Studies of the Movement of the Equine Pelvis

— Sacroiliac kinematics —

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— Sacroiliac kinematics

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Foreword

Equine sacroiliac joint injury/dysfunction (SID) is a common reason for wastage in the racing and performance horse industries causing poor performance, abnormalities of hind limb gait and lameness (Jeffcott and Dalin 1985). However, diagnosis of dysfunction of the equine sacroiliac region has been difficult. In humans, kinematic data has been used to determine normal and abnormal sacroiliac movement, particularly in response to manual manipulation by physiotherapists and such diagnostic testing has been validated as sensitive and specific for the diagnosis of SID (Lee & Vleeming, 2000; Laslett et al 2004).

Even though kinematic research has been used to advance SID diagnosis for people, there is little data available regarding equine sacroiliac joint (SIJ) kinematics. The project’s first aim was to examine sacroiliac kinematics in horses, in particular the relative movement between the pelvis and vertebral column. Second, clinical cases of SID were examined with the aim to investigate manual manipulation techniques extrapolated from humans to horses to determine whether such techniques could aid in the diagnosis of sacroiliac dysfunction in horses as they do in humans. Third, the information gained from the kinematic research and investigation of normal and clinically affected horses was used to increase knowledge of sacroiliac dysfunction, in particular to characterise features of the disease that would improve approaches to treatment.

The results of this study have shown that the equine pelvis, like the human one, is able to move in several planes relative to the vertebral column during both gait and during manual manipulation of the pelvis. Further, the movement changed between gaits, decreasing overall in the trot as has been the case in the vertebral column, indicating the involvement of the hind limb and back musculature surrounding the SIJ in stabilising and controlling its movement. These movements of the equine pelvis relative to the vertebral column occurred during gait, but were also able to be elicited by a physiotherapist performing manual testing of the pelvis using their hands, using techniques extrapolated from human SIJ testing.

Use of a kinematic approach to SID, borrowing from the human kinematic model, has advanced the knowledge of the equine SIJ, its function and the role of the pelvic musculature in both health and disease. Ultrasonography of the Dorsal sacroiliac ligament (DSIL) is a valuable non-invasive tool that will help detect SID in horses. This information will be valuable to veterinarians and physiotherapists managing SID and poor performance syndromes in athletic horses and will lead onto future work on the effect of physiotherapeutic intervention on the treatment of SID.

This project was funded from industry revenue which is matched by funds provided by the Australian Government.

This report is an addition to RIRDC’s diverse range of over 2000 research publications and it forms part of our Horse R&D program, which aims to assist in developing the Australian horse industry and enhancing its export potential.

Most of RIRDC’s publications are available for viewing, free downloading or purchasing online at www.rirdc.gov.au. Purchases can also be made by phoning 1300 634 313.

**Craig Burns**
Acting Managing Director
Rural Industries Research and Development Corporation
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Abbreviations

CSA  Cross sectional area
CV   coefficient of variation
DJD  degenerative joint disease
DSIL Dorsal sacroiliac ligament
DSP  dorsal spinous process(es)
L    Lumbar (vertebrae)
LS   Lumbosacral
m    muscle
mm   muscles
S    sacral (vertebrae)
SD   standard deviation
SID  sacroiliac dysfunction
SIJ  sacroiliac joint
T    Thoracic (vertebrae)
TB   Thoroughbred
TC   tuber(a) coxae
TL   Thoracolumbar
TS   tuber(a) sacrale
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Executive Summary

What the report is about

This report is about research undertaken in order to learn more about the motion surrounding the sacroiliac joint (SIJ) in horses and whether manipulation of the joint manually and detection of motion differences in clinically affected horses compared to unaffected horses would enable development of a clinical test for sacroiliac joint dysfunction (SID).

Who is the report targeted at?

This research is principally targeted at veterinarians and physiotherapists managing the performance of equine athletes, but this report is also suitable for all horse owners who want to know more about this prevalent and debilitating condition in their horses.

Background

Equine SID is a common reason for wastage in the racing and performance horse industries causing poor performance, abnormalities of hind limb gait and lameness (Jeffcott and Dalin 1985). However, diagnosis of dysfunction of the equine sacroiliac region has been difficult. There is variation in the presentation of SID between horses and difficulty in examining and imaging the area due to the size of the horse and its musculature and the deep location of the SIJ.

Despite the smaller size of humans compared to horses, many of the same issues regarding imaging of the sacroiliac region and accurate diagnosis exist. However, kinematic data from in vivo human SIJ research has been essential to enhancing diagnosis of SID in people, and the knowledge has shaped current diagnosis and treatment strategies for human SID (Hungerford, 2000; Sturesson et al, 1989). In humans, this kinematic data, as well as studies involving manual testing, has been used to determine normal and abnormal sacroiliac movement, such that manual manipulation tests are clinically useful. Manual pain provocations tests have been validated as being sensitive and specific for the diagnosis of SID (Lee & Vleeming, 2000; Laslett et al 2004).

Despite these advances for people, there is little data available regarding equine SIJ kinematics. Therefore, our first aim was to examine sacroiliac kinematics in horses, in particular the relative movement between the pelvis and vertebral column (sacroiliac movement). Secondly, we aimed to investigate manual manipulation techniques extrapolated from humans to horses to determine whether such techniques could aid in the diagnosis of SID in horses as they do in humans. Thirdly, we aimed to use the information gained from the kinematic research and investigation of normal and clinically affected horses to increase our knowledge of SID, in particular to characterise features of the disease that would improve our approach to treatment.

Objectives

In order to address the above aims over the two years of the project we had two main objectives:

- Investigation of sacroiliac kinematics: measurement of sacroiliac motion
  - Quantification of sacroiliac motion in vitro and correlation to the forces applied.
  - Quantification of sacroiliac motion in vivo
- Investigation of clinical disease
− Correlate clinical signs, diagnostic ultrasonography and sacroiliac kinematics in horses during manual physiotherapy manipulations affected by sacroiliac disease.

− To investigate the morphology of SIJ during naturally occurring disease in a group of Thoroughbred (TB) racehorses and compare with unridden Brumbies.

Our third objective was to put all of this information together:

• Implications for diagnosis and management of SID

This research is of benefit to veterinarians and physiotherapists working with athletic horses:

• To utilise the knowledge of sacroiliac joint motion, to improve diagnosis of sacroiliac joint dysfunction in horses

• To ultimately reduce wastage and poor performance in the equine industry due to sacroiliac joint dysfunction.

**Methods used**

Kinematic data investigating the direction and degrees of motion between the ilium and the sacrum was collected via wireless 3D orientation sensors mounted to the ilium and the sacrum. This data was collected in 2 stages:

1. **Investigating sacroiliac kinematics in normal horses**

Firstly in vitro studies involved dissecting cadaveric specimens and mounting the pelvis on a sacral stabilising device. The ilium was then moved manually using techniques that reflect clinical pelvic motion testing by physiotherapists, and forces measured using a hand pressure recording material.

Secondly the motion was investigated in clinically sound Thoroughbred horses (in vivo) both during gait (walk and trot) and during similar manual manipulations.

During the second part of the study the validity of using skin fixated sensors was tested by comparing the motion from such fixed sensors to sensors attached to pins embedded in the bony prominences of the pelvis and vertebral column.

2. **Investigating clinical disease**

The second study involved measurement of the motion between the ilium and sacrum using skin fixated 3D motion sensors during manual manipulation only in both clinically affected and unaffected Thoroughbred horses. This was due to the results from the first stage where it was found skin markers to be poorly correlated to bone fixated markers during gait, but that they were not-sufficiently different during manual manipulations. Data from clinical examinations and ultrasonography of the dorsal sacroiliac ligaments (DSIL) were also obtained. A second part of this study was added where pelvises from Thoroughbred racehorses that had been euthanized at the end of their careers were examined to investigate the types and degree of change within the SIJ to allow us to correlate this back to the motion sensor findings in affected horses and give some indication of the occurrence of disease in this population.

**Results/key findings**

The results of this study have shown that the equine SIJ, like the human one, has small yet complex movements at the joint surface. The greatest movement during manual tests applied by a physiotherapist to the pelvis in vivo, was in the sagittal plane (pitch). During gait, the greatest
movement was in the axial plane (roll). Further, the degree of movement changed between gaits, decreasing overall in the trot. This indicates the involvement of the hind limb musculature, which surrounds the SIJ, in stabilising and controlling its movement, similar to the epaxial musculature in stabilising the vertebral column – the SIJ is not just a passive structure hanging by its ligaments. **Despite it being a very strong and well supported joint, the SIJ does have movement and therefore may be susceptible to altered movement patterns, and injury.**

However, when we compared the manual movements of the pelvis between horses with SID and normal Thoroughbreds, differences between the degree of movement in most planes were not detected. To examine this further we performed detailed morphological studies on the pelvic bones of ex-racehorses euthanized at the ends of their careers. These studies revealed a very high prevalence of SIJ changes with varying degrees of bony extension, enlargement and bony reaction in the joint. These changes may be a response to altered forces being transmitted through the joint; they may limit movement, by partly stabilising the joint and reducing the amount of movement, or they may be a response to increased mobility at the joint. This may explain why in a mixed group of SID horses with disease of varying chronicity, changes in motion were too variable to be significant.

In horses with SID there were a number of other clinical findings. There was variable bony asymmetry and variable muscle atrophy patterns. Consistent features included difficulty stabilising on the hind-limb of affected side and an ultrasonographically detectable difference between the left and right DSIL indicating asymmetry between the pelvis and sacrum.

This information has improved our understanding of the equine SIJ and its control. We know that while movements in the SIJ are small, it is not an immobile structure and that it is controlled by the large musculature of the hind limb, pelvis and vertebral column, surrounding it, as in humans. Injury to the SIJ (and secondary periarticular muscle pain and dysfunction) or the surrounding musculature could result in SID through a loss of the control the musculature has over the joint and initiate the pathological processes evident in the ex-racehorses. Evidence of such altered neuromotor control in clinical cases may be detectable as asymmetry detected in the ligament between the vertebral column and pelvis – the DSIL. While we were not able to support the use of manual motion testing to diagnose SID in horses, we can advise imaging of the DSIL as a useful adjunct diagnostic aid together with clinical findings.

In conclusion, use of a kinematic approach to sacroiliac dysfunction pain, borrowing from the human neuromotor control model, has advanced the knowledge of the equine SIJ and its kinematics. Bony morphological changes within the SIJ provide insight into the underlying pathological processes and changes to sacroiliac motion during SID. Ultrasonography of the dorsal sacroiliac ligament is a valuable non-invasive tool that will help detect SID in horses. This information will be valuable to veterinarians and physiotherapists managing SID and poor performance syndromes in athletic horses and will lead onto future work on the effect of physiotherapeutic intervention on the treatment of SID.

**Implications for relevant stakeholders**

The Thoroughbred racing industry should take particular note from this research the high prevalence of major disease of the SIJ in an ex-racehorse population and ensure that information about this disease is not ignored. The message to horse owners and trainers is that this is a very real and highly prevalent condition and horses with unexplained poor performance or hind limb gait abnormalities should be investigated by a veterinarian-physiotherapist team.
**Recommendations**

Diagnostic and treatment recommendations are targeted at veterinarians and physiotherapists working with athletic horses. We recommend diagnostic protocols for SID should include the following:

- description of gait
- elimination of other causes of hind limb lameness
- pain response on palpation of middle gluteal and DSIL
- measureable bony asymmetry of tubera sacrale, and tuber coxae +/- tuber ischii
- inability to weight-bear well on the affected hind limb with lateral weight transfer – increased lateral sway of pelvis
- Ultrasonographically detectable asymmetry of DSIL
Introduction

Equine sacroiliac joint disease (SID) is associated with poor performance and hind limb lameness, and is an important cause of wastage in the performance horse industry (Jeffcott and Dalin, 1985). There has been a paucity of knowledge regarding diagnosis and treatment of equine SID as clinical signs are often not severe and differential diagnosis is difficult especially in chronic SID (Jeffcott et al., 1985; Jeffcott, 1980). Intra-articular analgesia of the SIJ in the horse is difficult to carry out due to the inaccessible location, narrow joint space, and presence of neurovascular structures at the caudal aspect of the joint (Engeli et al., 2004a). There are a number of imaging techniques available, but they have some limitations (Davenport-Goodall and Ross, 2004; Jeffcott, 1983). In a sample of 36 Thoroughbred racehorses, degenerative changes at the (SIJ) were observed in 100% of the subjects, post mortem (Haussler et al., 1999). Yet in a survey of wastage in the Thoroughbred racing industry, SID was not listed amongst the injuries and conditions to be ranked in frequency, which may have been due to the difficulty in definitive diagnosis of the condition. Back problems in general, however, were in the top quartile of trainer-ranked conditions regarding wastage (Bailey et al., 1997).

Long term follow up suggests that currently prognosis for SID in horses is poor with respect to return to previous level of performance. Acute SID may respond to rest and medication, but chronic SID requires appropriate management to restore joint and muscle function around the back and hindquarters (Jeffcott et al., 1985). However, recommendation for management of SID has been non-specific and there is a clear need for more specific manual intervention and muscle re-training to ultimately improve performance. To be specific with the direction of such a program, an understanding of the biomechanics and neuromotor control of the equine SIJ region needs to approach that of human. Very few studies have been carried out regarding specific treatment recommendations for SID, and most treatment for SID has been extrapolated from management of similar conditions affecting other areas of the musculoskeletal system in the horse (Haussler, 2004).

Sacroiliac dysfunction in horses

Clinical Signs

In performance horses in work, the main clinical findings are often just pain and reduced performance (Dyson and Murray 2003). More debilitating cases of SID, possibly associated with chronic pathological joint changes, result in poor performance and more marked gait changes, with asymmetry of associated muscles and/or bone (Jeffcott 1980; Jeffcott et al 1985).

Diagnosis

Despite the fact there is some evidence for usefulness of nuclear scintigraphy in SID diagnosis, the imaging technique is still required to be combined with relevant clinical signs (Dyson et al., 2004). This is because it is non-specific for the type of injury, be it bony or soft tissue based (Tucker et al., 1998). Ultrasound may be used in conjunction with other diagnostic procedures, as it is a useful imaging modality, and provides images of a variety of musculoskeletal features of the sacroiliac region (Engeli et al, 2004b). However, it requires to be interpreted in light of further physical examination of the region (Engeli et al, 2004b). Local analgesia does not allow discrimination between pain arising from periarticular joint structures, surrounding muscles and fascia, or neurovascular structures. This is due to diffusion of injected material around structures adjacent to the SIJ, it remains unclear as to the structures affected by the analgesia (Engeli et al, 2004a).
Sacroiliac dysfunction in humans

In humans, it has been shown that manual SIJ provocation tests are as predictive for SIJ being the source of pain as intra-articular analgesia (van der Wurff, et al., 2006). The use of battery of non-invasive manual tests developed to test for SIJ dysfunction in humans, can be enhanced by an understanding of the fundamental kinematics of the joint. These tests ascertain whether there is increased or decreased motion at the joint, or altered quality of joint motion compared to normal, and also include pain provocation tests (Laslett et al 2004; Lee & Vleeming, 2000). This has greatly improved the ability to differentially diagnose SIJ pain from other back pain syndromes and has improved the prognosis for those suffering from SID. We are proposing that a similar battery of tests can be developed for the horse.

The equine SIJ is similar in morphology to that of the human, although the latter joint is somewhat smaller in length and surface area (Miller et al 1987) and orientation within the pelvis differs between the species. As mentioned above, kinematic data from human SIJ research has been paramount in both establishing a diagnosis of SID, and shaping strategies for diagnosis and treatment of SID in the human athlete. As is currently the case in the equine species, little was known about amount of motion available at the human SIJ. Physiotherapists play a key role in assessment and management of SID as they are experts in movement analysis and are equipped with highly developed palpation skills – it has been shown that physiotherapists are able to detect, specific movements and responses around the SIJ (Hungerford et al, 2007).

Principles of kinematics and neuromotor control of the sacroiliac joint

Kinematic analysis is considered to be one of the most promising methods in modern equine research (Leach, 1987). Studies of kinematics of the vertebral column of the horse have improved our fundamental knowledge of segmental motion of the horse’s back (Audigie et al, 1999; Licka et al, 2001; Faber et al, 2000; 2001; Gomez-Alvarez 2006, 2007). However, in horses there is little data available regarding SIJ kinematics due to the inaccessibility of the joint in this species. However, preliminary kinematic studies undertaken in vitro by Degueurce et al (2004) demonstrate that small rotational movements of the equine sacrum in relation to the ilium can occur in a sagittal plane. Our own pilot kinematic research has detected relative motion between the ilium and sacrum in three orthogonal planes in vitro, with the largest movements being in the lateral plane. In vivo, we used ultrasonography to measure the change in cross sectional area (CSA) of the dorsal sacroiliac ligament with the change in CSA denoting lengthening of the structure and relative motion between the ilium and sacrum.

Results of studies performed on other quadrupeds suggest that the SIJ may have a regulatory function in locomotion and posture (Indahl et al., 1999; Murata et al., 2001). The presence of both nerve fibres and mechanoreceptors in the sacroiliac ligaments indicates that both proprioceptive and nociceptive

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1 For further information and a review on the SIJ and biomechanics of the equine SIJ by the authors please see: Goff et al. Biomechanics of the equine SIJ and relationship to sacroiliac dysfunction. The Veterinary Journal 2008 Jun;176(3):281-93.

information is received from the SIJ (Sakamoto et al., 2001; Vilensky et al., 2002). There have been no published reports on the innervation of the SIJ in the horse, so we may only extrapolate from studies in other species.

A further understanding of SIJ kinematics in horses will assist physiotherapists and veterinarians managing equine sporting injuries with an array of non-invasive, cost-effective tests similar to those used in human physiotherapy, to assess and diagnose SIJ disease.

The proposed research will be significant as information obtained from this program of research will expand on preliminary in vitro and in vivo findings, and will lead to a better understanding of diagnosis and treatment of sacroiliac disease in the horse.

**Objectives**

Our original stated objectives were as follows:

- To identify the magnitude and direction of motion available in both clinically normal and diseased equine SIJs
- Correlate clinical signs and three dimensional kinematics in horses affected by sacroiliac disease
- To develop more effective intervention for the management of sacroiliac disease in the horse, based on the kinematic data.

In order to address these objectives we divided the research into 3 methodological phases with the following objectives:

- **Part I: Investigation of sacroiliac kinematics**
  
  Hypothesis: that there is measurable motion between the pelvis and vertebral column during both gait and during manual manipulation of the pelvis by a physiotherapist.

- **Part II: Investigation of clinical cases**
  
  Hypothesis: That manual manipulation techniques extrapolated from humans to horses could aid in the diagnosis of sacroiliac dysfunction in horses as they do in humans

- **Part III: Implications for diagnosis and treatment of sacroiliac dysfunction**
  
  Hypothesis: That kinematic and clinical data from this research would provide evidence for diagnostic and treatment protocols for SID in horses.
**Methodology**

Studies were approved by the Institutional Animal Ethics Committee.

**Part I: Investigation of sacroiliac kinematics**

The use of orientation sensors represents an advance in equine biomechanics research. Wireless 3D miniature orientation sensors were used to quantify the relative motion of ilium and the sacrum. The kinematic data was collected in normal Thoroughbred horses and divided into 2 main studies:

- **Study 1**: Quantification of sacroiliac motion *in vitro* and correlation to the forces applied: using biomechanical modelling in cadaver specimens.
- **Study 2**: Quantification of sacroiliac motion *in vivo* during manual physiotherapy techniques at rest and during walking and trotting gaits

**Study 1. Quantification of sacroiliac motion in vitro**

**Objectives**

- To develop the appropriate pelvic coordinate system model.
- To describe changes in SIJ motion pre and post ligament resection
- To correlate degree of force applied to the degree of movement between sacrum and ilium

To complete the vitro work that was started in our pilot research, four additional cadaveric specimens were used in an experiment where the sacrum was fixed and the pelvis moved about the sacrum manually such that relative motion occurs between the sacrum and the ilium (SIJ motion) (Figure 1.). Rotational manual forces were applied by a physiotherapist (Goff) to the limit of movement (Maitland, 1986), in the following directions:

Cranial pelvic rotation (sagittal plane)

Caudal pelvic rotation (sagittal plane)

Oblique rotation (transverso-frontal plane)

The horses were humanely destroyed before being prepared for dissection. The dissection procedure involved disarticulation of the coxofemoral joints, lumbosacral junction and sacrocaudal junction. The musculature was removed and the ligaments remained intact. As in a previous study (Goff et al, 2006) a threaded steel rod (11mm diameter) was inserted into the sacral spinal canal, and emerged from the caudal vertebrae. 2 screws pinned the first sacral vertebral body and last caudal vertebra, and the sacrum was fixed by way of 4 screws drilled through the wings of the sacrum into a similarly shaped steel plate on the ventral side of the sacrum, such that the screws did not interfere with the SIJ. The steel plate was attached to a length of 26mm diameter box-sectional steel, which also sat underneath the ventral surface of the sacrum (Figure 1). The ends of the box sectional steel were G-clamped to the longitudinal bars of a large animal crush. This ensured the sacrum was stabilised and the pelvis was able to be moved in various planes around the fixed sacrum via force applied manually by a physiotherapist.
The force applied by the physiotherapist was recorded using Vermahide™ conductive matting pad placed between the hypothenar eminence of the hand of the physiotherapist, and the bony prominence of the pelvis. Forces were converted from voltage to Newtons.

**Figure 1**  Schematic diagrams of the in vitro pelvic experiment depicting stabilisation of the vertebral column allowing the pelvis to be manually manipulated (from: Goff et al. Movement between the equine ilium and sacrum – in vivo and in vitro studies. Equine Vet. J. Suppl. 36: 457-461. 2006.)

During application of forces, relative motion between sacral and ilial planes was recorded via the IC3 orientation sensors (Inertia Cube 3, InterSense, Bedford, MA, USA). The orientation sensors measure absolute orientation of any object relative to gravity and magnetic north. The IC3 sensors contain an accelerometer, a magnetometer and gyroscope in each orthogonal plane. The wireless range of the sensor is approximately 10 meters. The collection frequency for 4 sensors is 100Hz. Orientation is reported as Euler angles (yaw, pitch and roll) that correspond to movement in the coronal, sagittal and axial planes (Figure 2).
Six trials of each application of force were completed for all 4 specimens.

Transection of the sacrotuberous ligament and dorsal sacroiliac ligament was performed and application of forces repeated, to assess the effects of pelvic ligaments on amount and planes of movement.

Data were analysed using a custom analysis program (Labview 7.1, National Instruments, Austin TX, USA), and analysis of variance (ANOVA) carried out using general linear model option in Minitab. Terms for subject, side and motion were included in the model.

**Study 2. Quantification of sacroiliac motion in vivo**

**Objectives**

- Quantification of sacroiliac motion during manual physiotherapy motion tests for SIJ such that are used in the battery of manual tests for SID.
- Quantification of sacroiliac motion during normal gait (walk and trot)
- Quantify skin motion artefacts in live horses, that is, correlate results obtained from skin-fixated markers with results obtained from bone-fixated Steinman pins.

Six Thoroughbred horses were used in this study. There were two geldings and four mares, mean age 7.6 years (range 4 – 14 years); mean weight 519.6 kg (range 480 – 553kg), mean height (159 cm). Hind limb lameness was excluded by routine lameness evaluation. The horses were clipped and
shaved over an area encompassing the sacrum and tuberae sacrale. Fixomull stretch™ tape was applied over the bony prominences of each tuber sacrale and the spinous process of sacral vertebrae (S) 2 or 3, and an ink marker denoted the mid-point of each bony prominence. IC3 motion sensors (Inertia Cube 3, InterSense, Bedford, MA, USA; see Study 1) were placed over the ink mark on each tuber sacrale and sacral spine, and further fastened down with Micropore tape (Figure 3.).

Figure 3  Skin mounted sensors.

The same 6 horses also had Steinman pins inserted into the tubera sacrale and spinous processes of S3 and lumbar vertebra (L) 5. Prior to insertion of pins, horses were sedated and local anaesthetic injected into the area over the mentioned processes. A 4 – 8 cm long, 3.0mm thick Steinman pin was placed into the spinous processes and tubera sacrale without pre-drilling, such that each pin protruded approximately 1-2 cm above the skin. One hour after sedation a custom built lightweight bracket with IC3 motion sensor screwed to the same, was fixed to the end of each Steinman pin via a tightening nut (Fig. 4). Sensor 1 was attached over the left tuber sacrale; sensor 2 was attached over the right tuber sacrale and sensor 3 was attached over the sacral segment.

Figure 4  Bone mounted sensors on a horse while walking on the treadmill

Using both skin-mounted and Steinman pin-mounted orientation sensors, relative motion between the ilium and the sacrum was recorded during manual physiotherapy motion tests (Figure 5), and during walk and trot on a treadmill.
For gait, data was sampled at approximately 100-150 samples per second. Data were collected using a custom analysis program (Labview 7.1, National Instruments, Austin TX, USA). Ranges of motion were recorded in degrees (Euler angles) for each sensor, and amount of yaw, pitch and roll compared for walk and trot gaits, for both skin mounted and bone-implanted sensors. Comparison of the data from both skin fixated and bone pin fixation of motion sensors was undertaken to determine the effect of skin movement artefact in the skin fixated methodology and validate or reject its use in the clinical part of the project. Analysis was carried out using the GLM procedure in SAS version 8.2.

Data the physiotherapy motion tests applied to the pelvis was collected as for gait, but was sampled at 20 samples per second.
Part II: Investigation of clinical cases

Objectives

- To observe the effect of disease on in vivo sacroiliac motion and clinical parameters
- To utilise these changes in the development of diagnostic protocols for diagnosis of SID in horses.

Study 1: comparison of sacroiliac motion and clinical parameters between horses affected with SID and unaffected horses

Ten horses with evidence of SID were recruited from local Thoroughbred training facilities and compared with 13 control horses.

Clinical Assessment

Clinical assessment of SID or normal was determined by scoring with the following battery of tests:

Joint mobility: three point scale

Joint mobility was assessed using manual forces applied to the pelvis as for the manual testing procedures – that is, cranial, caudal and oblique rotations. A subjective score was supplied by the physiotherapist as outlined below

- Hypomobile
- Normal
- Hypermobile

Hock flexion test

Lameness response to test:

- Present (+)
- Absent (-)

Trot

- Normal
- Plaiting – three grades
  - Mild – small amount of crossing of one hind-limb of midline
  - Moderate – moderate amount of crossing of one hind-limb of midline
  - Severe – bilateral crossing of both hind-limbs of midline
Bony asymmetry

Palpable and or visual pelvic symmetry (bony, including measurement from the tuber coxae to the last rib)

- Grade 1 – minor difference confirmed by palpation
- Grade 2 – difference easily visually identified and confirmed by palpation
- Grade 3 – marked bony asymmetry

NB: for cranio-caudal position of tuber coxae a measurement was taken from cranial tubercle of TC to 18th rib

Muscle asymmetry

- Grade 1 – minor visual difference confirmed by palpation (tone changes)
- Grade 2 – difference easily visually identified
- Grade 3 – marked muscle asymmetry (Figure 6)

Pain response to muscle (Middle gluteal) palpation

- Grade 1 – mild withdrawal response or muscle fasciculation
- Grade 2 – marked contraction of muscle in response to palpation
- Grade 3 – marked contraction of muscle with marked withdrawal response/moving away

Pain response to dorsal sacroiliac ligament palpation

- Grade 1 – mild withdrawal response or muscle (middle gluteal/epaxial) fasciculation
- Grade 2 – marked contraction of muscle (middle gluteals/epaxial) in response to palpation
- Grade 3 – marked contraction of muscle (middle gluteal/epaxial) with marked withdrawal response/moving away

Unilateral weight bearing

Reduced ability to recruit pelvic muscles functionally in single hind leg weight bearing

- Grade 1 – mild increase in postural sway felt by examiner with lateral perturbation laterally
- Grade 2 – marked increase in postural sway as above
- Grade 3 – horse stumbles or collapses due to lateral perturbation or cannot weight-bear unilaterally on hind
**Figure 6** Horse with SID showing marked muscle asymmetry, with loss of the left gluteal musculature.

**Determination of sacroiliac motion during manual manipulation of the pelvis**

Sacroiliac motion was compared between normal and SID horses non-invasively using skin fixated 3D motion sensors during manual manipulation 7 clinically affected and 4 unaffected Thoroughbred horses.

Gait assessment was not performed due to the results from the first stage where it was found skin markers to be poorly correlated to bone fixated markers during gait, but that they were not-significantly different during manual manipulations.

The relative movement of the SIJ was recorded using three wireless orientation sensors (Inertia Cube 3, InterSense, Bedford, MA, USA; see Study 1, Part I). The Inertia Cube 3 (IC3) sensors measure absolute orientation of any object relative to gravity and magnetic north.

The horses were clipped over an area encompassing the tubera sacrale and the sacral spinous processes. Hair over the most cranial aspect of each tuber sacrale and the most palpable sacral spinous process (S2 or S3) was shaved to expose the skin. Sensors were numbered 1, 2 and 3, and then were glued directly to the skin with Superglue TM. Sensor 1 was glued over the left tuber sacrale; sensor 2 was glued over the right tuber sacrale and sensor 3 was glued over the sacral spinous process.

Horses were placed in stocks (where available) on a level hard surface and encouraged to stand squarely at all times during the testing. Orientation of the left and right ilium and the sacrum were simultaneously recorded by the sensors in three orthogonal planes (coronal, sagittal and axial movements) during rotational manual forces applied to the left and right pelvis by physiotherapist (LG). These manual forces were applied to the limit of movement (Maitland, 1986), in the following directions:

- Cranial pelvic rotation (sagittal plane)
- Caudal pelvic rotation (sagittal plane)
- Oblique rotation (transverso-frontal plane)

For each direction of rotation on each side, there were three trials. If the horse was not stationary at the time of application, or standing squarely, the application of rotation was repeated.

Data was sampled at 20 samples per second, a sampling rate chosen due to the relatively slow nature of the movement applied to the horse’s pelvis (for gait it is around 100-150 samples per second). Data were collected using a custom analysis program (Labview 7.1, National Instruments, Austin TX, USA) where they were represented as graphs. The difference between maximum and minimum values
on the graph was calculated and recorded as the Euler angle for each orthogonal plane, for each sensor.

For each direction of applied rotation (cranial, caudal and oblique), the average of yaw pitch and roll for each sensor was calculated. This data was entered into statistical package, STATA Version 10 which was used to run an ANOVA to ascertain if there were significant differences between motion of the horses with SID and the normal horses, and to see whether there were significant difference in motion left to right, within the normal and the SID groups.

**Measurement of cross sectional area (CSA) of DSIL**

Ultrasoundographic measurement of the DSIL CSA was performed in 10 horses with SID and 13 horses with no clinical signs of SID or hind limb lameness. Prior to the attachment of the orientation sensors to the horse’s skin, measurement of the DSIL was carried out using a 7MHz linear probe (Excelray digital ultrasound, Australia) orientated perpendicularly to the direction of the fibres of the DSIL. The probe was moved to the DSIL immediately caudal to the caudal aspect of the tuber sacrale, and the image taken at the same level for both the left and right DSIL. The images were downloaded and the CSA was measured, using Image J (Figure 7).

![Figure 7](image)

Figure 7  Measurement of the DSIL CSA from a horse with SID. In this image the right ligament (image on the right) is larger than the left. A difference in muscle size above the ligament is also subjectively noted.

The difference between the left and right DSIL CSA was calculated and tested for normality. Since the difference was not normally distributed, a Mann-Whitney test was used to compare the groups.

**Study 2: Sacroiliac joint morphology**

A second part of this study was added where pelvises from Thoroughbred racehorses that had been euthanized at the end of their careers were examined to investigate the types and degree of change within the SIJ to allow us to correlate this back to the motion sensor findings in affected horses and give some indication of the occurrence of disease in this population.

35 pairs of sacroiliac joints (SIJ) from racing thoroughbreds at the Hong Kong Jockey club (HKJC) were analysed in this study. The pelvises were collected from 35 TB racehorse geldings that had been declared for euthanasia, at the HKJC. 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. Veterinary records for each horse were obtained, outlining the reason for euthanasia, which included musculoskeletal (including back and sacroiliac pain) and other reasons affecting their racing performance. Following euthanasia, the pelvises were dissected out, and soft tissue was removed from the pelvis by placing the bones in a boiler for 24 hours. Following the procedure there were 30 pairs iliac surfaces, and 28 pairs of
sacral articular surfaces. The surfaces were photographed using a Canon EOS 30D digital camera, with EF-S17-85mm f/4.5.6 IS USM lens. The camera was mounted on a stationary arm, such that it could be moved away from, or towards, a fixed plate. The specimens were placed on the fixed plate, such that the joint surface was perpendicular to the surface of the lens. The distance of lens to joint surface was 270-310mm, depending on convexity/concavity of joint surface.
Results

Part I: Investigation of sacroiliac kinematics

Study 1. Quantification of sacroiliac motion in vitro

**Range of motion**

The greatest ranges of motion between the ilium and the sacrum were for roll (axial rotation) (6.8°) and yaw (movement in a coronal plane) (5.2°), during left oblique rotation (Figure 8).

**Figure 8** Image representing the direction of movement of the pelvis against a fixed vertebral column (See Fig 1).

The largest movements were for roll (axial rotation) and yaw (motion in coronal plane) which were 6.8° and 5.2° respectively.

**Effect of ligament transection on range of motion**

Pitch or movement in the sagittal plane was the only direction of motion that was consistently increased (almost doubled from 2.5° to 4.1°) following transection of the dorsal sacroiliac and sacrotuberous ligament, for all orthogonal planes. This suggests that the role of the two ligaments is to limit iliosacral motion in the sagittal plane. During caudal and cranial rotation, which are motions delivered to the pelvis in the sagittal plane, the average increase in pitch following transection was always greater than 1°, and was greater than 2° for left and right cranial rotation. There was no consistent increase in roll and yaw following transection, for caudal and cranial rotation. Left and right lateral rotation had increases in range of motion in all orthogonal planes following ligament transection, particularly in right lateral rotation, where the greatest value for increase in motion for all the data was for pitch. This suggests that sagittal movement is a component of lateral pelvic motion around the sacrum.

**Force applied**

The mean force applied before transection of the ligaments (162.1 N). The mean forces applied to the left side of the pelvis were in general greater than those applied to the right side of the pelvis indicating a side preference of the physiotherapist.
Study 2. Quantification of sacroiliac motion *in vivo*

**Quantification of sacroiliac motion during manual physiotherapy**

Compared to Study 1, the amount of motion detected in the live horse was reduced compared to that of the *in vitro* preparation. Further, there were differences in direction of movement that was elicited, where in the live horses the range of motion for yaw tend to be smallest, pitch tend to be largest with roll in the middle with pin fixated motion sensors (Table 1).

### Table 1  Mean degrees of movement of skin or pin mounted 3D motion sensors during manual physiotherapy manipulations of the pelvis in 3 orthogonal planes.

<table>
<thead>
<tr>
<th></th>
<th>Sensor 1</th>
<th>Sensor 2</th>
<th>Sensor 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yaw</td>
<td>.82</td>
<td>.81</td>
<td>.88</td>
</tr>
<tr>
<td>Pin</td>
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</tr>
<tr>
<td>Skin</td>
<td>.88</td>
<td>.96</td>
<td>1.0</td>
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<tr>
<th></th>
<th>Sensor 1</th>
<th>Sensor 2</th>
<th>Sensor 3</th>
</tr>
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<td></td>
<td></td>
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<tr>
<td>Pin</td>
<td>1.65</td>
<td>1.71</td>
<td>1.43</td>
</tr>
<tr>
<td>Skin</td>
<td>.68</td>
<td>.81</td>
<td>1.11</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
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<th>Sensor 2</th>
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<tr>
<td>Roll</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Pin</td>
<td>1</td>
<td>1.05</td>
<td>.79</td>
</tr>
<tr>
<td>Skin</td>
<td>1.19</td>
<td>1.27</td>
<td>0.95</td>
</tr>
</tbody>
</table>

**Quantification of skin motion artefacts during manual manipulation of the pelvis**

Movements for yaw for skin mounted data were on average larger that for pin mounted data while movements for roll for skin mounted data were on average larger that for pin mounted data. In contrast movements for pitch, were larger for pin mounted data than skin mounted data. (Table 1). For the majority of readings, there was no difference between skin and pin fixated markers. However, for left posterior rotation, there was a significant difference between skin and pin mounted data for yaw, on left tubersacrale (p = 0.001). For left cranial rotation, there was significant difference between skin and pin mounted data for pitch, on left tuber sacrale (p = 0.012), and for right tuber sacrale (p = 0.005). For oblique rotation there was significant difference between skin and pin mounted data for pitch, on left tuber sacrale (p < 0.001), right tuber sacrale (p = 0.005), and a trend for difference on the sacrum (p = 0.068).

**Quantification of sacroiliac motion during normal gait (walk and trot)**

In general the difference in orientation of the left and right ilium and sacrum as simultaneously recorded by the sensors in three orthogonal planes by the sensors, was greater during gait than during manual manipulation. It is possible this is due to the larger torques produced upon the pelvis by the powerful muscles of the horses’ pelvic limb and trunk.

Values for the walk were greater than those for the trot, except for yaw and roll, in skin mounted situation (table 2).
Walk

The mean range for motion in the coronal plane at the left tuber sacrale (sensor 1) was 6.48° skin mounted, and 6.18° pin mounted; at right tuber sacrale (sensor 2) was 6.04° skin mounted, and 6.24° pin mounted; at the sacrum was 5.84° skin mounted, and 5.43° pin mounted. There was no significant difference between skin and pin mounted data for coronal plane motion at the walk.

The mean range of motion for sagittal rotation at the left tuber sacrale (sensor 1) was 7.11° skin mounted, and 5.57° pin mounted; at right tuber sacrale (sensor 2) was 6.38° skin mounted, and 5.41° pin mounted; at the sacrum was 6.25° skin mounted, and 5.39° pin mounted.

There was significantly greater range of sagittal rotation for skin mounted data compared to pin mounted data (sensor 1 p = 0.0001; sensor 2 p = 0.0001; sensor 3 p = 0.0026).

The mean range of motion for axial rotation (motion about the transverse plane) at the left tuber sacrale (sensor 1) was 12.17° skin mounted, and 10.71° pin mounted; at right tuber sacrale (sensor 2) was 11.58° skin mounted, and 10.74° pin mounted; at the sacrum was 13.88° skin mounted, and 9.73° pin mounted. There was no significant difference in range of motion measured at skin mounted sensors versus pin mounted sensors over the tuber sacrale. However, there was a significantly greater range of axial rotation of the sacral segment (sensor 3) for skin mounted data compared to pinned data (p = 0.001) (Table 2).

Trot

The mean range for motion in the coronal plane for at the left tuber sacrale (sensor 1) was 7.10° skin mounted, and 4.54° pin mounted; at right tuber sacrale (sensor 2) was 6.32° skin mounted, and 4.61° pin mounted; at the sacrum was 6.97° skin mounted, and 3.81° pin mounted. There was a significant difference between skin and pin mounted data for all coronal plane motion (p = 0.0001) at the trot, with range of coronal plane motion for skin mounted data being greater than pin mounted data.

The mean range of motion for sagittal rotation at the left tuber sacrale (sensor 1) was 3.23° skin mounted, and 2.09° pin mounted; at right tuber sacrale (sensor 2) was 2.91° skin mounted, and 2.04° pin mounted; at the sacrum was 3.24° skin mounted, and 1.87° pin mounted. There was a significant difference between skin and pin mounted data for all sagittal rotation (sensor 1 and 3 p = 0.0001; sensor 2 p < 0.001) at the trot, with range of pitch for skin mounted data being greater than pin mounted data.

The mean range of motion for axial rotation at the left tuber sacrale (sensor 1) was 14.53° skin mounted, and 5.64° pin mounted; at right tuber sacrale (sensor 2) was 16.38° skin mounted, and 5.37° pin mounted; at the sacrum was 17.17° skin mounted, and 5.21° pin mounted. There was a significant difference between skin and pin mounted data for all axial rotation (p = 0.0001) at the trot, with range of axial rotation for skin mounted data being greater than pin mounted data. The difference between pin and skin mounted sensors was greatest during axial rotation compared to the other orthogonal planes. The mean values for axial rotation for skin mounted markers during trot were the largest overall (Table 2).

Quantification of skin motion artefacts during gait

The average of the results of the skin mounted sensors and the bone implanted sensors were compared and there was poor correlation between skin and pin mounted data for walk and trot, for all planes of motion except for yaw at the walk and pitch at the walk.
Table 2  Mean degrees of movement of skin or pin mounted 3D motion sensors during walking and trotting in 3 orthogonal planes (yaw or coronal plane; roll or axial plane; pitch or sagittal plane) for 6 Thoroughbred horses in Study 2.

<table>
<thead>
<tr>
<th></th>
<th>Walk</th>
<th>Walk</th>
<th>Walk</th>
<th>Trot</th>
<th>Trot</th>
<th>Trot</th>
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<tbody>
<tr>
<td><strong>Yaw</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pin</td>
<td>6.18 *</td>
<td>6.24 *</td>
<td>5.43 *</td>
<td>4.54</td>
<td>4.61</td>
<td>3.81</td>
</tr>
<tr>
<td>Skin</td>
<td>6.48 *</td>
<td>6.04 *</td>
<td>5.84 *</td>
<td>7.10</td>
<td>6.32</td>
<td>6.97</td>
</tr>
<tr>
<td><strong>Pitch</strong></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pin</td>
<td>5.57</td>
<td>5.41 *</td>
<td>5.39 *</td>
<td>2.09</td>
<td>2.04</td>
<td>1.87</td>
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<tr>
<td>Skin</td>
<td>7.11</td>
<td>6.38 *</td>
<td>6.25 *</td>
<td>3.23</td>
<td>2.91</td>
<td>3.24</td>
</tr>
<tr>
<td><strong>Roll</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pin</td>
<td>10.71</td>
<td>10.74</td>
<td>9.73</td>
<td>5.64</td>
<td>5.37</td>
<td>5.21</td>
</tr>
</tbody>
</table>

* = no significant difference
Part II: Investigation of clinical cases

Study 1. : comparison of sacroiliac motion and clinical parameters between horses affected with SID and unaffected horses

Clinical assessment

Ten horses with evidence of SID and 13 horses that were clinically sound were assessed (see methods). See table 3a for information regarding age height and gender. Table 3b outlines the specific clinical data for the 7 SID horses.

Table 3a  Age, gender and height of all horses.
(N= normal, S = sacroiliac dysfunction).

<table>
<thead>
<tr>
<th>Horse</th>
<th>Gender</th>
<th>Age</th>
<th>Height (hh)</th>
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<tbody>
<tr>
<td>1N</td>
<td>M (g)</td>
<td>2</td>
<td>16.2</td>
</tr>
<tr>
<td>2N</td>
<td>F</td>
<td>6</td>
<td>15</td>
</tr>
<tr>
<td>3N</td>
<td>M (g)</td>
<td>3</td>
<td>16.2</td>
</tr>
<tr>
<td>4N</td>
<td>M (g)</td>
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<td>16</td>
</tr>
<tr>
<td>5N</td>
<td>F</td>
<td>2</td>
<td>15.3</td>
</tr>
<tr>
<td>6N</td>
<td>M (g)</td>
<td>5</td>
<td>16.1</td>
</tr>
<tr>
<td>7N</td>
<td>F</td>
<td>13</td>
<td>15.3</td>
</tr>
<tr>
<td>8N</td>
<td>F</td>
<td>10</td>
<td>15.2</td>
</tr>
<tr>
<td>9N</td>
<td>M (g)</td>
<td>?</td>
<td>15.2</td>
</tr>
<tr>
<td>10N</td>
<td>F</td>
<td>2</td>
<td>15</td>
</tr>
<tr>
<td>11N</td>
<td>F</td>
<td>7</td>
<td>15</td>
</tr>
<tr>
<td>12N</td>
<td>M (g)</td>
<td>5</td>
<td>15.1</td>
</tr>
<tr>
<td>13N</td>
<td>M (g)</td>
<td>9</td>
<td>16</td>
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<td>1S</td>
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<td>15.3</td>
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<tr>
<td>3S</td>
<td>M (g)</td>
<td>9</td>
<td>17</td>
</tr>
<tr>
<td>4S</td>
<td>M (g)</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>5S</td>
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<tr>
<td>10S</td>
<td>F</td>
<td>2</td>
<td>15.2</td>
</tr>
</tbody>
</table>
Table 3b  Clinical assessment details for 7 horses with SID (1-7S) that were subjected to manual motion testing.

<table>
<thead>
<tr>
<th>horse</th>
<th>Weight bearing (1/2/3)</th>
<th>Plaiting (1/2/3)</th>
<th>Muscle asymmetry</th>
<th>Bony asymmetry</th>
<th>Pain response</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>gluteal</td>
<td>biceps</td>
<td>TC</td>
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<tr>
<td>1S</td>
<td>Grade 1 postural sway R</td>
<td>N</td>
<td>Grade 1 R</td>
<td>R</td>
<td>Left cranial</td>
</tr>
<tr>
<td>2S</td>
<td>Grade 2 postural sway R</td>
<td>N</td>
<td>Grade 1 bilateral</td>
<td>-</td>
<td>Right cranial</td>
</tr>
<tr>
<td>3S</td>
<td>Grade 2 postural sway R - stumbled away during test</td>
<td>3</td>
<td>Grade 1 bilateral</td>
<td>-</td>
<td>Left cranial</td>
</tr>
<tr>
<td>4S</td>
<td>Grade 1 postural sway R</td>
<td>3</td>
<td>Grade 1 L; 2 R</td>
<td>Grade 2 R</td>
<td>Right cranial</td>
</tr>
<tr>
<td>5S</td>
<td>Grade 1 postural sway L</td>
<td>1</td>
<td>Grade 1 bilateral</td>
<td>Grade 1 L</td>
<td>Old # TC L - no value</td>
</tr>
<tr>
<td>6S</td>
<td>Grade 1 postural sway L</td>
<td>N</td>
<td>Grade 1 L; 2 R</td>
<td>-</td>
<td>Right cranial</td>
</tr>
<tr>
<td>7S</td>
<td>Grade 3 instability</td>
<td>3</td>
<td>Grade 2 R</td>
<td>Grade 1</td>
<td>-</td>
</tr>
</tbody>
</table>

Legend: TC = tuber coxae, TS = tuber sacrale, DSIL = dorsal sacroiliac ligament, L = left, R = right, # = fracture

**Determination of sacroiliac motion during manual manipulation of the pelvis**

When we compared the manual movements of the pelvis between horses with SID and normal Thoroughbreds, differences between the degree of movement in most planes were not detected.

**Motion**

There were no significant differences between normal horses and those with SID for cranial or oblique rotation of the ilium on the sacrum. There were significant differences between horses with and without SID however, for left caudal rotation: sensor 1 for yaw (p=0.01) and pitch (p=0.036); sensor 2 for yaw (p=0.01); and sensor 3 for yaw (p=0.006); and right caudal rotation: sensor 1 for yaw (p=0.023), and roll (p=0.046); and sensor 3 for yaw (p=0.036).

**Differences left and right**

In the normal group there was no significant difference in movement of cranial rotation between left and right, except for roll on the (R) for sensor 2 (p=0.036). In the SID group there was no significant difference between left and right motion, for cranial rotation of the pelvis.

**For oblique rotation there was no significant difference in either group between left and right motion**

In the normal group during caudal rotation of the pelvis there were significant differences between left and right motion, on sensor 1 for yaw (p=0.014); sensor 2 for yaw (p=0.025) and roll (p=0.001); sensor 3 for yaw (p=0.008) and roll (p=0.004). In the SID group there was significant difference in sensor on sensor 2 for yaw (p=0.045)
Ultrasonography of the DSIL CSA

Of the 10 horses classified as having signs of SID, the mean cross sectional area of the left side was 0.70 ± 0.31 cm² and a median value of 0.70 cm². The mean cross sectional area of the right side was 0.88 ± 0.38 cm² and a median value of 0.86 cm². The mean difference of the right side to the left side in horses with signs of sacroiliac disease was 0.22 cm² with a standard deviation of 0.21 cm² and a median value of 0.13 cm² (Figure 8). A Mann-Whitney test showed a significant difference in the ‘difference from right to left DSIL CSA’ in normal horses as compared to SID horses (p = 0.0004).

Figure 9  Box plot representation of the mean difference between right and left DSIL in SID (n=10) compared with normal (n=13) Thoroughbred horses showing a significant difference (P<0.001).

Study 2: Sacroiliac joint morphology

Joint shape

SIJ shape was found to be altered by adaptive or remodelling processes in 71% of Thoroughbreds. The remodelling was usually in the form of joint extensions ranging from large expansions, to small osteophytes, and were classified based on a classification system of macroscopic findings proposed by Jeffcott and Dalin (1985). Type I was an expansion of the caudoventral angle, usually in a caudoventral direction. Type II was a broad expansion off the caudoventral angle, which extends more cranially, or may just extend off the ventral border, more cranially. Type III was an extension off the most caudal aspect of the joint, in a mediocaudal direction. Type IV refers to smaller osteophytic joint expansions, along the margin of the joint (Figure 10). There were combinations of these types of joint expansions, most commonly II/III. Normal joints were considered to be those with a very clearly defined, smooth joint margin, with no other significant joint surface changes or adaptations, and with no extension of the subchondral bone beyond the margin.
Figure 10  Schematic diagram of different types of sacroiliac joint changes:
A. Type I left sacral surface, B. Type II left sacral surface, C. Type III right sacral surface, D. Type IV left sacral surface.

Of all the sacral and iliac surfaces examined, 22.3% of joints were considered normal; 29% were Type I; 19.4% were Type II; 7.4% were Type III; 2.9% were Type IV and 18.6% were a combination of types (Table 4). There were differences in the frequency of the type of expansion occurring on iliac articular surfaces, compared to the sacral articular surfaces. Normal shape joints were most common in the iliac surfaces, with Type I and Type II being equally represented. Type I shape was seen most in the sacrum, with the least frequent sacral joint type being Type IV. There were no Type IV shape changes recorded from the iliac surfaces.

Articular surface adaptive changes

With respect to degree of adaptive change at the articular surface, joints were graded as follows

1. Mild - minor adaptive changes in the articular cartilage and joint margins that are unlikely to be pain producing
2. Moderate - more obvious adaptive changes in the articular cartilage and joint margins, that may be associated with pain production
3. Severe - marked adaptive changes in the articular cartilage and joint margins, or greater than 25% of surface of joint with the appearance of subchondral bone changes, or reactivity – likely to be pain producing (Figure 11).
Figure 11  An example of left iliac surface of a 5 yo TB gelding with severe articular changes (Type II) Spatulate joint.

Extensive bony proliferation significant at caudal aspect, consisting of multiple osteophytes, irregular lipping and significant area of subchondral bony reaction. Deep crevice runs caudally into ilium from this area.

The average age of horses in mild grade was 6; moderate was 6.04 and severe was 8.3. However, there was no correlation between age and grade of severity of SIJ changes.

There was, however, a correlation between surface area of the articular surfaces, and the grade of joint surface change (Spearman $r = 0.43; p < 0.001$). The horses with more severe changes had a larger iliac surface area of $22.46 \pm 2.12$ cm$^2$. Horses with moderate changes had an iliac surface area of $19 \pm 2.41$ cm$^2$, whereas the iliac surface with mild changes had a surface area of $18.36 \pm 2.68$ cm$^2$ (Figure 12).

Figure 12  Average of surface area (cm$^2$) of iliac articular surfaces for mild, moderate and severe grades of bony change.
<table>
<thead>
<tr>
<th>Type</th>
<th>mild sacral</th>
<th>mod sacral</th>
<th>severe sacral</th>
<th>mild ilium</th>
<th>mod ilium</th>
<th>severe ilium</th>
<th>number of type, sacral (%)</th>
<th>number of type, iliac (%)</th>
<th>number of type, iliac and sacral</th>
<th>% of type of all iliac and sacral</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>10</td>
<td>14</td>
<td>2</td>
<td>7</td>
<td>6</td>
<td>0</td>
<td>26 (66.66)</td>
<td>13 (33.33)</td>
<td>39</td>
<td>30</td>
</tr>
<tr>
<td>II</td>
<td>3</td>
<td>5</td>
<td>5</td>
<td>6</td>
<td>2</td>
<td>5</td>
<td>13 (50)</td>
<td>13 (50)</td>
<td>26</td>
<td>20</td>
</tr>
<tr>
<td>III</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>4</td>
<td>3</td>
<td>1 (10)</td>
<td>9 (90)</td>
<td>10</td>
<td>7.6</td>
</tr>
<tr>
<td>IV</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4 (100)</td>
<td>0</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>combination</td>
<td>1</td>
<td>8</td>
<td>10</td>
<td>1</td>
<td>5</td>
<td>0</td>
<td>19 (76)</td>
<td>6 (24)</td>
<td>25</td>
<td>19</td>
</tr>
<tr>
<td>Normal</td>
<td>7</td>
<td>0</td>
<td>0</td>
<td>18</td>
<td>5</td>
<td>0</td>
<td>7 (23.33)</td>
<td>23 (76.66)</td>
<td>30</td>
<td>23</td>
</tr>
<tr>
<td>TOTALS</td>
<td>23</td>
<td>30</td>
<td>17</td>
<td>34</td>
<td>22</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: normal joints were considered to be those with a very clearly defined, smooth joint margin, with no other significant joint surface changes or adaptations, and with no extension of the subchondral bone beyond the margin.
Discussion of Results

This study has achieved its aims by increasing the knowledge of sacroiliac kinematics in horses, and highlighting how pathology of the SIJ affects the neuromotor control of the region.

Sacroiliac kinematics

The results of this study have shown that the equine SIJ, like the human one, has small yet complex movements at the joint surface. SIJ motion was able to be detected using 3D wireless motion sensors in 3 orthogonal planes. The greatest movement during manual tests applied by a physiotherapist to the pelvis \textit{in vivo}, was in the sagittal plane (pitch). During gait, the greatest movement was in the axial plane (roll). Sacroiliac movement was greater during gait that during manual manipulation of the pelvis indicating the role of the limbs and associated musculature in SIJ movement. The movement decreased from the walk to the trot, reflecting increased muscle recruitment and increased neuromotor control of the region.

This indicates the involvement of the hind limb musculature, which surrounds the SIJ, in stabilising and controlling its movement, similar to the epaxial musculature in stabilising the vertebral column – the SIJ is not just a passive structure hanging by its ligaments. \textit{Despite it being a very strong and well supported joint, the SIJ does have movement and therefore may be susceptible to altered movement patterns, and injury.}

Sacroiliac motion was affected by how the motion sensors were attached with greater motion occurring in most planes using skin fixated markers than pins. Further, there was a poor correlation between pin and skin fixated markers during gait. This was less apparent during manual manipulation of the pelvis, but limits the use of the 3D motion sensors to resting manual tests vs. gait testing as a clinical tool.

Sacroiliac joint dysfunction

When the manual movements of the pelvis between horses with SID and normal Thoroughbreds were compared, differences between the degree of movement in most planes were not detected either overall between SID and control Thoroughbreds or between the left and right sides of SID Thoroughbreds.

To examine this further we performed detailed morphological studies on the pelvic bones of ex-racehorses euthanized at the ends of their careers. These studies showed revealed a very high prevalence of SIJ changes with varying degrees of bony extension, enlargement and bony reaction in the joint. These changes were associated with a significant increase in surface area of the joint. Therefore, these changes may be a response to altered forces being transmitted through the joint; they may limit movement, by partly stabilising the joint and reducing the amount of movement, or they may be a response to increased mobility at the joint. This may explain why in a mixed group of SID horses with disease of varying chronicity, changes in motion were too variable to be significant.

In horses with SID there were a number of other clinical findings. There was variable bony asymmetry and variable muscle atrophy patterns. Consistent features included difficulty stabilising on the hind-limb of affected side and an ultrasonographically detectable difference between the left and right DSIL indicating asymmetry between the pelvis and sacrum.

This information taken together has improved our understanding of the equine SIJ and its control. We know that while movements in the SIJ are small, it is not an immobile structure and that it is controlled by the large musculature of the hind limb, pelvis and vertebral column, surrounding it, as in humans. Injury to the SIJ (and secondary periarticular muscle pain and dysfunction) or the
surrounding musculature could result in SID through a loss of the control the musculature has over the joint and initiate the pathological processes evident in the ex-racehorses. Evidence of such altered neuromotor control in clinical cases may be detectable as asymmetry detected in the ligament between the vertebral column and pelvis – the DSIL. While we were not able to support the use of manual motion testing to diagnose SID in horses, we can advise imaging of the DSIL as a useful adjunct diagnostic aid together with clinical findings.

In conclusion, use of a kinematic approach to sacroiliac dysfunction pain, borrowing from the human neuromotor control model, has advanced the knowledge of the equine SIJ and its kinematics. Bony morphological changes within the SIJ provide insight into the underlying pathological processes and changes to sacroiliac motion during SID. Ultrasonography of the dorsal sacroiliac ligament is a valuable non-invasive tool that will help detect SID in horses. This information will be valuable to veterinarians and physiotherapists managing SID and poor performance syndromes in athletic horses and will lead onto future work on the effect of physiotherapeutic intervention on the treatment of SID.
Implications

Implications for diagnosis and treatment of sacroiliac dysfunction

The Thoroughbred racing industry should take particular note from this research the high prevalence of major disease of the SIJ in an ex-racehorse population and ensure that information about this disease is not ignored. The message to horse owners and trainers is that this is a very real and highly prevalent condition and horses with unexplained poor performance or hind limb gait abnormalities should be investigated by a veterinarian-physiotherapist team. Field based diagnostic strategies are vital in order to increase the diagnosis in Australian performance horses.

Evidence for a neuromotor control model of equine sacroiliac dysfunction

Our research has identified that movement exists in three different planes (and combinations thereof) between the equine spine and the equine pelvis. Further, that these movement vary, depending on gait, with a general decrease in motion in all planes associated with increased neuromotor control (sensory nerve networks and resultant periarticular muscular control that dictate and control joint position) in the trot versus the walk. This is similar to kinematic findings in the equine back (Faber et al. 2000, 2001). These findings help dictate the treatment available for affected horses where ultimately the aim should be to improve muscular control and function in the area, rather than just reduce the pain by use of medications locally or systemically.

Implications for diagnostic testing

While our research did not find manual motion tests useful in the diagnosis of SID, we did find a battery of other non-invasive field applicable tests that can help diagnose this insidious problem without the need for referral to a major equine centre.

Manual manipulation of the equine pelvis to detect differences in motion or relative sacroiliac movement are not a useful diagnostic test and movement tests are poorly correlated with other clinical factors. This is likely to be due to the inherent variation in morphological change within the bony SIJ as well variation in neuromotor control in the surrounding musculature. Further research investigating clearly defined acute SID may reveal more consistent results, but cases of varying chronicity are unlikely to be rewarding.

We recommend a more consistent diagnostic approach including clinical evaluation and ultrasonography of the DSIL as outlined below.
Recommendations

Diagnostic and treatment recommendations are targeted at veterinarians and physiotherapists working with athletic horses. We recommend initial field diagnostic protocols for SID should include the following:

- description of gait
- elimination of other causes of hind limb lameness
- pain response on palpation of middle gluteal muscle and DSIL
- measureable bony asymmetry of tubera sacrale, and tuber coxae +/- tuber ischii
- in ability to weight-bear well on the affected hind limb with lateral weight transfer – increased lateral sway of pelvis
- Ultrasonographically detectable asymmetry of DSIL
References


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Sakomoto, N. (2001). An electrophysiological study of the mechanoreceptors in the sacroiliac joint and adjacent tissue Spine 26, E468-71


List of presentations

2008

5th International Symposium on Rehabilitation and Physical Therapy in Veterinary Medicine,

- Preconference Course – assessment and treatment of the equine sacroiliac joint
- Invited speaker – physiotherapy management in equine sacroiliac joint disorders ; August 13-18, Minneapolis, USA

Convention for Veterinarians and Physiotherapists, Management of equine back pain. 19-20 April, Stockholm, Sweden,

2007

Australian Physiotherapy Association Conference week – Equine Sacroiliac joint update - October 4-8, Cairns, Queensland, Australia (invited speaker)

2006

7th International Congress of Equine Exercise Physiology, Preliminary studies to investigate the range of in vivo and in vitro movement of the sacroiliac movement in the horse (presented by Dr. Catherine McGowan) Fontainebleu, France – August

Australian College of Veterinary Scientists Science Week, The Equine Sacroiliac Joint, Gold Coast, Queensland, Australia – June (invited speaker)

The Australian Equine Science Symposium, Biomechanics of the Equine Back and Sacroiliac Joint, Gold Coast, Queensland – June (invited speaker)

2005

Australian Animal Physiotherapy Group Annual Conference (two presentations):

(1) The Equine sacroiliac joint kinematics

(2) The Horse-Rider Integrated Pelvis, Werribee, Australia – December (invited speaker)

Musculoskeletal Physiotherapists Association Conference, Change in cross-sectional area of equine dorsal sacroiliac ligament during application of manual forces to the ilium (poster presentation) Brisbane, Australia – November

CSP Congress, The Equine Sacroiliac Joint, Birmingham, UK – October (invited speaker)

Publications:


Equine sacroiliac joint injury/dysfunction (SID) is a common reason for wastage in the racing and performance horse industries causing poor performance, abnormalities of hind limb gait and lameness. However, diagnosis of dysfunction of the equine sacroiliac region has been difficult.

Use of a kinematic approach to SID, borrowing from the human kinematic model, has advanced the knowledge of the equine SIJ, its function and the role of the pelvic musculature in both health and disease. Ultrasonography of the Dorsal sacroiliac ligament (DSIL) is a valuable non-invasive tool that will help detect SID in horses.

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