tissues other than *multifidus* and *sacrocadualis caudalis 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 to 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. Lumbosacral 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 (Figure. 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 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, and Intraclass correlation coefficient (ICC [2,1]) and the standard error of measurement (SEM) were calculated. The mean and standard deviation 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 $P<0.05$.

Phase II: Measurement of the equine epaxial muscles using ultrasonography

MRI multifidus mm CSA reliability
MRI was chosen as the gold standard for CSA measurements of the *multifidus mm*. To determine the reliability of measure:re-measure CSA from MRI, 2 Standardbred horses (both five years old) were euthanased then dissected to obtain 40 cm x 40 cm spinal sections from T11 to the tail. MRI images were taken at 1cm axial slices, cranial to caudally (Bruker AVANCE spectrometer interfaced to an Oxford 2T whole body magnet). CSA was measured blindly on three occasions using the Standard Bruker analysis package on 7 CSA images in 4 vertebral regions (T14, T18, L6/S1 and S2). Anatomical dissection was subsequently performed on both horses to verify the location and anatomical relationship of *multifidus mm* and compared to MRI images with fascial margins, fascicle bundles, attachments and relationships between the epaxial muscles recorded. Unfrozen cross-sections of the spinal segments studied were also obtained. Video and still photography was used to record these findings. To assess the repeatability and measurement error of the data Standard Deviation (SD) for individual, pooled and entire data for all regions was calculated to derive a 95% confidence interval/limit of agreement. The coefficient of variation (CV) for all regions was calculated to analyse the reliability of intra-rater repeated measures.

Ultrasonographic multifidus mm CSA reliability

To determine the reliability of measure re-measure CSA from ultrasonography, 2 Australian Stock horse geldings were imaged using real time ultrasonography using a Mysono-201 (Excelray, Australia) ultrasound machine with a 4-7 MHz curved linear probe at a depth of 15cm with *multifidus mm* and its fascial boarders in view at T13/14, T18/L1, L3/4 L5/6 and the *Sacrocaudalis dorsalis m* complex at the 3rd Sacral vertebra. Cross-sectional area measurements were analysed blindly on 3 occasions using specialized software (Image J) by the same examiner. The same operator repeated the ultrasonographic examination at each site three times, with each image being analysed three times.

Data were analysed for intra- and inter-rater reliability at all levels,and left vs right side in the same horse.

Effect of age, breed and conditioning on multifidus mm CSA

Multifidus mm CSA was measured by the same person at 4 sites of the back (T13, T18/L1, L5 and S3). These were chosen based on the results of the reliability data. CSA was measured in 6 horses in 5 groups: 2 year old unbroken Australian Stock Horses, 2 year old Thoroughbreds in pre-race training, mature Thoroughbreds in race training, mature Standardbreds in race training and aged horses. Images were analysed using image J and CSA at the different levels compared. Measurement of *multifidus mm* in Warmbloods CSA was attempted, but was not possible due to the large size of the muscle being beyond the limits of the ultrasound probe being used.

Phase III: Ultrasonography in equine back pain

All racehorses presented for euthanasia at the Hong Kong Jockey Club and subjected to routine post mortem procedures during the period of April – July 2006 were recruited. Jockey Club records and the racing and training history were examined and a clinical examination of the horse performed. Following routine post mortem procedures, the thoracolumbar spine and pelvis was dissected, macerated and examined for the presence of bone pathology.

Clinical History

A thorough clinical history including clinical findings, performance history and results of lameness examination and other diagnostic tests were obtained.

Ultrasonographic examination

Ultrasonographic examination was performed with the horses lightly sedated by the attending veterinary surgeon, and standing in stocks using a VingMed system 5 ultrasound machine with different probes ranging from 2.5 – 10 Mhz depending on the depth required. Images were taken and stored using the software on the ultrasound machine for later analysis using Image J. As well as the 4 specific regions of the back, additional views were taken in these horses to determine the presence of bony changes on the facet joints of the entire thoracolumbar spine, and images of the pelvis and dorsal sacroiliac ligament were also obtained.

Clinical Examination

Clinical assessment comprising of a full gait assessment and observation of dynamic vertebral motion, stability and dysfunctions was performed. A physical and manual examination was performed including specific provocation tests. Where necessary this was performed in stocks to prevent lateral or excessive movement. Digital video recording was taken of gait for subsequent analysis. Photographs of conformation, muscle bulk and vertebral and pelvic symmetry were taken. All information from the examination was recorded verbally on a voice recorder and later reviewed in association with the images.

Post mortem examination

Gross soft tissue lesions; muscular, ligamentous and fascia were noted and photographed. The thoracolumbar vertebral column and sacropelvic region were assessed for the following abnormalities:

- morphology of the spinal column; number of vertebrae, sacralisation of lumbar vertebrae, presence and locations(s) of *interspinalis mm*, presence and location(s) of lumbar dorsal spinous process bursa
- interference or impingement of dorsal spinous processes / overriding
- interference or impingement of transverse processes / overriding
- evidence of gross bone remodelling/ gross degenerative changes of the facet joints (zygophyseal joints); gross enlargement of the dorsal facets
- evidence of gross bone remodelling/ gross degenerative changes of the thoracolumbar and lumbosacral articulations and intervertebral discs (degenerative intervertebral disc disease)
- evidence of gross bone remodelling – gross degenerative changes of the lumbar inter-transverse joints
- evidence of acute or chronic sacroiliac joint injury or luxation; chronic laxity or signs of subluxations
- presence (signs of) of spondylosis or ankylosis
- osseous lesions; fractures
- ligamentous lesions
- fascial lesions
- muscular lesions
- *Multifidus mm* appearance; adipose tissue within the muscle.

A steel rod was passed down the length of the spinal canal and fixed at both ends to ensure vertebrae stayed in correct alignment. The spine was then boiled to remove all remaining soft tissues and stored until examination. Spines were subsequently examined for evidence of gross bone pathology.

The thoracolumbar vertebral column and sacropelvic region were divided into 5 regions and scored using the scale of 0 = no changes, 1 = mild changes, 2 = moderate changes and 3 = severe changes. The regions were:
- vertebral bodies and end plates
- facet joints and articular processes
- Lumbosacral complex: Lumbosacral joint, intertransverse joints
- sacroiliac complex; sacral and ilial surfaces photographed and graded as per Jeffcott et al. (1985); CSA (Image J) and degenerative joint disease
- over riding thoracolumbar dorsal spinous process and lumbar transverse processes.

Each region was assessed and scored for following abnormalities:
- fractures
- spondylosis
- evidence of lysis of and/or periosteal new bone formation on the dorsal spinous processes
- evidence of lysis of and/or periosteal new bone formation on the transverse processes
- periarticular new bone formation associated with the dorsal facet joints
- lysis of bone associated with the dorsal facet joints
- any other lesions.

Active new bone formation was considered a major finding and its presence required before a lesion could be graded as severe.

The identity of all macerated vertebral samples was coded and the bone pathology recorded by the investigators blinded to the identity of the horse.

Results

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

Vertebral formula variation

The conventional cervical and thoracic vertebral formula was found in all horses examined. However, the expected L6, S5 formula with L6-S1 as the maximal dorsoventral motion, was only found in 67 % (80/120) horses. By breed, the expected lumbosacral vertebral formula was found in; 60% of Thoroughbreds (39/65), 100% Standardbreds (24/24) and 55% others (17/31).

Lumbosacral variations were found in 33% of horses (40/120). The variations that occurred included:

- Five lumbar vertebrae instead of six, but the normal 5 sacral formula, with maximal dorsoventral motion L5-S1. This occurred in 8% (5/65) Thoroughbreds, 0% Standardbreds and 16% (5/31) others.

- The conventional L6-S5 formula but a variation of the lumbosacral region with maximal dorsoventral motion at the L5-L6 intervertebral segment. This occurred in 32% (21/65) Thoroughbreds, 0% Standardbreds, 29% (9/31) others. This was apparent as a spinous process/vertebral orientation divergence of L5 cranially and L6 caudally, and *interspinalis mm* between L5 and L6 (Figure 1).

This variation had two subsets:

1. L5-L6 divergence with *m. interspinalis* present between L5 and L6 only, and various stages of L6-S1 intervertebral disc sacralisation characteristically evident. This occurred in 24% (16/120) Thoroughbreds, 0% Standardbreds and 23% (7/120) others (Figure 2)

2. L5-L6 divergence with a more normalised lumbosacral 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-L6. This occurred in 8% (5/120) Thoroughbreds, 0% Standardbreds and 6% (2/120) others.

MRI

MRI images showed the detail of the muscles and the cross sectional arrangement of the *multifidus mm*. Of note was the presence of adipose tissue between the spinous processes, lamina and lateral sacrum and the *multifidus mm -sacrocaudalis dorsalis m*, and in close proximity to the facet and sacroiliac joint. On MRI and gross inspection the intact *multifidus - sacrocaudalis dorsalis m* complex appeared homogenous beneath its delineating fascial encasement, comparable to the human lumbar multifidus (Macintosh and Bogduk 1986 a, b) (Figure 1).
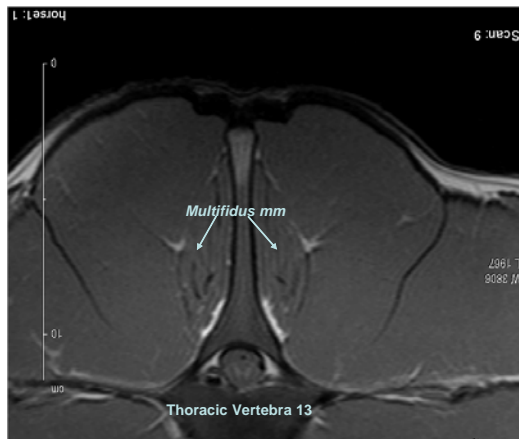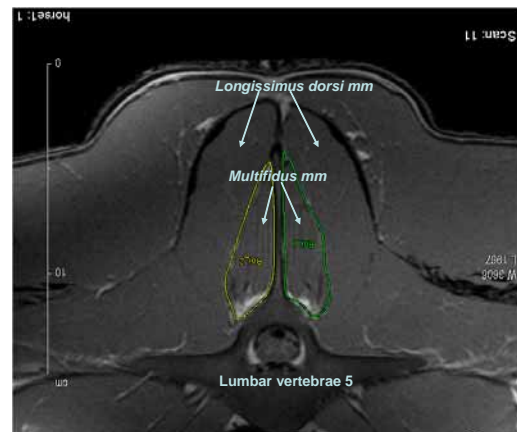

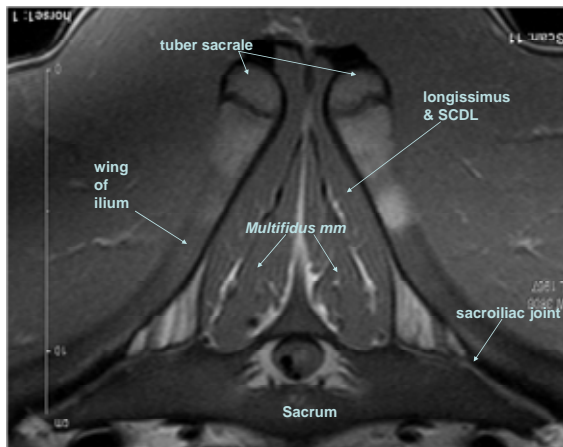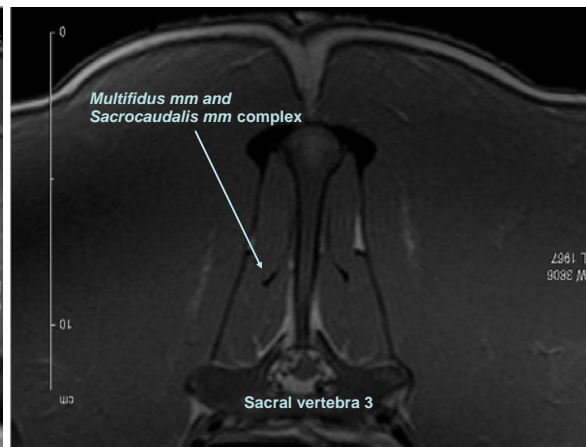Figure 1a T13

Figure 1b L5

Figure 1c S1

Figure 1d S3

Figure 1: MRI images of the equine back at T13 (1a), L5 (1b), S1 (1c) and S3 (1d). Note muscle is grey, fascia is black and adipose tissue is white. In 1b the multifidus has been traced.

Anatomical dissection

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 (Figure 2). 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 mm* 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 (Figure 2).
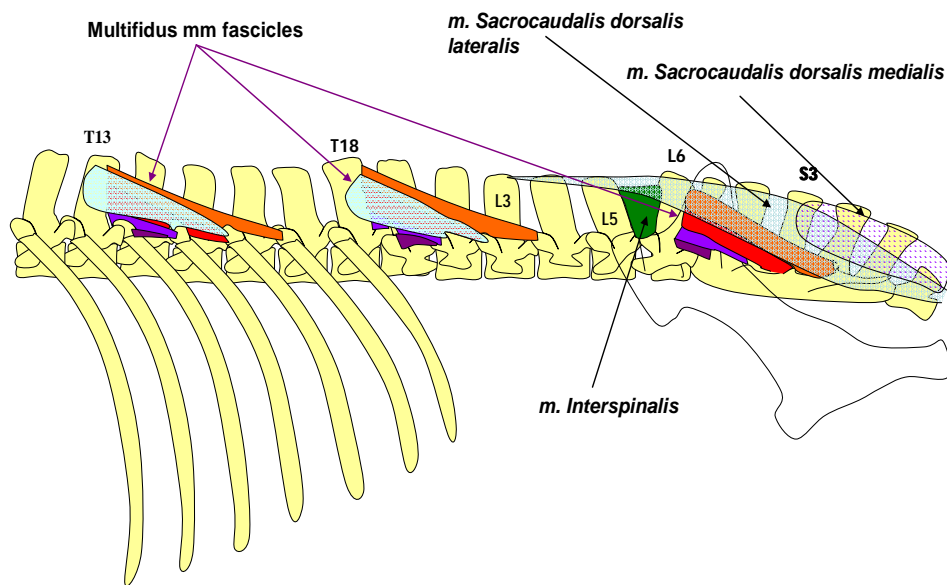
Figure 2: Anatomy of the equine epaxial muscles. The *multifidus mm* can be seen as 5 overlapping fascicles at each vertebral level (only T13, T18 and L6 are shown for clarity). The *multifidus mm* increased in size caudally, with the largest bulk of muscle evident at the lumbosacral region, where most motion occurs. In the lumbosacral region the *sacrocaudalis dorsalis lateralis m* is a caudal extension of the *multifidus mm.* The spine depicted in this figure represents 30% of the Thoroughbreds examined with the divergence of the lumbar vertebrae occurring at L5-L6, instead of the expected L6-S1. Note the presence of *interspinalis m* between the diverging vertebrae (L5 - L6).

Fascicles of *sacrocaudalis dorsalis lateralis m* appeared to have the same morphology as the *multifidus mm*, replicating and replacing the most lateral of the multifidus fascicles commencing at L4, L5, and L6 depending on LS variations. 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 *sacrocaudalis dorsalis lateralis m* also followed the same pattern as *multifidus mm* attaching to the lateral border of L5 or L6 and the lateral border and lamina of the sacrum. Fascicles of *sacrocaudalis dorsalis lateralis m* continued beyond the sacrum following similar morphology along the caudal vertebrae. *Sacrocaudalis dorsalis m* 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. On direct visual inspection the cross-sectional area of the *multifidus mm* and

sacrocaudalis dorsalis lateralis m bundles were much larger at the LS junction. This gradual increase in size continued caudally with *sacrocaudalis dorsalis medialis m* from S3 caudally.

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*, *sacrocaudalis dorsalis lateralis m* and *sacrocaudalis dorsalis medialis m* mm from the bone and the *interspinalis mm* (Figure 2).

Biomechanics
The reliability for measurement of the angle of the spinous processes was very good with an ICC [2,1] of 0.99. The standard error of the measurement (SEM) was 0.41° and the smallest detectable difference was 1.1°.

The mechanical function (moment arm and force vector) of the *multifidus mm* 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 significantly between the two groups (p<0.001) (Figure 3). Within each group there was a large degree of variability in angle but not direction (cranial or caudal) from T13-L5.

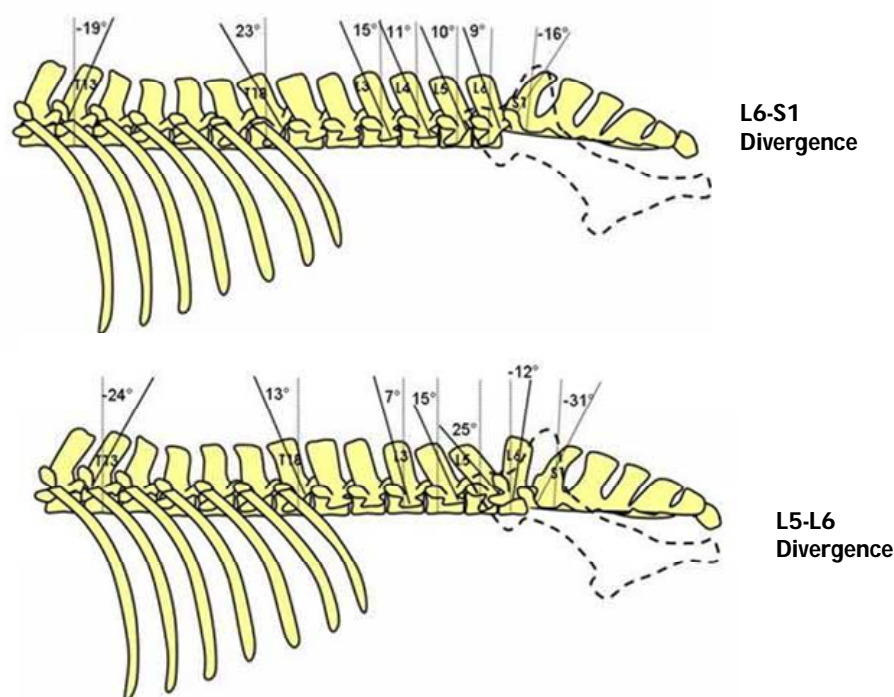Figure 3: Mean spinous process angles (°) of orientation relative to the vertebral body at vertebral level T13, T18, L3, L4, L5, L6 and S1. The examples depicted above show the "normal" anatomy present in 2/3rd of horses in the upper schematic, while the lower schematic depicts the variation of L%-L6 divergence present in 1/3rd of horses. Note the lower variation did not occur in any Standardbreds examined.

Phase II: Measurement of the equine epaxial muscles using ultrasonography

MRI multifidus mm CSA reliability

Median coefficient of variation (CV) for all 56 individual readings was 1.7%. All readings except one (at T14 in horse 1) were below 5% CV showing good intra-rater reliability of measurement of multifidus CSA using MRI. The Standard Deviations (SD) were calculated for all readings and graphed (Figure 4). The pooled SD for all readings was calculated to be 0.22 cm^2 to derive a 95% confidence interval of $\pm$ 0.43cm. There was consistency of measurement along the spine with no specific region or CSA size shown to create more measurement error than any other region. The results confirm that MRI has excellent intra-rater reliability and therefore may be used as a standard for further comparative investigation of non invasive measurement methods such as real time ultrasound imaging to measure *multifidus mm* in the normal/abnormal horse with back pain (see also Figure 1).
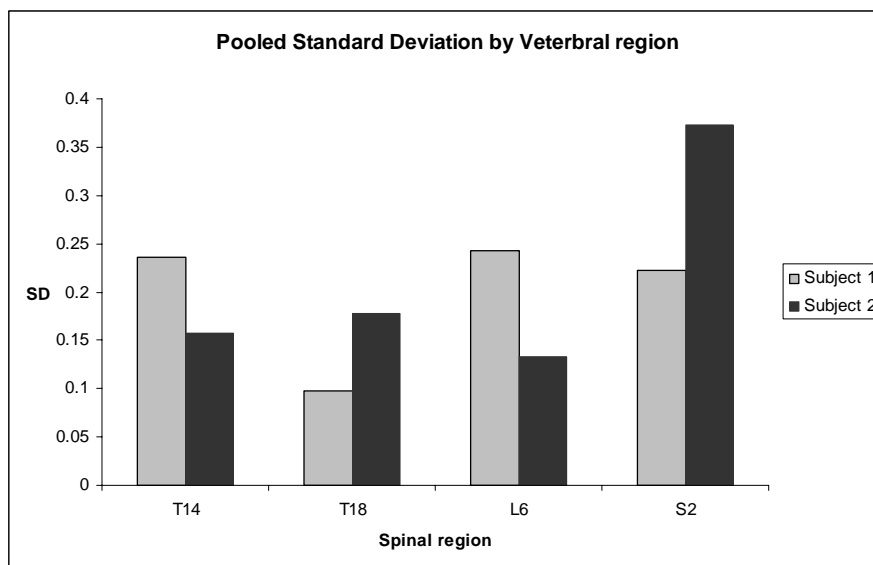
Figure 4: pooled SD for MRI CSA for 2 Standardbred horses showing a very low SD (0.22 cm^2) indicating the excellent reliability of measurement of muscle CSA using this technique.

Ultrasonographic multifidus mm CSA reliability

Ultrasonography of epaxial musculature along the vertebral column from T13 to S5 reveals striking differences in the shape and size of *multifidus mm*, with multifidus largest in the lumbosacral region (Figure 5). This fits with the biomechanical function of the lumbosacral region having the most dorsoventral motion and therefore requiring the greatest amount of stability (see Phase I). The "long view", over the intervertebral space at all levels was most repeatable other than at T13 where there was no difference. The greater variability of the facet or "short" view may be due to variability of facet size and/or shape (see Phase III). The *longissimus dorsi m*. cross sectional area was able to be measured in the lumbosacral region (L5) where it narrows down sufficiently just cranial to the tuber sacrale to enable a cross sectional area to be obtained.
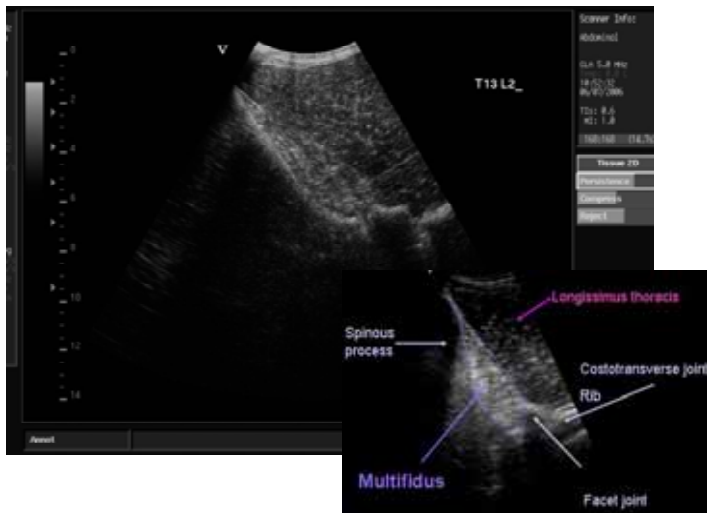
Figure 5a T13

Figure 5b T18/L1
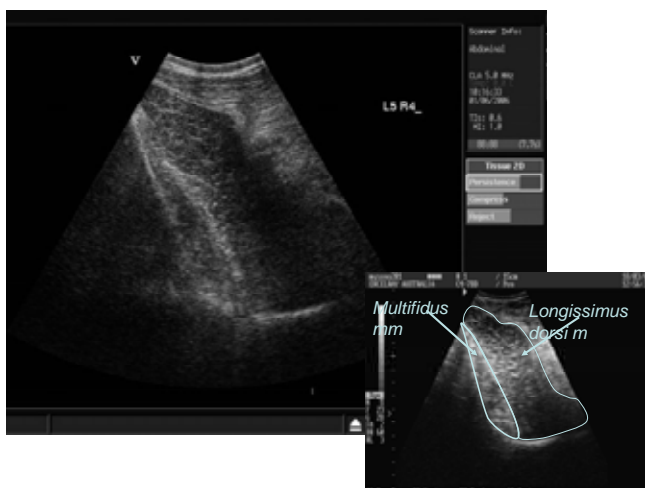
Figure 5 c L5
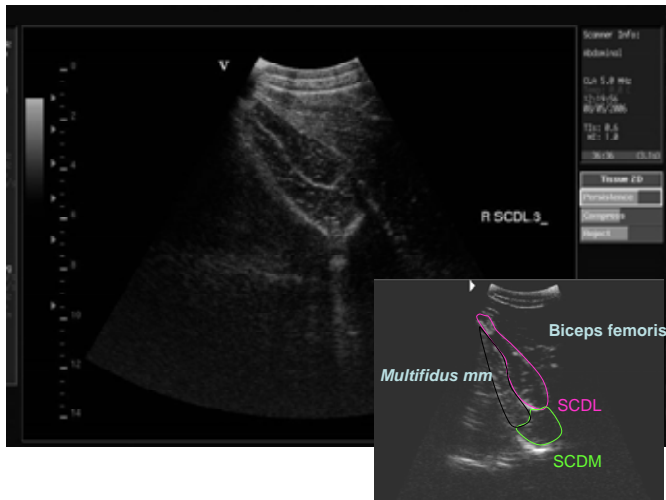
Figure 5d S3

Figure 5: *Multifidus mm* CSA using ultrasonography at levels T13 (5a), T18/L1 (5b), L5 (5c) and S3 (5d).

The reliability for measurement of the *multifidus mm* CSA was good with an ICC [2,1] of 0.83. The standard error of the measurement (SEM) was 0.78 cm with the smallest detectable difference of < 1.5cm occurring at all levels. The relative variance components of measurement of CSA were 56% inter-operator variance, 11% intra-operator and 33% image variance i.e. the variance was minimised by having just one operator and taking several images of each site. There was significant effect of horse but not of side of the image indicating that 'normal' horses have symmetrical epaxial muscles. Compared to the MRI measurement of CSA repeatability, the pooled SD was 0.4 cm^2, thus almost double, but still within what was considered acceptable limits.
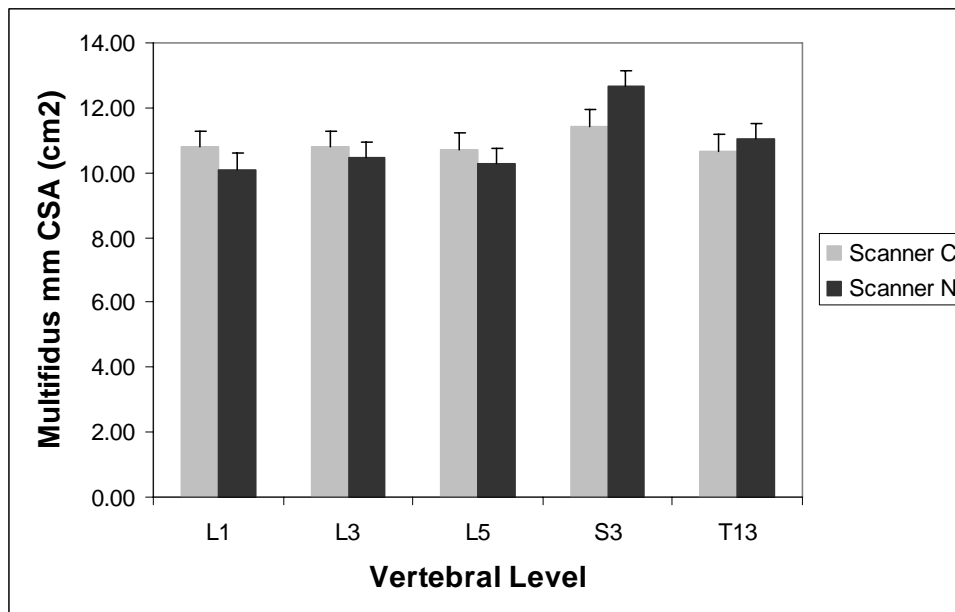
Figure 6. Difference between 2 operators (inter-operator reliability) for measurement of *multifidus mm*. CSA (cm^2) in 2 Australian Stock horses.

Effect of age, breed and conditioning on multifidus mm CSA

There was no difference between *multifidus mm* CSA in any of the 'unbroken' young horses (Australian Stock Horses and Thoroughbreds in pre-race training), mature Standardbreds and aged horses (P>0.1). However, mature Thoroughbreds in race training had significantly larger *multifidus mm*. CSA at all levels measured. However, within each group there was significant between horse variability.

Phase III: Ultrasonography in equine back pain

There were 22 Thoroughbred racehorses presented for euthanasia and available for pre- and post-mortem examination as outlined herein. The mean weight of the horses was 493.2 (±25.5) kg, mean age 6.2 (± 1.9) years and the mean height was 164.8 (±3.7) cm. All horses were euthanased due to chronic unresolved or acute severe musculoskeletal problems some also with concurrent respiratory or gastrointestinal problems (Table 1). Fifteen (68%) had a prior history of back pain that had been previously treated by veterinarians, chiropractors and/or physiotherapists. Only two horses had a history of solely hindlimb lameness all of the other horses had forelimb lameness problems or a combination of hindlimb and forelimb. Ninety one percent of horses had subjective asymmetrical biceps femoris muscle mass and 82% had subjective asymmetrical gluteal muscle mass on clinical examination (Figure 7).

Figure 7: Horse 33 showing marked asymmetry of upper hindlimb musculature with noticeable atrophy on the right side.

Of the 22 horses, 17 (77%) had evidence of severe pathology (Grade 3) in their spines that was likely to be causing significant dysfunction (Table 1). Of those horses with Grade 3 or severe lesions, all except one had notable asymmetry between the left and right *multifidus mm* at different levels of the vertebral column. The one horse that did not have asymmetry, had bilateral pathology. Of the 5 horses that did not have Grade 3 lesions on post mortem examination, two had asymmetry. However, one of these horses had multiple moderate grade lesions and evidence of prior severe lesions, and the other had a moderate grade stress fracture that may have caused the asymmetry.

Of the 15 horses with a prior history of back pain, 12 (80%) had a grade 3 lesion, while of the 7 horses without any specific history of back pain, 6 (86%) also had a grade 3 lesion. This finding highlights the possibility of under diagnosis of back pain in horses.

Table 1: Horse details, ultrasonographic findings and post mortem findings in 22 racehorses.
Legend: *CSA = cross sectional areas, DJD = degenerative joint disease, DSIL = dorsal sacroiliac ligament, DSP = dorsal spinous processes, EIPH = Exercise induced pulmonary haemorrhage, L = left, R = Right, SI = sacroiliac, SID = sacroiliac disease*

Horse	Age	Time in training at HKJC	Reason for euthanasia	History of back pain	*Multifidus mm* CSA asymmetry	Grade 3 lesion	Postmortem findings directly related to ultrasound CSA (corresponding grade 3 lesions)
1	8	4 years 4 months	L fore chronic lameness	YES	YES	YES	T17.18 bilateral facet intra-articular stress fracture evident through to the vertebral canal T18.L1 right facet very enlarged marked facet DJD L2.3 right stress fracture evident through to the vertebral canal L4.5 bilateral severe DJD and moderate intra-articular stress fractures
2	7	3 years 7 months	L fore, Lhind chronic lameness + EIPH	NO	YES	YES	T15.16 left facet lytic/cystic lesion, destroyed intra-articular and periarticular joint surfaces and margins
3	6	4 years 1 month	L & R fore chronic lameness, EIPH, back pain	YES	YES	NO	No grade 3 skeletal lesion found post mortem Note grade 2 intra-articular stress fractures
4	10	7 years	All 4 limbs chronic lameness	YES	NO	NO	No grade 3 skeletal lesion found post mortem
5	4	10 months	L fore breakdown	NO	NO	NO	T17.18 severe DSP impingement, proliferation and eburnation
6	5	3 years 7 months	L&R fore chronic lameness, back pain, hind limb cellulitis	YES	YES	YES	L4.5 extremely severe over-riding and impinged DSP marked proliferation and eburnation Bilateral severe SID and DSIL lesion
8	4	19 months	SDFT tendonitis	NO	YES	YES	L3.4 right facet moderate to severe stress fracture
10	5	2 years 5 months	Left fore medial suspensory lig rupture	NO	YES	YES	T15.16 left facet moderate DJD, severe intra-articular stress facture L2.3.4 left inter-transverse joint DJD Left severe SID
11	6	3 years 6 months	R&L fore chronic lameness	NO	YES	YES	T18.L1.L2.l3 left facet joint intra-articular stress fracture, moderate DJD L1.2 right facet joint intra-articular stress fracture, mod DJD
12	7	4 years 6 months	R&L fore chronic lameness, back pain	YES	YES	NO	At time of postmortem no grade 3 skeletal lesion found, however evidence of prior more severe lesions
13	7	4 years 11 months	R&L fore chronic lameness	NO	YES	YES	L3.4 right facet moderate DJD, severe, very deep intra-articular cleft/stress fracture
14	5	2 year 10 months	R&L fore chronic	YES	YES	YES	Right L4.5 facet joint severe DJD

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Horse	Age	Time in training at HKJC	Reason for euthanasia	History of back pain	*Multifidus mm* CSA asymmetry	Grade 3 lesion	Postmortem findings directly related to ultrasound CSA (corresponding grade 3 lesions)
			lameness				
16	7	3 year 9 months	R&L fore chronic lameness	YES	YES	YES	L1.2 and L2.3 severe intra-articular unilateral (left only) facet joint fractures Evidence of marked adaptive periarticular changes laminae, pedicle and spinal canal with moderate bone proliferation osteophytes on the articular pillar
17	7	4 years 5 months	Multilimb chronic lameness, old pelvic stress fracture	YES	YES	YES	L5S1 (L6 transitional vertebrae) chronic fracture affecting the right facet joint, laminae and neural arch
18	5	19 months	R&L fore chronic lameness	YES	YES	YES	L5.L6 DSP severe over-riding with marked proliferation and eburnation L5.6 incomplete ankylosis of entire left lumbosacral joint complex including the inter-transverse joint and transverse process, right smooth complete ankylosis
20	5	21 months	ILH, R fore chronic lameness	YES	NO	YES	T17.18 right facet joint sever DJD T18.L1 Bilateral facet joints severe DJD uneven joint surfaces, erosions, periarticular osteophytes, buttressing, generally very enlarged L1.L2 facet joint stress fracture, very large cleft L4.5 incomplete bilateral ventral ankylosis of the inter-transverse joints, with signs of active remodeling and marked proliferation
22	6	3 years 9 months	L fore chronic lameness	NO	YES	YES	L1.2 right moderate -severe osteophytes on the articular pillar L2.3 L3.4 left very large facet intra-articular cleft and fracture
24	3	9 months	Fractured R tubercoxae, R fore chronic lameness	YES	YES	YES	Fractured right tubercoxae (pelvis) and L3.L3. Transverse processes one month prior to euthanasia, on postmortem the fracture had calcified sufficiently for union L5.6 facets and inter-transverse joints bilateral marked DJD and clefts/stress fractures T16.17.18 and L4.5 Severe over-riding DSP with marked bone degeneration, proliferation and eburnation. Severe overlapping, convexity of L4 on the left A significant CSA asymmetry caudal toT18 correlates with pelvic fracture
27	7	7 months 3 years in riding school post racing career	R&L fore chronic lameness Gastric ulceration Back pain	YES	YES	YES	T18.L1 left facet severe intra-articular clefts, stress fractures L3.4 left facet severe intra-articular clefts, stress fractures
29	4	2 years	Poor performance R hind chronic lameness	YES	NO	NO	
30		2 years 8months	R&L fore chronic lameness Gastric Ulcers	YES	YES	YES	T11-T17 Very severe DSP impingement/over-riding severe proliferation and eburnation L5.6 left severe stress fracture however minimal bone proliferation
33	3	2 years 10 months	Unresolved right hind lameness for 7months	YES	YES	YES	L4.5.6 left facet incomplete fracture Right ilium and SI joint complete "old" ankylosed fracture , right SI joint surfaces and ligaments completely destroyed, now partially ankylosed L4 and L5 right transverse processes old fracture evident, now ankylosed

Discussion of Results

This study has achieved its aims by increasing the knowledge of back pain in horses, and highlighting how pathology of the back itself or other parts of the musculoskeletal system is reflected in the epaxial muscles. The main objective was to achieve these outcomes using ultrasonography, a non-invasive and readily available tool for use in equine practice. Ultrasonographic measurement of the epaxial muscles proved to be a reliable tool and in horses with back pain showed clearly asymmetry of the epaxial muscles close to regions of severe pathology.

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

The first phase of the research was required due to the apparent contradictions in descriptions of the details of the anatomy of the equine epaxial muscles and the need for detailed anatomical knowledge prior to ultrasonography of a particular region. This study increased the understanding of the equine back and is, the authors' believe, the first comprehensive study of the anatomy of the deep epaxial muscles in the equine spine. Further, the study highlighted the high prevalence of anatomical variations in the lower back/lumbosacral vertebral formula, especially in Thoroughbred horses. The variations were dramatic and could potentially have effects on performance. The overall variability in the current study (~ 40% of Thoroughbreds) was comparable to a study in a much smaller number of Thoroughbreds (Haussler et al., 1997) where 39% had L5-S1 variation. The other breeds, except Standardbreds, also had a high prevalence of lumbosacral variation. However, the other breeds with variation were all unbranded horses assessed to be predominantly Thoroughbred and Australian Stockhorse types. As stated, in contrast, Standardbreds had 100% conventional vertebral formula indicating a breed difference in expected lumbosacral vertebral formula. Whether the variations confer an advantage or disadvantage in predisposition to back pathology is unknown, but many of the variations did reduce maximal dorsoventral motion at the lumbosacral joint, and reduction in flexion at least could reduce the ability of a horse to 'collect' its gait during exercise.

The *multifidus mm* in the horse is comparable to that in humans comprising a series of overlapping fascicles grouped into bands from each vertebrae running cranio-caudally in their attachments (Bogduk and Twomey, 1987) and having a significant role in segmental stabilisation, proprioception and postural control of the spine. *Multifidus mm* comprised a series of musculotendinous units as described by Haussler (1999b) although the fascicles are not all short as described (Haussler 1999b) but variable in length as they span between 1-4 adjacent vertebral segments. Fascicles originate from the spinous processes and vertebral lamina and insert onto the articular and mamillary processes rather than the opposite (Nickel et al., 1986; Haussler 1999b), with no attachment onto the transverse process as stated by Haussler (1999).

There are some major differences between the horse and man in the lumbosacral region. *Sacrocaudalis dorsalis mm* with its attachment to the tail (or coccyx) is not present in humans.
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). Thus, the requirement for muscular control of the equine lumbar spine is limited over much of its length. However, as most motion is localized at the level of divergence of the spinous processes (lumbosacral region) the requirement for control at this level is high. This is supported by the increased bulk of muscle in the region. The presence of a bursa associated with the long tendinous cranial attachments of *Sacrocaudalis dorsalis lateralis mm* in the majority of horses may also be interpreted to suggest that considerable motion and forces are imparted on the spinous processes. This bursa has not previously been described, and may be an important structure to palpate in a clinical examination of the back.

The *sacrocaudalis dorsalis mm* 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. The morphology of *sacrocaudalis dorsalis mm* mirrors that of the other multifidus fascicles, although the *sacrocaudalis dorsalis mm* fascicles are larger and longer, extending to the

caudal vertebrae. *Sacrocaudalis dorsalis lateralis mm* was an extension of the *multifidus mm* (Getty, 1975), originating from L4-6. Nickel et al. (1986) and Evans (1993) contradict this by describing SCD medialis as an extension of *multifidus mm*, which may also be correct although SCD medialis originates from S3. Nickel (1986) reported that *sacrocaudalis dorsalis lateralis mm* was an extension of *m. longissimus* although the present study refutes this. *Sacrocaudalis dorsalis mm* being extensions and having the same role as *multifidus mm* may prove useful clinically in that these muscles are superficial as they run along the tail head/caudal vertebrae and atrophy associated with back or pelvic pathology in this region can be detected via visual examination.

The present data demonstrate biomechanical similarities between the horse and results of studies on humans (Macintosh and Bogduk, 1986b). Therefore as with the human it may be hypothesised that in the horse the *multifidus* and *sacrocaudalis dorsalis mm* 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).

Measurement of the equine epaxial muscles using ultrasonography

A major objective of the project was to objectively measure the equine epaxial muscles. This was achieved and repeatability was good in normal horses. The variation in CSA measurements from ultrasonographic images was greater than that from the "gold standard" MRI images, but still low and within acceptable limits. When all sources of variation for an ultrasonography CSA measurement were examined, it was clear that the variability in measurement could be reduced by having the same operator doing the CSA measurements, instead of two people, and by taking several (3) images of the same location and with the measurement taken as an average of 3 measurements from the 3 images (i.e. 9 measurements per site). This was the protocol that was followed for all studies after results from this initial study were obtained. Because 3 images were taken from each side, the number of locations within the thoracolumbar spine from T13 caudally (some 15 levels each with an intervertebral and facet view) was reduced to 4 key locations in an attempt to streamline the protocol and reduce the time taken for each examination. These locations were chosen based on a combination of these being known to be sites of greatest movement in the equine spine, the sites being readily imaged, and the repeatability of the measurements in the initial study. These were T13, T18/L1, L5 (L6 was unable to be images due the wing of the ilium obscuring the view) and S3 (Figure 5).

In young horses there was little difference between athletic breeds in overall size of the *multifidus mm* at the different measurement sites when averaged. There were considerable variations between individuals within a breed or age group, but consistently no difference between left and right measurements in the same horse. In the conditioned horses there was an increase in *multifidus mm* size, while in aged horses the size of *multifidus mm* had again decreased.

Despite ultrasonography being increasingly used as a clinical diagnostic tool in equine practice, repeatability has only been determined in horses in the heart (Kris and Rose, 2002) and superficial digital flexor tendon (Pickersgill et al., 2001). It is vital to know that tools used for diagnostic purposes are reliably measuring what they are supposed to. Thus, the data presented here indicates that ultrasound provided excellent repeatability and reliability for measurement of the equine *multifidus mm*. As such we predict ultrasonography will become a valuable diagnostic tool in the investigation of equine back pain.

Ultrasonography in equine back pain

The project was greatly enhanced by the collaboration of the Hong Kong Jockey Club and the results improving knowledge of equine back pain, its underlying pathology, and assisting in the development of ultrasonography as a diagnostic tool in equine back pain. The major finding of this part of the study was that horses with severe pathology consistently had significant left to right asymmetry of their *multifidus mm* at levels at or close to the pathology in question. This asymmetry was not present in the young horses in the repeatability studies performed previously, and leads us to the conclusion that

asymmetry detected on ultrasonography may be an important diagnostic indicator of back pain/pathology in horses.

The project was originally planned to study ultrasonography in clinical cases and to attempt to use current diagnostic techniques in an attempt to determine the pathology present. This included algometry and EMG. However, as discussed in the introduction, diagnosis of back pain is very difficult and often relies on a process of elimination. We were fortunate in this study to have the opportunity to examine a variety of horses post mortem and document in detail the full range of pathology present.

The prevalence of a prior history of back pain in these horses was high considering their age (mean age six years) and previous prevalence estimates of this sign, but certainly not compared to that reported from specialist back or chiropractic practice (Haussler, 1999a). The prevalence of significant back pathology (lesions graded as severe or Grade 3) was also high (almost 80%). Those horses that did not have severe or Grade 3 pathology, all had some degree of mild to moderate changes. While these horses were from a racing population, they were horses that had reached the end of their racing careers, principally due to musculoskeletal problems so the prevalence was undoubtedly higher than a well performing racing population. However, the findings of this study highlight that pathological problems of the back and back pain are very likely to be prevalent in all types of athletic horses and justifies development of non-invasive tools for diagnosis.

Of considerable interest to the authors is the finding that of the seven horses without a history of back pain, six of these also had severe pathology or at least one Grade 3 lesion in their backs. This, and the overall high prevalence of significant back pathology again supports the under diagnosis of significant back pathology in athletic horses. Previous studies have documented a high prevalence of pathological lesions in Thoroughbred horses (Haussler et al., 1998, 1999c) but it has not been known exactly which lesions are pain producing or performance limiting and which lesions are incidental or benign. In this study, the combination of severe pathology and *mutifidus mm* atrophy or asymmetry gives a strong indication of the significance of the pathology found.

In this study the most common lesions that were associated with both severe changes and *multifidus mm* asymmetry were stress fractures of the facet joints and/or associated degenerative joint disease. Pelvic fractures, sacroiliac dysfunction and lumbosacral degenerative joint disease were less common. Few horses had overriding dorsal spinous processes, with only one (Horse 5, Table 1) having this as the only finding and this horse had no asymmetry of its *multifidus mm* or history of back pain. Facet joint pathology was able to be imaged in many cases using the same technique as for the CSA of *multifidus mm* and represents an area where pathology may be directly imaged in affected horses. This is consistent with recent practice trends that are demonstrating the value of ultrasonography of the musculoskeletal system (Denoix, 1999) and supports greater use of ultrasonography in equine practice.

One problem with our technique which became rapidly apparent was that the four regions examined initially proved insufficient to detect asymmetry when it occurred. This is because the asymmetry in many cases, particularly more chronic cases appeared to be localised to the level of the pathology and not extending throughout the spine. In man, spinal disease and dysfunction are also accompanied by changes in the *multifidus mm* such as atrophy (Hides et al., 1994, 1996, 2001), but this is predominantly seen in acute lower back pain, with atrophy less evident with chronicity. The fact that asymmetry was evident in chronic cases demonstrated that the pathology was still active or progressing. This is consistent with the grading system used as it was these active bony changes that were used in the pathological grading system to place a lesion in the severe or Grade 3 category and supports the contention that lesions in this category are likely to produce pain or dysfunction in affected animals. In humans chronic back pain sufferers have altered muscle on biopsy with fat infiltration and loss of muscle fibres (Rantanen et al., 1993) so further work to identify fat with newer ultrasound machines and better technology may help provide even more information in the future.

In conclusion, use of a novel approach to equine back pain, using the human neuromotor control model, has advanced knowledge of the equine back, its anatomy, function and the epaxial muscle

response to pathology. Ultrasonography of the epaxial muscles is a valuable non-invasive tool that will help detect back pain and associated pathology in horses. This information will be valuable to veterinarians and physiotherapists managing back pain and poor performance syndromes in athletic horses and will lead onto future work on the effect of physiotherapeutic intervention on the recovery of epaxial muscle function following back pain.

Implications

The implications of this research are that we have developed a reliable, non-invasive tool for assessing back pain and associated muscular dysfunction in horses. Further, that we have found a clear correlation between pathological findings and objective measurements of epaxial muscle CSA using ultrasonography in horses with back pathology and/or a history of back pain. Severe pathological findings were both common and resulted in a measurable asymmetry in the CSA of *multifidus mm* from side to side at or close to the level of pathology. While this technique is not simple, and requires a lengthy examination, repeated images and detailed measurements following the examination, it will be a very useful tool for veterinary and physiotherapy clinicians in diagnosis of back problems in horses.

Recommendations

This project has validated a tool to aid in the diagnosis of back pain in horses and further research is warranted to demonstrate its use clinically in normal horses and in monitoring the response to therapy for back pain in horses. The results of this project indicate that back problems are highly prevalent in athletic populations and increased attention to the diagnosis and treatment of back problems is warranted. The results of this study will benefit clinical veterinarians and physiotherapists who are treating back pain in horses, but ultimately will also benefit horse owners and trainers who benefit from increased education and availability of techniques for their horses' clinicians. Further refinement of the technique in future studies will assist in its wider adoption amongst clinicians, in both the diagnosis and monitoring of treatment of back problems in athletic horses. Future studies using the neuromotor control/physiotherapeutic model are warranted, with a focus now on treatment of back problems in horses.

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Appendices

List of presentations

Royal Veterinary College Veterinary Physiotherapy Conference 2004. Equine Back Pain research update from the University of Queensland. Presented by Dr Catherine McGowan based on literature review and early finding of MRI, ultrasonographic and dissection data.

Australian Veterinary Association May 2005. Ultrasonography and back pain, back pain evaluation using the human physiotherapy model. Two lecture presentations by Dr Catherine McGowan and Ms Narelle Stubbs.

Manual Physiotherapy national congress November 2005. Epaxial Musculature and it Relationship with Back Pain in Horses. Poster presentation by Ms Narelle Stubbs.

Australian Animal Physiotherapy Group National conference December 2005; equine Back pain research update. Presented by Ms Narelle Stubbs.

ICEEP accepted oral presentation and Invited submission for Equine Veterinary Journal Supplement (International conference on equine exercise physiology 7) August 2006. Presented by Ms Narelle Stubbs.

The Australian College of Veterinary Scientists Science Week 2006. Epaxial Musculature and its Relationship with Back Pain in Horses. Presented by Dr Catherine McGowan.

Publications:

Stubbs, N.C., Hodges, P.W., Jeffcott, L.B., Cowin, G., Hodgson D.R. and McGowan C.M. (2006). Functional anatomy of the caudal thoracolumbar and lumbosacral spine in the horse. *Equine Vet. J. Suppl.* 36: 393-399.

McGowan, C.M., Stubbs, N.C. and Jull G. (2007). Review: Equine physiotherapy: a comparative view of the science underlying the profession. *Equine Vet J.* 39(1): 90-4.