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Review

Structural and biomechanical aspects of equine sacroiliac joint function and their relationship to clinical disease

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Abstract

Pain originating from the sacroiliac joint (SIJ) in horses has long been associated with poor performance, yet specific diagnosis of sacroiliac dysfunction (SID) has been difficult to achieve. Clinical presentation of SID appears to fall into two categories. The first, presenting as pain and poor performance, is responsive to local analgesia of periarticular structures with poorly defined pathology. The second presents primarily as poor performance with bony pathological changes as a result of chronic instability. Diagnostic tests based on biomechanics as well as manual provocation for SIJ pain have formed the basis of tests currently used to diagnose SIJ dysfunction in humans. This review summarises the anatomy and biomechanics of the equine SIJ and current biomechanical, innervation and motor control concepts in human SID. The relationship between abnormal SIJ motion and altered neuromotor control with clinical disease of the equine SIJ are discussed. Future utilisation of these principles to develop new diagnostic and management tools for the equine SID is promising.

Keywords: Horse; Sacroiliac disease; Poor performance; Neuromotor control; Physiotherapy

Introduction

Pain originating from the sacroiliac joint (SIJ) in horses has long been associated with poor performance, abnormalities of hindlimb gait and lameness (Rooney, 1979; Jeffcott, 1980; Jeffcott et al., 1985). However, specific diagnosis of sacroiliac dysfunction (SID) has been difficult to achieve in horses, and this has been attributed to the often mild, chronic clinical signs and the location of the joint (Haussler, 2004). Consequently, diagnosis of SID has been based on a process of elimination of other conditions, such as thoracolumbar pathology, low grade lower hindlimb lameness, thrombosis of caudal aorta or iliac arteries and exertional rhabdomyolysis, mild ataxia ('wobbler' disease), and cauda equina neuritis (Jeffcott and Dalin, 1985; Dyson, 2003).

A major obstacle to the successful diagnosis of SID in the horse is the dearth of information on the biomechanics of the joint. The SIJ is particularly inaccessible due to its depth within the pelvis and the surrounding musculature, making it impossible to palpate the joint externally. Little is known about the three dimensional movement of the SIJ in horses, and this has prevented the establishment of an effective model with which to study the biomechanics of the SIJ.

In humans, pain originating from the SIJ contributes up to 30% of non-specific low back pain and referred distal limb pain (Schwarzer et al., 1995; Maigne et al., 1996). Differentiation of SIJ pain from low back pain was difficult in the past due to a lack of understanding of the complex motion and neuromotor control mechanisms associated with SIJ function (Van der Wurff et al., 2006). However,

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research into the biomechanics of the SIJ has described the amount and direction of movement of the normal and abnormal joint (Jacob and Kissling, 1995; Hungerford and Gilleard, 1998; Sturesson et al., 2000) and the muscle responses to abnormal SIJ movement (O'Sullivan et al., 2002; Hungerford et al., 2003). Diagnostic tests based on this research as well as manual provocation tests for SIJ pain (Van der Wurff et al., 2006) have formed the basis of the battery of tests currently used to diagnose SID in humans.

A similar approach to biomechanics research may be relevant to the horse for both the diagnosis and treatment of SID. An understanding of the movement disorders associated with the specific pathological changes in SID may lead to better management of affected horses by addressing the underlying mechanical or neuromotor causes of the condition (Haussler et al., 1999). This review will consider the importance and prevalence of equine SID, and present an overview of the structure and function of the joint. The current evidence regarding the biomechanics of the SIJ in humans and horses will be related to the changes observed in equine SID and used to explore appropriate diagnostic and treatment modalities, and proposals for future management of equine SID.

Definitions of joint stability and neuromotor control

There is some confusion and controversy about the use of the term 'instability' as it pertains to the SIJ. A true clinical instability, where there may be damage to structures restraining a joint's movement, has been referred to by Lee (1995) as 'pathological hypermobility'. In the human SIJ, gross instability due to subluxation is described as injury resulting from significant energy input (traumatic) (Brolinson et al., 2003). Two such cases of acute catastrophic SIJ injury were reported by Haussler et al. (1999).

A functional instability refers to a situation where muscles and other restraining soft tissues are not providing appropriate resistance to movement for a given joint. This is thought to occur in the equine SIJ, where mild articular instability may result in gradual remodelling of the joint (Jeffcott et al., 1985). Brolinson et al. (2003) term this loss of functional integrity of the stabilising system of the SIJ 'microinstability', which is reported to be common in human patients with recurrent or chronic SID. In the vertebral column, the so-called neutral zone is a region of intervertebral motion where little resistance is offered by passive structures (Panjabi, 1992). This neutral zone is a clinically important measure of joint stability in humans and has been shown to increase with dysfunction or weakness of the vertebral column stabilising muscles (Panjabi, 1992).

Functional stability of the SIJ is thus reflected by the size of the neutral zone, which is affected by the stabilising muscles of the SIJ. The control or maintenance of functional stability is termed neuromotor control. This is important in preventing excessive movement that may lead to degenerative changes or predispose to pain and dysfunction. The prevalence of functional instability would be impossible to measure effectively in vitro, but a large neutral zone may be indicated by the presence of adaptive or degenerative changes in the SIJ.

Prevalence of SID in horses

The prevalence of chronic SID in racing and competitive horses is considered to be high, but specific diagnosis often remains equivocal (Jeffcott et al., 1985). Based on the variability of descriptions of equine SID in the literature, it is possible that there exist two clinical presentations of SID in horses (Dyson and Murray, 2003). The first occurs in performance horses, still in work, where the main clinical findings are pain and poor performance, with the signs usually responsive to regional analgesia (Dyson and Murray, 2003). As yet the pathology of these cases has not been well described, but due to the response to periarticular analgesia, it may be speculated to be associated with pain in periarticular structures as occurs in humans (Vleeming et al., 1996) rather than chronic bony changes of the SIJ. This may also explain why some horses have no significant asymmetry of the pelvis and gait changes are variable (Dyson and Murray, 2003).

The other, more debilitating form of SID, resulting in poor performance and more marked gait changes with asymmetry of associated muscles and/or bone, has been reported to be associated with chronic pathological joint changes (Jeffcott, 1980; Jeffcott et al., 1985). These horses show little pain response and show little improvement to regional analgesia (Jeffcott et al., 1985). These two variations of SID may in reality simply be different ends of a single continuum depending on the degree of bony changes that have occurred.

Jeffcott (1980) found clinical and radiological evidence of SID in 14% of 443 cases of equine thoracolumbar disorders. In a later study Jeffcott (1983) found radiographic evidence of sacroiliac pathology in 6/20 horses referred with a diagnosis of lumbosacral or pelvic injury. It has also been found in normal horses that degenerative changes occur with increasing age, and that there is an increase in surface area of the SIJ in horses with greater body weight (Dalin and Jeffcott, 1986a,b).

In a series of 36 thoroughbred racehorses that died or were euthanased at a racetrack in the USA, all were reported to show some degree of degenerative change at the SIJ (Haussler et al., 1999). The degenerative changes were graded mild (8%), moderate (61%) and severe (31%) in these horses, which were aged 2–9 years. Apart from two horses that displayed evidence of acute SIJ injury with joint laxity associated with catastrophic injury just prior to euthanasia, the remainder of the horses did not show any evidence of chronic SIJ laxity or fibrosis on postmortem examination, despite the presence of degenerative changes within the joint. The authors attributed the lack of laxity or fibrosis to the fact that horses with such pathology

would have poor performance, be removed from racing and would not be represented in this series. The apparent lack of clinical signs of chronic SID, despite such a high occurrence of degenerative changes, may have been due to abnormalities on the joint surfaces such as indentations, erosions and remodelling being adaptive changes, and therefore having minimal clinical significance. Conversely, SIJ laxity may not be a feature of low grade SID with the SID due to 'functional instability' of the SIJ as opposed to a 'clinical instability', and consequently less apparent at postmortem.

In a group of 74 horses with pain in the SIJ region, dressage horses and showjumpers were found to be more at risk for SID than horses from other disciplines including racing, eventing and general purpose (Dyson and Murray, 2003). Horses most affected by SIJ pain also tend to be older, taller and heavier (Dyson and Murray, 2003), with horses used for low level competition having less incidence of SIJ pain.

Anatomy and function of the SIJ

Structure

The equine SIJ lies between the wing of the ilium and the wing of the sacrum (Fig. 1). It is described as an atypical synovial joint because the iliac surface is covered in fibrocartilage and the sacral articular surface in hyaline cartilage (Dalin and Jeffcott, 1986a,b; Cassidy and Townsend, 1986; Haussler, 2004). The hyaline cartilage tends to be thicker, whiter and smoother than the fibrocartilage, which usually has a bluish-brown colour (Cassidy and Townsend, 1986; Dalin and Jeffcott, 1986a). The closely fitting joint surfaces are flattened and angled approximately 30° with the horizontal plane (Dalin and Jeffcott, 1986a). The shape of the joint varies from L-shaped to C-shaped and the contour of the joint may be flat or concavo-convex (Dalin and Jeffcott, 1986a; Goff et al., 2006) (Fig. 2).

The joint capsule closely approximates the joint margins and is reinforced ventrally by the strong ventral sacroiliac ligament (VSIL). The dorsal sacroiliac ligament (DSIL) has two parts – a cord-like portion runs caudomedially from the dorsal aspect of each tuber sacrale to the apices of the sacral spinous process (short, or dorsal DSIL), and a sheet-like projection runs from the caudal tuber sacrale and caudomedial aspect of the iliac wing to the lateral sacral crest, also blending ventrocaudally with the sacrotuberous ligament (long, or lateral DSIL) (Denoix, 1996; Haussler, 2004) (Figs. 3a and 3b). The interosseous ligament is situated dorsally to the synovial part of the articulation, and its fibres run vertically between the wing of the ilium and the wing of the sacrum on the first sacral vertebra

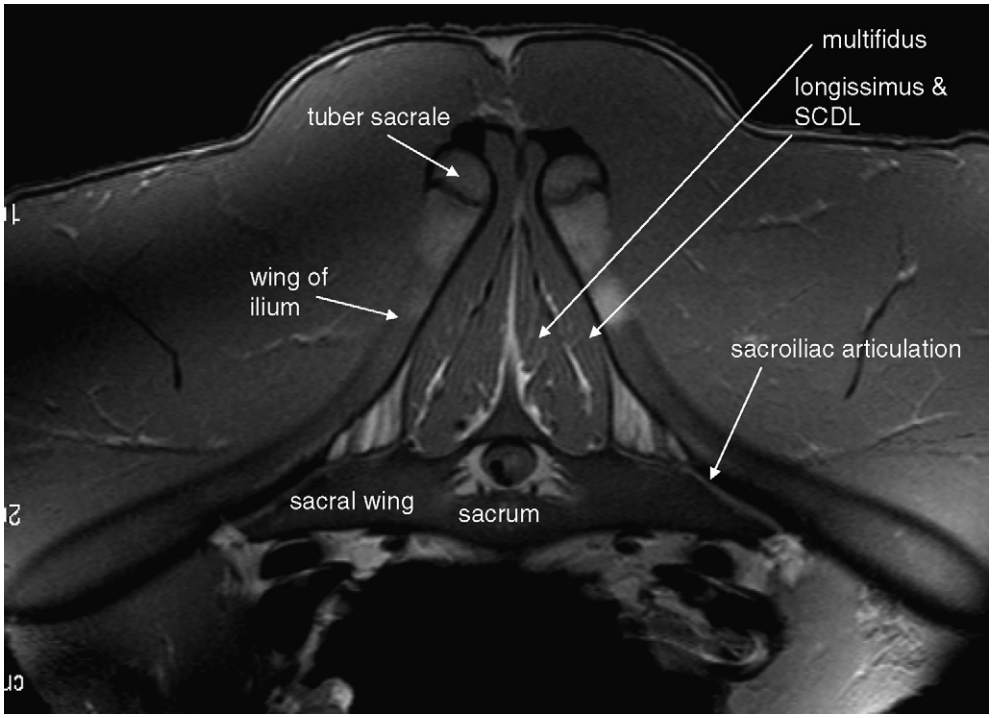

Fig. 1. Transverse section of magnetic resonance image of the sacroiliac region at the level of body of the first sacral vertebrae. High intensity (white) areas represent fat, low intensity (black) areas represent ligaments and cortical bone, while mid intensity areas (grey) represent muscle. The sacroiliac articulation can be seen between the wings of the sacrum and ilium. The low intensity region represents apposition of cortical bone and the fibrocartilage of the iliac surface and is adjacent to higher intensity sacral articular cartilage. The high intensity area dorsomedial to the sacroiliac articulation is the interosseous ligament region with fatty infiltration. The multifidus (medially) and longissimus and sacrocaudalis dorsalis lateralis (SCDL) (laterally) muscles can be seen filling the space between the dorsal ilia. Dorsally, overlying the tuber sacrale, the large muscle mass of the middle gluteal muscle can be seen.

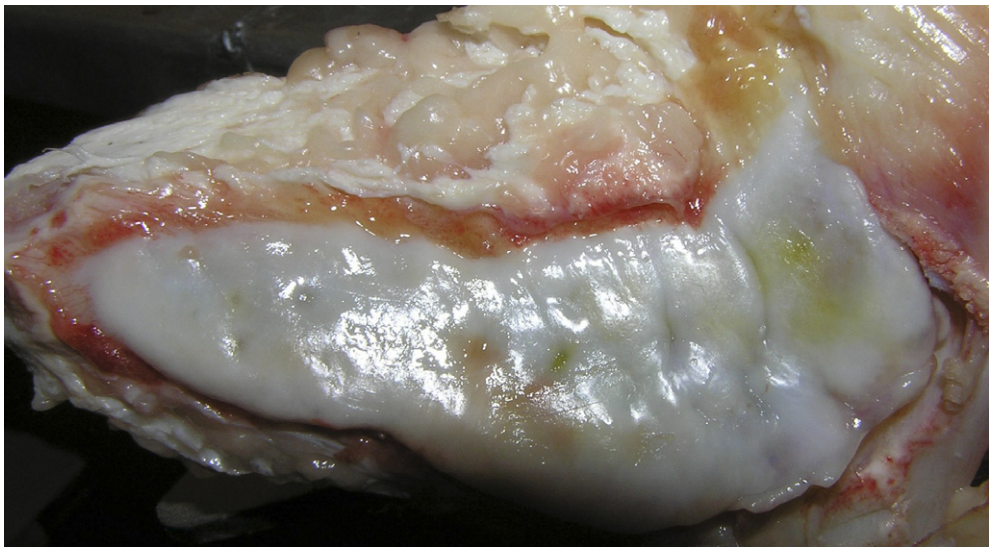

Fig. 2. The left sacral articular surface of a horse showing sock shaped, well defined articular margins. The caudal aspect of the joint is on the right hand side of the photograph. The features of slight discolouration and dimpling of the surface are considered to be within normal limits.

(Denoix, 1996). The sacrosciatic or broad sacrotuberous ligament does not cross the sacroiliac joint, but runs from the lateral aspect of the sacrum and transverse processes of the first and second caudal vertebrae to the ischiatic spine and tuber ischium in a broad quadrilateral sheet. The caudal border blends with the vertebral head of semimembranosus (Sisson, 1975). The middle gluteal muscle inserts into the DSIL and broad sacrotuberous ligament (Sisson, 1975). The cranial gluteal artery and vein cross the VSIL (Denoix, 1996). Other structures that lie ventromedial to the SIJ are the cranial gluteal nerve and the sciatic nerve (Haussler, 2004).

SIJ function and the myofascial system

The morphology of the SIJ in the horse indicates that it is designed for gliding movements. This is based on suggestions that the sacroiliac articular cartilage may never be subject to full weight bearing like most joints. It is more subjected to shearing than orthogonally directed compres-

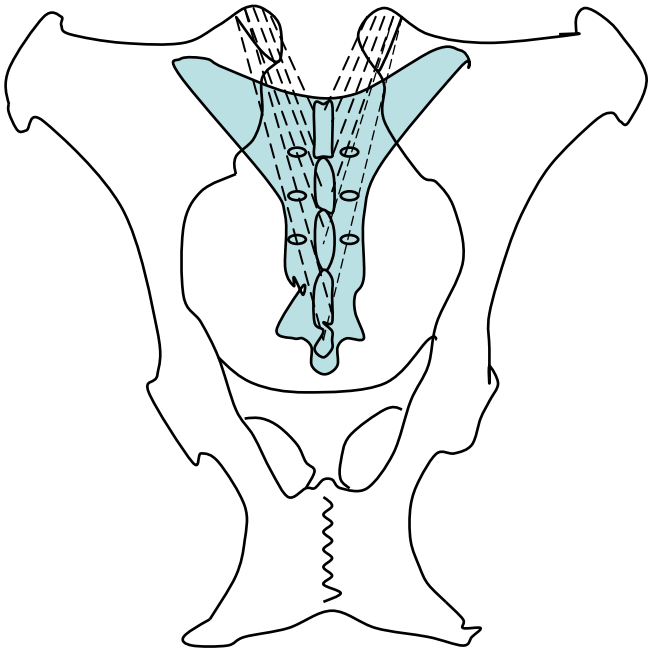

Fig. 3a. Schematic dorsal view of pelvis showing position of sacrum and short dorsal sacroiliac ligament (hatched lines) which runs from the tuber sacrale to the sacral spinous processes.

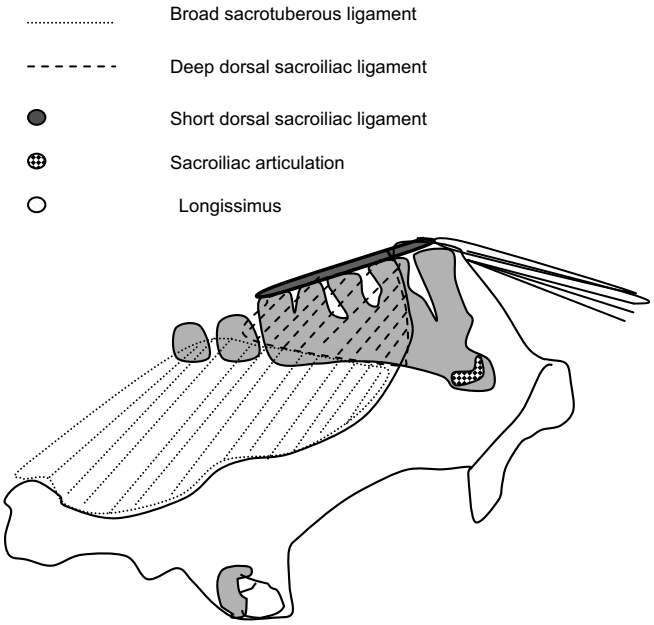

Fig. 3b. Schematic right lateral view of the pelvis showing the position of the sacroiliac joint between the wing of the ilium and the wing of the sacrum, sacrotuberous ligament and the two parts of dorsal sacroiliac ligament, and its relation to the tendon of the longissimus muscle.

sive forces (Ekman et al., 1986; Dalin and Jeffcott, 1986a,b).

The role of the SIJ is to transfer the forces from the horse's hindlimb to the thoracolumbar vertebral column (Jeffcott et al., 1985; Denoix, 1996). This transfer of forces may be achieved via the interconnections of the ligaments particularly the DSIL and sacrotuberous ligament, and the related fasciae. These ligaments are anchored through the thoracolumbar and gluteal fasciae and the hamstring–sacrotuberous ligament complex (Brolinson et al., 2003; Haussler, 2004).

The fascia of this musculoligamentous 'sling' is the attachment site for multiple major muscle groups of the vertebral column, abdomen and hindlimb and includes the fascia of the sacrocaudalis, or tail–head muscle group (morphologically similar to multifidus), of which sacrocaudalis dorsalis lateralis inserts as far cranially as the fifth lumbar vertebra (Stubbs et al., 2006). The sacrocaudalis group fascia is continuous cranially with the DSIL and the gluteal fascia, which is attached to the sacral spines as well as the DSIL (Sisson, 1975). The long head of the semimembranosus muscle attaches to the caudal border of the sacrotuberous ligament. The vertebral head of the biceps femoris arises from the sacrum as well as the tail–head fascia and sacrotuberous ligament. The thoracolumbar, gluteal and superficial abdominal fasciae are continuous (Sisson, 1975). The corresponding human fascial system contains nerves that belong to both a small diameter unmyelinated C-fibre system and a large diameter fibre system with encapsulated endings, typical of mechanoreception and proprioception. Thus, force transfer through the SIJ region may be under proprioceptive control of neural elements within the tissues surrounding the SIJ (Brolinson et al., 2003).

Innervation and neuromotor control

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. Research has demonstrated a link between stimulation of the SIJ in quadrupeds and muscle responses. It has also been established that SIJ innervation is similar in the human compared to other animals (Indahl et al., 1999; Murata et al., 2001; Brolinson et al., 2003). In rats, the ventral aspect of the joint is supplied by rami from the 1st lumbar to 2nd sacral nerve roots, and the dorsal aspect by rami from 4th lumbar to 2nd sacral nerve roots (Murata et al., 2001). In humans, caudal ligaments (DSIL) of the joint are supplied by lateral branches of the caudal primary rami of the 4th lumbar to 3rd sacral nerve roots (Mooney, 1997), and the more caudal ligaments (sacrotuberous and sacrospinous) contain axons derived from the 2nd to 4th sacral nerve roots (Mooney, 1997; Vilensky et al., 2002). The cranial ligamentous structures are supplied by the 2nd lumbar to the 2nd sacral nerve roots (Mooney, 1997).

The presence of both nerve fibres and mechanoreceptors in the sacroiliac ligaments indicates that both proprioceptive and nociceptive information is received from the SIJ (Sakomoto, 2001; Vilensky et al., 2002). Although it is not known how the central nervous system utilises such information, it seems likely that proprioceptive information is involved in neuromotor control of the trunk and pelvis (O'Sullivan et al., 2002; Hungerford et al., 2003). In a porcine model, stimulation of nerves in the ventral region of the SIJ resulted in contraction of the gluteus maximus and quadratus lumborum muscles, whilst stimulation of the superficial dorsal SIJ capsule resulted in muscular responses in the multifidus muscle group (Indahl et al., 1999). These results suggest that the SIJ may have a regulatory function in locomotion and posture. It is possible that the different parts of the SIJ have different roles in such locomotive and postural control (Indahl et al., 1999). It has been suggested that SID may result from mal-recruitment of the gluteus maximus muscle during weight bearing (Hossain and Nokes, 2005). Alternatively, it could be that altered stimulation to the ventral region of the SIJ results in its decreased contraction.

Motion at the SIJ

Little is known about the range and direction of motion possible in the equine SIJ. This is largely due to the coverage of the joint by the wing of the ilium and depth of the overlying middle gluteal musculature (Jeffcott et al., 1985; Faber et al., 2000) (Fig. 1). It has been assumed that there is minimal motion available at the joint due to the closely fitting joint capsule and surrounding ligaments. However, studies in humans have discovered that viscoelastic sacroiliac ligaments are subject to creep, suggesting that sustained postures or loads may result in deformation at the SIJ with time (Vleeming et al., 1992).

Studies have revealed that the ridges and grooves found on the opposing surfaces of the human SIJ are adaptations to forces transmitted through the SIJ (Vleeming et al., 1990b,c). Similar changes are seen in horses (Cassidy and Townsend, 1986; Dalin and Jeffcott, 1986a). It is thought that these macroscopic changes imply mobility exists and the changes are a response to increases in body weight and torques. These stabilising features of the joint are an adaptation to such forces (Vleeming et al., 1990b). Dalin and Jeffcott (1986b) found a strong correlation between equine SIJ articular surface measurements and body weight.

Measurement of motion at the SIJ

There is no doubt that some movement occurs at the SIJ, although the extent in both humans and horses is considered to be small and complex, with coupled movements between different planes of motion (Faber et al., 2000; Berthelot et al., 2006). Coupling of motion in three-dimensional joint kinematics refers to rotations or translations in

directions other than the main movement that occur concurrently with movement designated as the main movement at the joint (Lee, 1995).

Human studies

Validation of SIJ motion has been established both in vivo and in vitro. In vivo studies have involved colour Doppler imaging of vibration (Buyruk et al., 1995), kinematic studies using skin markers (Hungerford and Gilleard, 1998; Hungerford et al., 2001) and tantalum balls and Kirschner wires implanted into the pelvic bones (Jacob and Kissling, 1995; Sturesson et al., 2000). The authors agree that the rotational and translatory movements of the ilium relative to the sacrum are small, involving coupling of motion. A study using bone implanted markers found that during single leg stance tests, the mean rotation of the ilium around the sacrum was 0.2° with a mean translation of 3 mm (Sturesson et al., 2000). The average rotation at the SIJ during single leg stance test was 2° (Jacob and Kissling, 1995).

Studies using skin markers found reliable patterns of motion at the SIJ during single leg stance as well as significant differences in symptomatic and non-symptomatic subjects ($P < 0.05$) (Hungerford and Gilleard, 1998; Hungerford et al., 2001). On the non-affected SIJ, mean caudal ilium rotation was 1° accompanied by a mean translation of the ilium caudally of 4 mm, and ventrally of 2.3 mm. On the affected SIJ, the mean rotation of the ilium relative to the sacrum was 2°, accompanied by a translation of the ilium of 7.5 mm caudally and 3.5 mm ventrally. A similar pattern of increased joint laxity in symptomatic versus non-symptomatic people was demonstrated using Doppler imaging of vibration across the joint (Buyruk et al., 1995, 1999; Damen et al., 2002).

Equine studies

The amount and direction of SIJ motion in the horse has not yet been successfully measured in vivo. However a recent in vitro study revealed small amounts (<1°) of motion of the sacrum relative to the ilium, during thirty cycles of flexion/extension of the lumbosacral junction (Degueurce et al., 2004). The study measured nutation and counternutation which describe the relative motion of sacrum with respect to the ilium in the sagittal plane. Nutation refers to an increase in distance between the ischial bones and the sacrum, and counternutation refers to a decrease in this distance. The amplitude of SIJ nutation doubled after desmotomy of DSIL and sacrotuberous ligaments (Degueurce et al., 2004) which implies that DSIL and sacrotuberous ligaments have a role in limiting motion of the ilium relative to the sacrum in the sagittal plane.

However, due to the anatomical orientation of the SIJ, lying at an angle of 30° to the horizontal (Dalin and Jeffcott, 1986a), movement in other planes may be more representative of in vivo motion. In another in vitro study, measurement of SIJ motion was undertaken during the application of manual forces to the ilium in sagittal, lateral and oblique planes, against a fixated sacrum (Goff et al., 2006). While results for sagittal motion were similar to those in the previous study, greater degrees of motion were recorded for lateral and oblique rotation in the coronal and axial planes (2.56° ± 0.29° and 2.25° ± 0.29°, respectively). Further, when manual forces were applied in the sagittal plane (cranial rotation), there was also movement in the axial (1.28°) and transverse planes (1.25°). This coupled motion about the ilium during movements, suggests that the motion at the SIJ is complex.

Degenerative or adaptive changes around the equine SIJ and the relationship with biomechanics

Articular surface changes

A study of the gross morphology of the SIJs from 43 horses up to fourteen years of age, which had no history of a back problem, revealed a small percentage of joints with small and medium sized spur formation at the sacral joint margins (Dalin and Jeffcott, 1986a). Only small spur formations were reported at the iliac joint margins, occurring on the caudal and medial margins. Most of the features affecting the sacral articular surfaces, such as small clefts, fissures, wrinkling, irregularity of joint outline, and unevenness of articular cartilage appeared to be related to increasing age. The iliac articular surface of all older horses had a brownish appearance often with wrinkling of the surface. Compared to the sacral side, crevices and creases on the iliac side were less common, but there were also areas devoid of articular cartilage.

A postmortem study of SIJs in eleven horses with chronic poor performance revealed evidence of cartilaginous degeneration in all cases, but this was not dissimilar to changes seen in a general population of horses (Jeffcott et al., 1985; Dalin and Jeffcott, 1986a). Two horses displayed histological evidence of arthrosis, and all but one had articular extensions, mostly on the caudal margin of the joint. Small periarticular spurs were detected close to the joint capsule in two cases. The authors concluded that the most significant finding, remodelling and enlargement of the articular surfaces, may have resulted from a prolonged mild instability of the SIJ (Fig. 4). This may be what Panjabi (1992) referred to as functional instability with increased neutral zone.

In a series of 36 thoroughbred racehorses, degenerative changes were observed at the sacral and iliac articular surfaces in 100% and 72% of specimens, respectively. The types of changes observed included lipping of articular surfaces, cortical buttressing, indentation of articular surface, osteophytes and intra-articular erosions (Haussler et al., 1999). The medial aspect of the SIJ showed the most degenerative change. On the sacral surface, articular lipping was found medially, ventromedially and ventrally, whereas on the iliac surface lipping was only found medially. Sacral

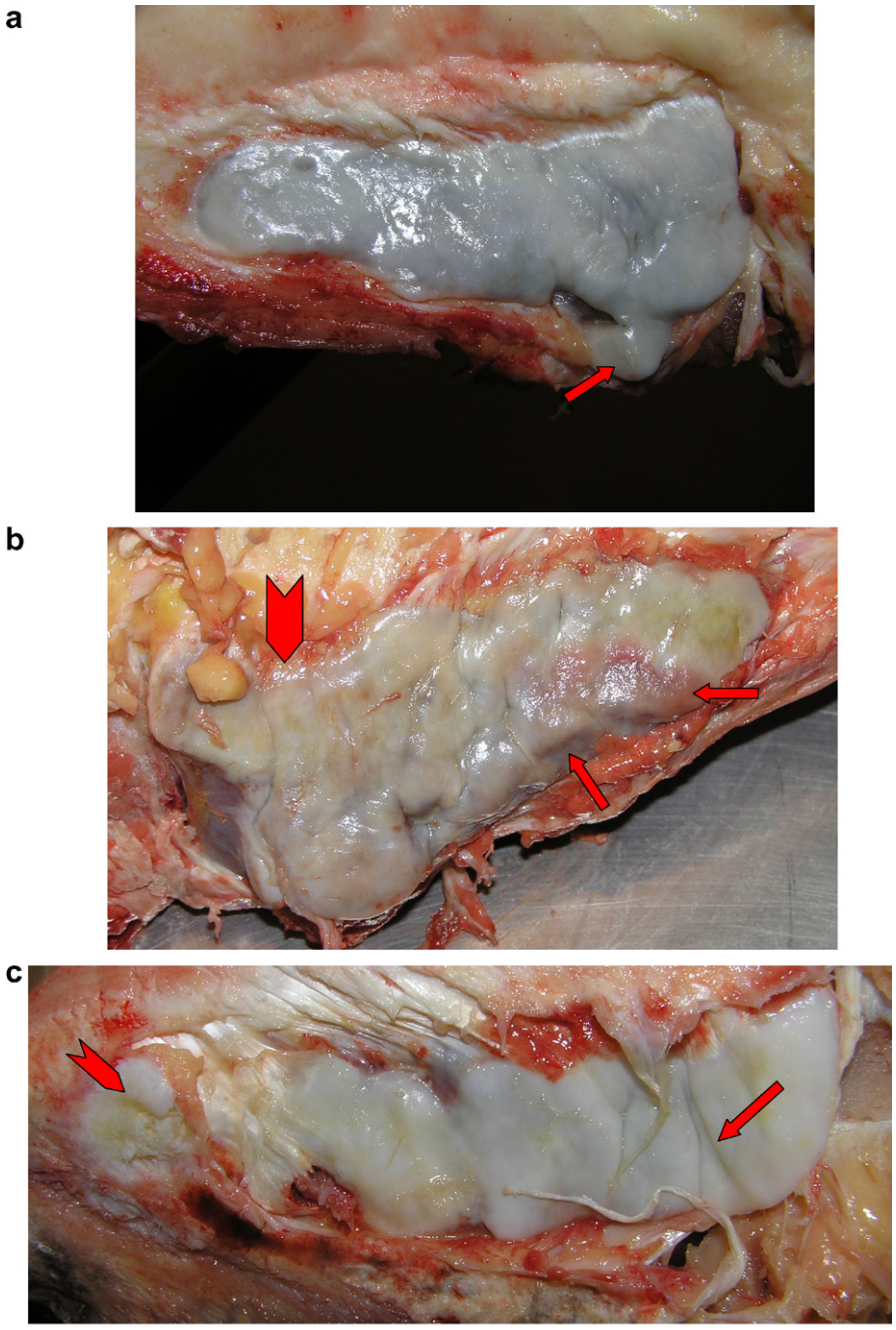

Fig. 4. Variations in sacral articular surface in horses are based on the categories proposed by Jeffcott et al. (1985) and Dalin and Jeffcott (1986a). (a): Type 1 – This is an example of articular extension (arrow) on the caudo/medial margin of the left sacral articular surface of a horse. The caudal aspect of the joint is towards the right side of the photograph. (b): Type 2 – Broadening of the right sacral articular surface can be seen, mainly in a dorso-ventral direction towards the caudal aspect of the joint, which is toward the left side of the photograph (arrow head). This broadening results in less clearly defined joint margins than those of the normal sacral articular surface – compare to Fig. 2. The articular cartilage also appears irregular, with some areas of early thinning (arrows). (c): Type 3 – Left sacral articulation of a horse showing a joint extension on the cranial aspect of the joint, which is towards the left side of the photograph. This extension fits into a corresponding notch on the iliac articular surface. Also visible are some minor folds in the joint surface (arrow).

cortical buttressing was ventromedial and ventral and iliac indentations were ventromedial and ventral. Osteophytes were more uniformly distributed around the SIJ margins. While such changes were reported as pathological, some of these may be subclinical adaptive changes (Vleeming et al., 1990a). Further, in the population of horses considered by Haussler et al. (1999), SIJ articular lesions were symmetrical whereas sacral asymmetry and asymmetry of articular extensions occurred in horses with history of chronic poor performance (Jeffcott et al., 1985).

Dyson and Murray (2003), in their series of 74 horses, described one horse with severe clinical signs and a positive response to regional local anaesthetic injection. On subsequent postmortem examination, it was reported to have extensive modelling changes of both SIJ. The authors do not describe the changes in detail, but comment that four additional horses, with similar clinical signs, also had extensive modelling changes at the SIJ postmortem.

The presence of degenerative SIJ changes may indicate a response to altered mechanical load or functional instability and an increased neutral zone. The location of joint surface changes recorded by two studies was predominantly ventrally, medially and caudally (Jeffcott et al., 1985; Haussler et al., 1999). These degenerative changes may be the cause or result of altered nerve stimulation at the medial aspect of the joint and altered contraction of the middle gluteal muscle (Indahl et al., 1999).

The presence of intra-articular erosion of cartilage was also seen in some horses (Jeffcott et al., 1985). However, it is not known whether such degenerative changes are a cause of pain (Cassidy and Townsend, 1986). Some evidence in humans suggests that degenerative osteoarthritic changes of the spine and pain have poor correlation (Witt et al., 1984).

Ligamentous changes

Insertional desmopathy is a term synonymous with enthesopathy (Denoix, 1996). Haussler et al. (1999) noted the presence of enthesophytes near the sacrum and the ilium in 39% in their series. These were usually associated with attachment of SIJ ligaments. Unlike articular surface changes, the presence of enthesophytes was not associated with age or prevalence or severity of degeneration at the SIJ. Denoix (1996), using ultrasonography, noted enthesopathy-like changes at the DSIL insertion into the tuber sacrale, such as bone surface irregularities, hypoechoeic areas and modified fibre orientation close to the ligament insertion as well as within the ligament in clinical cases with painful response to palpation of the DSIL.

In human extremity joints, the frequency of enthesophytes in the absence of underlying forms of arthritic disease suggests that they are a result of mechanical factors rather than arthritic disorders. The frequency of enthesophytes increased with age, but was independent of sex or the site examined, and there was a plateauing in frequency after the age of sixty (Shaibani et al., 1993). In the Achilles tendon, enthesophytes can develop without the need for preceding microtears or any inflammatory reaction. The increased surface area created at the tendon–bone junction may be an adaptive mechanism to ensure the integrity of the interface in response to increased mechanical loads (Benjamin et al., 2000). It may be concluded that the enthesophytes reported by Denoix (1996) and Haussler et al. (1999) could be evidence of increased mechanical load through the SIJ.

Process of SIJ degeneration

Studies in animals have shown that unloading of a joint, rather than overloading, combined with poor muscular control and weakness, may predispose to joint degeneration (Herzog et al., 2004; Laurent et al., 2006). This supports the concept of functional instability and increased neutral zone, and is consistent with the theory of Jeffcott et al. (1985) following a postmortem investigation of SIJs of horses with chronic poor performance. In humans with joint instability related to cranial cruciate ligament injury, there is rapid development of degenerative changes characteristic of osteoarthritis in femoral articular cartilage (Nelson et al., 2006). Chondral defects cause changes in biochemical and biomechanical properties of equine articular cartilage adjacent to the area of defect. This may represent remodelling as an adaptive process or degeneration secondary to an altered distribution of joint forces (Strauss et al., 2005).

If the equine musculoligamentous 'sling' and fascial system surrounding the SIJ is under proprioceptive control of neural elements within the tissue, then any cause of altered proprioception or altered load transfer through the SIJ may be a reason for development of joint surface changes in horses. If the forces are increased due to body mass or joint torque, and neuromotor control systems are within normal limits, then articular surface changes, such as development of opposing ridges and grooves, or indentations, may be considered to be adaptive. Should the neuromotor control in the SIJ region be compromised, an increase in the shearing forces being transmitted through the sacroiliac articular surfaces may occur, due to functional instability or laxity, resulting in degenerative changes such as erosions. Altered weight bearing or load transfer may be due to direct trauma to the pelvis and SIJ region, or may be secondary to hindlimb or thoracolumbar injury.

Causes of SID

The causes of pain in equine SID are still speculative (Dyson and Murray, 2003). It has been questioned in human musculoskeletal medicine whether pain arises from the articular part of the SIJ, or the tissue surrounding the joint such as the DSIL (Haufe and Mork, 2005; Berthelot et al., 2006). Vleeming et al. (1996) have reported the human DSIL as a pain producing structure.

In horses, ultrasonography has been used over the dorsal DSIL to indicate the presence of desmitis (Engeli et al., 2004b) and local analgesia of the structure can determine if it is a pain causing structure (Engeli and Haussler, 2004). Dyson and Murray (2003) performed periarticular infiltration of 20 mL of local anaesthetic solution around the SIJ of 34 horses with suspected SID, and subsequently found a marked improvement in performance in all horses. However, the sacroiliac region injection technique described by Dyson and Murray (2003) cannot be considered specific to the SIJ due to the entry point of needle, angle of inser-

tion, length of needle used, and the relatively large volume of local anaesthetic solution delivered (Engeli and Haussler, 2004). Diffusion of local anaesthetic solution into a number of structures in the sacroiliac and lumbosacral region can occur some distance from the site of injection when volumes are between 15 mL and 20 mL (Engeli and Haussler, 2004). The structures involved in production of SI region pain remains unclear, based on the results of Dyson and Murray (2003). Further studies are required involving more specific sacroiliac periarticular injection techniques using 8–9 mL of anaesthetic solution per SIJ deposited as close as possible to the medial joint margin (Engeli and Haussler, 2004; Engeli et al., 2004a).

Regardless of the source of pain, there is evidence that altered neuromotor control around the SIJ may be important in contributing to, or be the result of SIJ pain (Indahl et al., 1999; O'Sullivan et al., 2002; Richardson et al., 2002; Hungerford et al., 2003; Hossain and Nokes, 2005). Hungerford et al. (2003) have demonstrated evidence of the importance of motor control and coordination of recruitment of lumbopelvic muscles for normal function and stability of the SIJ. Contraction of the human transversus abdominis muscle decreased SIJ laxity as measured by Doppler imaging of vibration (Richardson et al., 2002).

In humans with SIJ pain, delayed onset of obliquus internus abdominus, multifidus, and gluteus maximus surface electromyographic activity suggests an alteration in the ability of these muscles to assist in transferring load from the lower limb through the pelvis during single leg stance (Hungerford et al., 2003). This supports research by Hungerford and Gilleard (1998); Hungerford et al., 2001 demonstrating altered kinematics of the SIJ associated with weight-bearing in individuals with pelvic/SIJ pain and suggests a role for muscles in dynamic SIJ stability. Individuals with SIJ pain show compensatory strategies of the neuromuscular system, in an attempt to enhance stabilisation of the SIJs during straight leg raising (O'Sullivan et al., 2002). The ability of clinicians to manage SID in humans has been enhanced not only by kinematic evidence regarding amount and patterns of SIJ motion, but also by studies involving investigation of neuromotor control of the SIJ.

Clinical assessment of the SIJ

Humans

There is no single clinical technique that is both sensitive and specific for the diagnosis of SID (Brolinson et al., 2003). Fluoroscopically guided sacroiliac injection has been reported to be the only definitive diagnostic method (Dreyfuss et al., 2004), but even this may have limited specificity. Contrast medium injected into the SIJ was shown by Fortin et al. (1999) to leak into adjacent tissues in 61% of cases.

It has recently 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). These tests are described as pain provocation tests for the SIJ, and are designed to compress the articular surfaces and/or stress the extra-articular structures of the joint. Pain provocation tests include Gaenslen's test, distraction, compression, thigh thrust, and sacral thrust tests (Van der Wurff et al., 2006; Laslett et al., 2005; Kokmeyer et al., 2002) and have an acceptable level of interexaminer reliability (Laslett and Williams, 1994). Two of four positive tests (distraction, compression, sacral and thigh thrusts) or three or more of the full set of five tests are the best predictors of SIJ pain, verified by a positive response to intra-articular analgesia of the SIJ (Laslett et al., 2005a; Kokmeyer et al., 2002).

When all five SIJ provocation tests are negative, painful SIJ pathology may be ruled out (Laslett et al., 2005a). In 216 patients with lumbopelvic pain, a physiotherapist was able to identify, using manual SIJ testing techniques as part of the blinded clinical diagnosis, the tissue source of the pain (lumbar facet joint, intervertebral disc and SIJ) compared to diagnosis based on available reference standards such as imaging and facet and SIJ blocks (Laslett et al., 2005b)

Manual tests to estimate the range (hypo/hypermobility) and direction of SIJ motion are also used clinically to gather sensitive information regarding the functional status of the SIJ. These include the degree of movement of the SIJ during application of manual force and, specifically, in analysing movement of the sacrum relative to the pelvis in weight-bearing through the pelvis (Lee, 2004). Thus, in human musculoskeletal medicine a battery of clinical tests exists, where manual SIJ pain provocation tests provide the diagnostic standard and SIJ motion tests allow manual therapists to gain information regarding the functional status of the SIJ.

Equines

Clinical signs

Clinical examination remains important in the diagnostic assessment of horses with SID (Haussler, 2003) although clinical presentation may vary as discussed above. Horses with SID may have marked or mild asymmetry of the bony prominences of the pelvis (tuber coxa and tuber sacrale), and may show asymmetry of the hindquarter muscles (Jeffcott, 1980; Jeffcott et al., 1985; Dyson and Murray, 2003). Lameness and gait asymmetries, particularly at slow speeds, may be noticeable (Jeffcott, 1980) and horses may be unable to weight bear well on the affected hindlimb, especially when the contralateral leg is lifted for periods of time such as when being shod (Tucker et al., 1998; Dyson and Murray, 2003). Plaiting of the hindlimbs has also been noted at the trot with scuffing or dragging of the hind toes (Jeffcott, 1980) but a variety of gait patterns were described by Dyson and Murray (2003), with some horses showing more than one gait abnormality. The most consistent clinical feature is reduced hindlimb impulsion

and history of poor performance (Jeffcott et al., 1985; Dyson and Murray, 2003).

Manual tests

No single manual test of the ilium or sacrum is indicative of the presence of SID, but a battery of these tests can be helpful in diagnosis. In acute cases there may be spasm in the middle gluteal muscle, and vertebral heads of semimembranosus, semitendinosus and biceps femoris muscles with little muscle atrophy (Haussler, 2003). Pain provocation tests induce variable pain responses in chronic SID. Such tests include (1) palpation over the short DSIL, (2) SIJ compression tests via a medially directed force on the dorsal apices of the tuber sacrale or caudomedially directed force on the tuber coxae, (3) a ventral force directed though the sacral spinous process and sacro–caudal junction, and (4) detection of pain on palpation of the middle gluteal muscle (Tucker et al., 1998; Haussler, 2003; Varcoe-Cocks et al., 2006). As in humans, motion tests to evaluate movement have been described by Haussler (2003). However, it is not yet clear as to which structures of the SIJ are being tested.

Local analgesia

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 and Haussler, 2004). Engeli and Haussler (2004) have reviewed a number of periarticular and intra-articular injection techniques, and have described a technique to reliably deliver an appropriate volume of anaesthetic solution to an area immediately adjacent to the caudal two-thirds of the SIJ, with some diffusion. They also describe analgesia of the dorsal portion of DSIL. Thus, the use of local analgesia may help to discriminate between pain arising from the SIJ region and sacroiliac ligament desmitis (Engeli and Haussler, 2004), but does not discriminate between pain arising from periarticular joint structures, surrounding muscles and fascia, or neurovascular structures. This is due to diffusion of injected material within and along structures adjacent to the SIJ, thus it remains unclear as to which structures are being affected by the analgesia (Engeli and Haussler, 2004).

Diagnostic imaging

There are a number of imaging techniques available, but they have some limitations. The size of the pelvic muscles, superimposition of large bowel on skeletal structures, and limited possibility of projections, have all posed the main difficulties in radiology (Jeffcott, 1983). Dorsal recumbency and thus general anaesthesia are required for both radiography and linear tomography (Jeffcott, 1983). Nuclear scintigraphy may be useful to identify SID in combination with other clinical signs (Dyson et al., 2003). However, it is non-specific for the type of injury whether bony or soft tissue based (Tucker et al., 1998). Abnormal radiopharmaceutical uptake may be associated with osteoarthritis, strain of insertions of ligaments or incomplete fracture of the ilium at base of the SIJ (Davenport-Goodall and Ross, 2004).

Ultrasonography has been used to detect fractures of the tuber coxae, wing and shaft of ilium (Tucker et al., 1998; Pilsworth et al., 1994) as well as abnormalities of the short DSIL and asymmetries and irregularities of the tuber sacrale (Denoix, 1996; Tomlinson et al., 2003). The latter feature may be considered a normal finding (Engeli et al., 2004b). Engeli et al. (2004b) suggest that incongruencies between right and left DSIL may be due to an unlevel tuber sacrale, and so should not be the sole finding to determine the presence of sacroiliac desmitis. The width of the SIJ and the VSIL plus periarticular remodelling has also been accurately measured (Denoix, 1996; Tomlinson et al., 2003; Engeli et al., 2004b). Thus, when used in conjunction with other diagnostic procedures, ultrasound appears to be a useful imaging modality, and may be used to image a variety of musculoskeletal features of the sacroiliac region (Engeli et al., 2004b).

Management of SID

In humans, the use of analgesics, anti-inflammatory agents, sacroiliac and periarticular injection of corticosteroid, and prolotherapy (injection of a sclerosing agent) have each been advocated as sole treatments for SID, but effective treatment and rehabilitation often relies on development of a specific physiotherapy program based on biomechanical findings (Brolinson et al., 2003). Such a program is achieved via manipulation and/or manual techniques to restore balance in joint kinematics and application of specific muscle re-training to restore length and strength balance in lumbopelvic/lower limb musculature (Dreyfuss et al., 2004). This approach addresses the articular, muscular, fascial and ligamentous components in the lumbopelvic–hip complex, and is developed on a case by case basis (Dreyfuss et al., 2004).

Management of SID in horses is based on the clinical presentation and includes use of rest, and anti-inflammatory medication, prolotherapy and exercise (Haussler, 2003). Reduction of pain associated with SID is important, but it should be noted that complete rest may be contraindicated due to the possible adverse effects of reduced pelvic and hindlimb muscle function and worsening functional instability of the SIJ (Haussler, 2003). In cases of chronic SID, anti-inflammatory medication can result in temporary improvement in performance (Jeffcott et al., 1985; Dyson and Murray, 2003), however, it is ideal to rehabilitate the horse so improvement is consistent and lasting. A specific rehabilitation program based on biomechanical findings may achieve this.

Prolotherapy, or the intra-articular injection of analgesic or anti-inflammatory medication, is impractical in the horse due to the inaccessibility of the SIJ (Haussler, 2003). However, while regional analgesia is considered a viable alternative to intra-articular injection, the effects of

such may represent a reduction in pain in periarticular structures, including supporting musculature and nerves. Thus, there is a risk of anaesthetising the structures contributing to neuromotor control of the SIJ, as was postulated to occur in one instance (Engeli and Haussler, 2004). This could potentially increase the transmission of adverse movement or forces through the SIJ.

Exercise to build up the muscles of the back and hindquarters (Jeffcott and Dalin, 1985) is more appropriate. However, recommendations for exercise to manage SID have been non-specific and there is a clear need for more specific muscle re-training to enhance functional stability of the region, and ultimately improve performance, in individual cases. 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 the human SIJ. The former may guide the development of manual mobilisation and/or manipulation techniques which can be applied to the equine pelvis and SIJ, to improve joint kinematics. The latter may enable the application of specific exercise, as demonstrated in the case of human SIJ hypermobility (Richardson et al., 2002).

Conclusion

SID is an important and prevalent cause of poor athletic performance in horses. However, current knowledge of specific diagnosis, management and rehabilitation strategies for SID is limited and further investigations are clearly warranted. The opportunity to employ the principles of biomechanics and neuromotor control should be considered as they have dramatically improved both the diagnosis and treatment of SID in human medicine in recent years. The development of a range of specific manual techniques to test the biomechanics of the SIJ offers potential for the assessment of equine SID. This could lead to a series of SIJ provocation tests used with other diagnostic modalities, such as scintigraphy and ultrasonography, to provide a more definitive non-invasive diagnosis of SID. Despite the many difficulties discussed in this review much has been achieved in recent years and the outlook for a better understanding of sacroiliac dysfunction in the horse is encouraging.

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