Observer Reliability assessing 'Threshold Levels' in color Doppler imaging of vibration of the sacroiliac joint video clips

James Crossley

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Declaration

Name of candidate:

This Research Project is submitted in partial fulfilment for the requirements for the Unitec degree of Masters of Osteopathy

Candidate's Declaration

I confirm that:

- This Research Project represents my own work;
- The contribution of supervisors and others to this work was consistent with the Unitec Regulations and Policies.
- Research for this work has been conducted in accordance with the Unitec Research Ethics Committee Policy and Procedures, and has fulfilled any requirements set for this project by the Unitec Research Ethics Committee.

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THESIS ABSTRACT

The concept of sacroiliac joint (SIJ) motion dysfunction is an area of contention in manual therapy. Manual methods of assessing the SIJ have been constrained by poor reliability and a lack of an agreed 'gold standard'. Doppler Imaging of Vibration has been proposed as one alternative method of evaluating SIJ motion. The aim of this thesis was to determine the intra-rater and inter-rater reliability of a group of observers scoring 'Threshold Levels' using pre-recorded video clips of Doppler Imaging of vibration (DIV) of the SIJ. 12 observers of varied clinical experience ranked 12 repeated and randomly assorted DIV clips. Intra-observer reliability ranged from 'moderate' to 'very high'. Inter-observer reliability was 'very high' indicating that observers can reliably assess 'Threshold Levels' for DIV of the SIJ in pre-recorded video clips. The present study demonstrates that observers can make reliable judgments regarding Threshold Levels of DIV of the SIJ using video clips. Further research is required to establish the validity of the technique, including work demonstrating correlation with alternative measures of SIJ laxity/stiffness.

Keywords:

Sacroiliac joint, motion, Doppler, vibration, reliability, sacroiliac joint dysfunction

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Introduction to thesis

The following thesis is structured in three sections:

Section 1. Literature Review
Section 2. Manuscript
Section 3. Appendices

The literature review provides the theoretical basis for the experimental study reported in Section 2 of the thesis. Section 1 includes an overview of relevant literature with specific reference to the controversies surrounding movement abnormality at the sacroiliac joint. Topics covered in 'Section 1' include a brief review of the anatomy of the sacroiliac joint and an overview of the utility of clinical testing. The concept of 'sacroiliac dysfunction' is introduced, followed by an overview of the osteopathic perspective of sacroiliac joint dysfunction, including historical background and current application. The clinical examination of the sacroiliac joint is then reviewed, including the three main areas of manual testing, which are; pain provocation, positional assessment and motion testing.

The use of an objective imaging-based approach is introduced as a possible alternative, or adjunct, to manual testing. A rationale for the use of Doppler Imaging of vibration is presented with discussion of the existing literature related to this method. Requirements for further research are identified and a research question is proposed that drives the experimental investigation, reported in 'Section 2' of the thesis.

Section 1: Review of Literature

The sacroiliac joint and low back pain

Low back pain is one of the most common musculoskeletal conditions affecting 70-85% of the population at some stage of life (Andersson, 1999). Whilst the majority of acute low back pain disorders resolve within a four-week period, reoccurrence is common (Croft et al. 1998), and a small number of disorders become chronic and represent a major cost to society (Dillingham, 1995, Croft et al., 1998). Of the total number of cases, 85% are classified as “non-specific” because a definitive patho-anatomical diagnosis cannot be made using current clinical methods (Dillingham, 1995). The causes of non-specific low back pain are multidimensional but may include contributions from patho-anatomical, neurophysiological, biomechanical and psychosocial factors (O’Sullivan, 2005). A biomechanical model emphasises the role of joint restriction in creating mechanical stress on lumbo-pelvic tissues thereby predisposing ‘mechanical lower back pain’ (O’Sullivan, 2005). The sacroiliac joint (SIJ)has been identified as one potential site of mechanical restriction. The following discussion explores these issues, starting with a concise review of anatomy of the region.

Anatomy of the sacroiliac joint

The anatomy and physiology of the SIJ has been well described in many texts. Whilst an extensive review of *all* anatomical aspects of the SIJ is beyond the scope of the present review, an appreciation of the structure and function of the SIJ is helpful in understanding the theoretical contribution SIJ motion may make in predisposing mechanical low back pain.

The SIJ is a synovial joint formed by the articulation of the sacrum suspended between the two ilia, described as a “reverse keystone” between the two pelvic bones (Vleeming, 2007). The SIJ is inherently stable (Vleeming, 1990a and b), having to withstand large compressive forces during weight bearing (O’Sullivan and Beales, 2007). The SIJ is particularly susceptible to shear forces (Vleeming, 2007) and the terms “form” and “force” closure were coined by Vleeming (2007) to describe the forces involved in maintaining joint stability.

‘Form closure’ relates to the stability derived from structural factors including the bony morphology (Vleeming, 1990). Several structural elements contribute to ‘form closure’ of the SIJ. The sacrum is wider cranially than caudally and wider anteriorly than posteriorly, allowing the sacrum to become ‘wedged’ into the ilia (Vleeming, 2007). A series of bony ridges and grooves on the articular surfaces of the sacrum contribute to stability by creating a high friction co-efficient (Vleeming, 1990a). Form closure is optimised during nutation (forward rotation of the sacrum relative to the iliac bones), when the SIJ has maximum congruence of its articular surfaces (Vleeming, 2007). During counter-nutation (backward rotation of the sacrum relative to the ilia) the pelvis is thought to be relatively less stable and additional support is provided by ligamentous and muscular structures (Foley and Buschbacher, 2006).

‘Force closure’ refers to the functional factors assisting stability, including the action of various muscles that act to enhance pelvic stability, allowing effective load transfer (O’Sullivan and Beale, 2007). Richardson et al. (2002) demonstrated that voluntary contraction of deep stabilising muscles (Transverse abdominis, multifidus, internal oblique) increases the stability of the SIJ. The combined effect of form and force closure means that the movement of the SIJ is inherently small (Jacob and Kissling, 1995).

Movement at the sacroiliac joint

The SIJ has been described as moving in nutation (anterior rotation), counter-nutation (posterior rotation), angular rotation and translation (Wilder et al., 1980).Whilst movement occurs, the requirements for stability of the SIJ and its role in resisting shear forces means this movement is very small in non-weight bearing (Sturesson et al., 1989, Jacob and Kissling, 1995, Vleeming et al., 1992) and even less in weight bearing (Sturesson et al., 2000). Sturesson et al. (2000) measured motion at the SIJ in participants during standing hip flexion using roentgen stereophotogrammetric analysis (RSA) (Sturesson et al., 2000). Range of motion at the SIJ was less than 4 degrees of rotation and up to 1.6 degrees of translation (Sturesson et al., 2000). Greatest amount of movement, as much as 5.6 +/- 1.4mm, occurs when going from recumbent to standing (Weisl, 1955). It is this inherent lack of movement at the SIJ that has given rise to debate within manual therapy regarding its functional significance.

Sacroiliac dysfunction

The concept of '*SIJ dysfunction'* remains a controversial area (Freburgerand Riddle, 2001), with great debate regarding what constitutes dysfunction, its relationship to mechanical low back pain and treatment using joint manipulation.

Definition of sacroiliac joint dysfunction

There appears to be considerable confusion in the literature when describing 'sacroiliac joint dysfunction'. Whilst SIJ dysfunction has been described as "pain in or around the region of the joint due to mal-alignment or abnormal motion of the joint" (Riddle and Freburger, 2002), careful reading of the wider literature reveals that pain has been identified at the SIJ without any discernable mal-alignment or abnormal motion (Sturesson et al, 2000). Conversely, motion abnormality has been found to exist *without* the SIJ being a source of pain. Confusion is heightenedas the terms SIJ dysfunction and SIJ pain are commonly used interchangeably, as though they have the same meaning (Laslett et al, 2005). Various terms have been used to describe movement at the SIJ or lack of it, including SIJ 'stiffness' and 'laxity'. These terms are poorly described in the text and are at times used interchangeably.

An osteopathic perspective on sacroiliac joint dysfunction

In Osteopathic circles, it is a commonly held concept that the sacroiliac joint not only moves, but this subtle movement is very important for the biomechanics of the spine and pelvis (Kissling and Jacob, 1996). Various Osteopathic models have been proposed to describe and categorize Osteopathic SIJ lesions (Fryette, 1954, Mitchell and Mitchell, 1995, Kuchera and Kuchera, 1992). Historically, Dr. H. Magoun started lecturing on sacral dysfunction in 1942, in 1954 Harrison Fryette discussed sacroiliac joint, it's anatomy, dysfunctions and treatment in the "Principles of Osteopathic Technique"' and in 1958 Fred Mitchell wrote regarding sacroiliac dysfunction in the paper "Structural Pelvic Function". These papers laid the foundation for Osteopathic principles regarding SIJ dysfunction.

Many Osteopathic practitioners base their treatment on the concept that disturbance of SIJ motion are thought to have serious consequences for efficient biomechanical function (Stone, 2002). The sacrum is required to be "level in order for the spine to be correctly orientated in static posture and it needs to be symmetrically mobile during locomotion to ensure the transference of a uniform oscillation of motion through the spinal column"

(Stone, 2002, pg. 167). What movement is present is thought to be fundamental in the efficient transmission and absorption of gravitational and ground reaction forces during weight bearing and locomotion within the lumbo-pelvic region (Hossain & Nokes, 2005). SIJ movement can become either restricted or poorly controlled during loading due to either excessive or insufficient articular compression (Lee, 2004).

Argument against the importance of sacroiliac joint motion

Some therapeutic textbooks refer to groups that have purportedly refuted the presence of movement at the SIJ (Stone, 2002, Greenman, 2003). It is more reasonable to assume that in certain areas of manual medicine, the importance of SIJ movement has been downplayed. The cause of which could include; the small amount of movement evidenced to occur at the SIJ; research that movements of the SIJ cannot be reliably assessed using manual methods (Tulberg et al., 1998);the findings of Sturesson et al. (2000) that patients presumed to have SIJ pain had no range of motion differences between symptomatic and asymptomatic sides,(measured using RSA); and studies in which manipulation failed to change the position of the SIJ (Tullberg et al., 1998). Due to the anatomical makeup, intra-articular displacements within the SIJ are unlikely to occur (Tulberg et al., 1998). Distortions of the pelvis observed clinically are likely secondary to changes in the pelvis and trunk muscle activity, resulting in directional strain and not positional changes within the SIJ itself (Tulberg et al., 1998). Lastly, pain relief resulting from manipulation of the SIJ has been theorized to result more from nociceptive inhibition based on neuro-inhibitory factors and/or altered patterns of muscle activity (Pickar, 2002), rather than a change in alignment or motion.

Despite controversy surrounding motion at the SIJ, manual therapists have attempted to develop clinically useful diagnostic tests of the SIJ. Numerous signs of sacroiliac pain and dysfunction have been advocated by clinicians, including pain provocation, regional abnormalities in myofascial length-tension relationships, selected postures, leg length changes, static and dynamic changes in osseous landmarks, and asymmetrical movements of the pelvis (Goode, 2008). The following is a review of literature surrounding manual testing of the SIJ, starting with an introduction to statistical analysis of clinical testing.

Statistical measures of diagnostic utility

To evaluate the use of manual testing of the SIJ we need to appreciate the elements that contribute to the clinical diagnostic utility of any test procedure, including reliability, validity, sensitivity and specificity.

Reliability

Reliability has been defined as:

> The extent to which a test measurement or device produces the same results with different investigators, observers, or administration of the test over time. If repeated use of the same measurement tool on the same sample produces the same consistent results, the measurement is considered reliable.
> Mosby (2002, p.78.)

Reliability refers to the reproducibility of values of a test, assay or other measurement in repeated trials on the same individuals (Hopkins, 2000). Better reliability implies better precision of single measurements and better tracking of changes in measurements in research or practical settings (Hopkins, 2000).There are several components that may influence reliability in this experimental design; instrumental reliability, intra-rater, inter-rater, and inter-subject reliability (Domholdt, 2005).

Validity

Reliability alone is not sufficient to support the quality of a diagnostic test (Hilde et al., 2005). Reliability is a necessary, but not sufficient, condition for validity (Domholdt, 2005). Validity is the strength of our conclusions, inferences or propositions (Domholdt, 2005). The 'medical validity' of a scientific finding has been defined as the 'degree of achieving the objective' namely in answering the question in which the physician asks (Buttner, 1997).

Sensitivity and specificity

Appropriate levels of sensitivity and specificity are essential elements of any screening or diagnostic test. Laslett et al. (2005, pg. 143) states that 'sensitivity and specificity are key statistical measures applied to estimate diagnostic accuracy and calculate the likelihood ratios of a positive or negative test'. Sensitivity is the proportion of true-positive findings on the screening test of patients with the disorder who test positive (Cibulka & Koldenhoff, 1999). Specificity is the proportion of true negative findings on the screening test of patients without the disorder compared to those with the disorder (Cibulka and Koldenhoff, 1999). These elements combine to determine the 'positive predictive value', the proportion of patients with a positive test who actually have the disorder. The negative predictive value of a test is defined as the proportion of patients with a negative test who really do not have the disorder (Cibulka and Koldenhoff, 1999).These values contribute to the *'clinical usefulness',* which is the ability of a test to help establish a prognosis or act as a guide to treatment.

There are also practical implications that contribute to the clinical usefulness of any diagnostic test, including issues of availability of equipment, cost, the invasiveness of the procedure, adverse consequences of the test and so on. All of these factors need to be considered in evaluating a clinical test, and these statistical measures form the basis of our evaluation of the manual testing techniques for the SIJ.

Manual testing of the sacroiliac joint

Typically manual tests of the SIJ can be grouped into three categories, pain provocation, positional assessment and motion palpation. The literature in each area is extensive and the following review, whilst not exhaustive, hopes to highlight some of the key issues related to reliability and validity of manual testing of the SIJ.

Pain provocation

The SIJ is broadly accepted as a potential pain generator in cases of low back pain (Bogduk, 1995),estimated to be the source of nociception for approximately 19% of all LBP (Manchikanti et al., 2001). The currently accepted method of confirming or excluding the SIJ as a source of pain is fluoroscopically guided, contrast-enhanced intra-articular anaesthetic block (Laslett et al, 2005). Investigators have reported that 22% to 30%of subjects with pain around the SIJ region experienced some relief following anesthetic injection of the joint (Bernard& Kirkaldy-Willis, 1987).Whilst intra-articular anaesthetic block is recognised as the gold standard, the invasiveness of the technique makes it impractical in clinical practice. As such, therapists utilize alternative methods of assessing the SIJ as a potential source of back pain.

Manual tests that stress the SIJ to reproduce the patient's symptoms are known as 'pain provocation' tests. Several studies have assessed inter-examiner reliability of pain provocation testing (Laslett and Williams, 1994, Dreyfuss et al., 1996, Laslett et al., 2005). Whilst Laslett and Williams (1994) concluded that certain tests have been shown to have acceptable inter-examiner reliability, much of the research indicates that individual pain provocation tests have insufficient reliability, sensitivity and specificity and therefore limited validity (Dreyfuss et al., 1996). Current evidence suggests that these tests alone cannot predict the results of the criterion standard diagnostic injection (Laslett et al., 2005).

Laslett et al. (2005) indicates that the use of 'clusters' of SIJ pain provocation have improved sensitivity, specificity and prediction scores when trying to predict the results of fluoroscopically guided, contrast-enhanced SIJ blocks. A cluster is a composite of tests that assumes that each test may stress different structures within the SIJ region. Laslett et al. (2005) suggested counting the number of 'positive tests' (i.e. tests that reproduced the patient's pain) and identified the SIJ as a pain generator when there were three or more positive tests, with an estimated sensitivity of 93.8%, specificity and 78.1%, when tests were applied in this manner. Laslett et al. (2005) concluded that SIJ tests have "significant diagnostic utility" (p. 217) when three or more of a full set of six diagnostic tests (distraction bilaterally, compression, thigh thrust bilaterally or sacral thrust) were used as positive predictors of a positive intra-articular SIJ block.

A diagnostic tool is generally assessed in reference to an accepted criterion standard. Anesthetic block has been called into question as a gold standard for SIJ pain generation. Van der Wurff, Meyne & Hagmeijer (2000) state that "anesthetic block arthrogram seems to investigate intra-articular sources of pain and not the whole SIJ complex including the ligaments" and secondly, that there is a "lack of certainty that the anesthetic block is affecting all parts of the joint capsule" (Van der Wurff et al., 2000, pg. 94). Despite this and whilst Hilde (2005) argues that all tests in a cluster should have a reasonable reliability, a pain provocation cluster appears to have good diagnostic utility in identifying the SIJ as a pain generator in the case of low back pain.

O'Sullivan (2005) highlights that identification of a painful structure does not provide an insight into the underlying mechanisms that drives the pain. Testing positional or motion abnormalities of SIJ dysfunction has been appealing to manual therapists to guide their treatment approach to mechanical low back pain. In a study by Battié et al. (1994), surveying 186 therapists about the care of patients with low back pain, it was revealed that 75% of the therapists use screening procedures they believed tested for SIJ function (or dysfunction), rather than for pain generation. This trend occurs despite unfavorable research regarding reliability of positional and motion assessment of the SIJ.

Positional assessment

Positional assessment of the SIJ generally involves a clinician making judgments about the relative position of bony landmarks related to the SIJ, including iliac crest levels, palpation of posterior superior iliac spine (PSIS) levels, and palpation of anterior superior iliac spine (ASIS) levels, with the patient positioned either in a supine, sitting or standing position (Hungerford, Gilleard & Lee, 2004).Unfortunately, the anatomical location, bony structure and complex anatomy of the sacroiliac joint make it a difficult region to assess (Cibulka and Koldenhoff, 1999), with many of the positional and functional tests of the SIJ suffering from poor inter-examiner reliability (Laslett et al., 2005).

Holgram and Walin (2007) investigated the inter-examiner reliability of two examiners assessing a series of bony landmarks related to the pelvis (transverse processes of L5, sacral sulci, inferior lateral angles of the sacrum, and the medial malleoli). Assessment was performed in a clinical setting in twenty-five participants, aged 18–78 years, with low back pain and/or sacroiliac pain. The proportion of observed agreement was 40–44% and Holmgren and Waling (2007) concluded that they doubted the utility of these tests as methods for detecting asymmetry in clinical practice.

Potter and Rothstein (1985) examined the inter-examiner reliability of therapists using palpation to evaluate the symmetry of bony landmarks associated with the SIJ (ie, SIJ alignment). Examiners (chosen based on high levels of clinical competence)assessed a sample of 17 patients suspected of having dysfunction in the SIJ region. The percentage of agreement for the 6 tests ranged from 35% to 43%, suggesting that the inter-examiner reliability for assessments of SIJ alignment was poor. Of interest in this study were the findings that the level of experience of the assessor did not alter reliability.

In a systematic review of literature, Van der Wurff et al (2000) determined that nine clinical tests of movement or palpation/landmark identification lacked sufficient reliability (max kappa (k) scores ranged from 0.02 to 0.42) and concluded insufficient validity of positional testing.

In an intervention study of the SIJ, Tullberg et al.(1998) used intra-osseous markers and roentgen stereophotogrammetric analysis to determine the position of the SIJ (i.e. the position of sacrum in relation to ilium in standing). Measurement was performed prior to and following manipulation and mobilization procedures in 10 patients. Patients were chosen who expressed unilateral pain in the area of the SIJ and who were tested as being positive in at least 10 out of 12 tests of movement or symmetry of bony landmarks associated with the SIJ. The roentgen stereophotogrammetric analysis indicated essentially no change in the position of the sacrum relative to the ilium following the interventions. Failure to find positional changes contradicted examiner testing that indicated that tests of the SIJ region, positive prior to the intervention, were judged to be negative following the intervention. These findings raised into question the validity of data obtained with symmetry tests of alignment of the SIJs. Tullberg et al.(1998) did not control for the potential biases of the examiners, who were aware which subjects received the intervention. In doing so this research design reproduced a situation commonly seen in clinical practice, which often follows a test-treat-retest model.

This research highlights an inherent lack of reliability of manual positional testing of bony landmarks related to the SIJ. These findings are of interest when we consider many clinicians base their therapeutic approach on positional findings.

Motion testing

Motion testing of the SIJ can be varied, but generally involves identifying the location of bony landmarks related to the SIJ. Conclusions regarding function are derived from their relative movement during a motion controlled by the patient. Evaluation of the utility of motion testing has followed a similar pattern to that of positional testing.

Dreyfuss et al. (1996) reported poor agreement between the findings of a physician and those of a chiropractor when performing the Gillet test (κ= 0.22) and the spring test (κ= 0.15) on 85 subjects suspected of having dysfunction in the SIJ region.

Potter and Rothstein (1985) reported poor inter-examiner reliability for a series of tests (Gillet, Supine Long Sitting, prone knee flexion) that required the examiners to make judgments about the movement of bony landmarks. The percentages of agreement between therapists for these tests ranged from 24% to 50%. A weakness of Potter and Rothstein's study was that they did not calculate kappa coefficients. Therefore, reported agreement includes chance agreement, and because observed percent agreement was below 50% we would expect corrected kappa scores to be considerably lower.

As with pain provocation testing, Cibulka and Koldenhoff (1999) examined the use of a cluster of tests, using a combination of symmetry and movement tests to determine whether a patient had dysfunction in the SIJ region. Two therapists with an unspecified amount of training in the test procedures examined 26 patients with low back pain of a nonspecific origin. They determined that dysfunction in the SIJ region was present in a patient if at least 3 of the following 4 tests were positive (standing flexion test, the prone knee flexion test, the supine long sitting test, and palpation of PSIS heights in a sitting position). Inter-examiner agreement between the therapists for determining the presence of 3 positive tests was high (κ= 0.88). Whilst this study supports the diagnostic value of SIJ dysfunction testing when assessment of innominate alignment or motion is used in combination, in a cluster, this study received criticism in the literature for several reasons. Their method did not confirm that the patient's symptoms were originating from the SIJ. Cibulka and Koldenhoff (1999) did not quantify the size of the difference for the tests to be positive. Tests were also classified simply as positive or negative, regardless of whether the tests indicated dysfunction on the right or left side and regardless of the type of asymmetry present (i.e. whether the tests indicated the possibility of an anteriorly or posteriorly rotated innominate).Therapists therefore may have agreed that 3 or more tests were positive without agreeing on the side involved or the type of asymmetry present. Examination and management of people with SIJ region dysfunction requires identification of the involved side, type of asymmetry present, and correction of the asymmetry (Hilde et al., 2005).

In summary, the diagnostic utility of positional and motion testing is questionable when attempting to draw conclusions regarding SIJ function (Riddle & Freburger, 2002, Cibulka & Koldehoff, 1999). As Van der Wurff et al. (2000) conclude, ‘a precondition for accepting a diagnostic test to be valid and useful in clinical practise is that the test in question must have acceptable reliability'. The inherent complexity of this region makes assessment difficult, and not surprisingly the reliability of manual testing is less than acceptable. Many of the positional and motion tests are influenced by other structures in the lower back and hip and consequently the tests lack precision. Furthermore, assessment and interpretation of the tests are often not standardized (Hilde et al., 2005). Although the use of a combination of movement and symmetry tests to identify dysfunction in the region of the SIJ appears to yield more reliable data than the use of a single test, Fregerger and Riddle (2001) conclude that further studies are needed to explore the usefulness of combining tests.

The diagnostic utility of SIJ motion testing is difficult to evaluate due to the lack of an agreed 'gold standard' (Van der Wurff et al., 2000,Laslett et al., 2005). The only credible reference standard for SIJ mobility is radiostereometric x-ray analysis, taken during flexion and extension with metal markers embedded into the sacrum and ilia (Sturesson et al., 2000). This technique whilst reliable is highly invasive, posing obvious clinical drawbacks (e.g. low compliance, risk of infection).Given this, and the poor reliability of manual testing, there is a requirement for further study into a reliable, non-invasive gold standard for testing of SIJ motion.

Doppler imaging of vibration

In a series of studies, one research group reported the development of a technique that may provide an alternative method of evaluating SIJ motion, Doppler Imaging of Vibration (DIV) (Buyruk et al. 1995a, 1995b, 1999). DIV uses vibration transmitted through the SIJ, between the iliac and sacral bones. Intensity of vibrations is detected by Colour Doppler Imaging (CDI) and is used to indicate joint "stiffness" (Buyruk et al., 1995a). Buyruk et al. (1999) proposed that the difference between vibrational feedback from the medial and lateral aspect of one SIJ was representative of joint motion.

The following is a description of this technique applied by Buyruk et al. in their three studies. In their experimental designs, subjects were positioned prone with muscles relaxed on an examination table. To exclude the influence of muscle tension on the amount of passive motion of the SIJ, measurements were performed in a stationary, neutral and unloaded position. Subjects were asked to relax the gluteal muscles, biceps femoris and erector spine muscles, as these were hypothesized to make a significant contribution to the “stiffness” of the joint (Buyruk et al., 1995b).

Buyruk et al. used a signal generator to produce sinusoidal signals, that were amplified before being transformed to vertical vibrations produced by a device they termed an “excitor”(see Fig. 1). This vibration generator was positioned next to the table, without contacting it and a vertical metal rod was attached. A plate was attached to the top of this rod that contacted the subject’s ASIS. Vibrations of 200 Hz (with an amplitude not exceeding 0.05 mm and an input power of 1.4W) were applied unilaterally through the plate to the ASIS. Buyruk et al (1995b, p.119) proposed “the vibrations propagate with a spherical distribution in the pelvis up to the SIJ area, reducing the importance of the accuracy of the contact point”. A sonographer assesses the subsequent vibration using Colour Doppler Imaging (CDI) apparatus.

The intensity of the vibration pixels of the sacrum and ilium appeared simultaneously on a monitor at a ‘Threshold Level’displayed in colour on the CDI monitor. Below this level conventional grey-scale B-mode images are displayed. The ‘Threshold Level’ indicates the necessary signal power to display on the Doppler device as motion (Buyruk et al.1995b). The sonographer could alter the gain of the Doppler device, and a Threshold Level was found at which the Doppler colour image of the vibrating bony landmark appears changing from grey scale to colour, first for the iliac aspect of the joint and then for the sacral aspect. Since the Threshold Levels are directly related to the vibration energies of the bone, a large difference between the Threshold Level of the sacrum and ilium was proposed to indicate a large loss of energy through the SIJ, indicating an “instable joint”(Buyruk at al, 1995a). Conversely, a small difference provides an indirect indication of a “stiff joint”. Measurement of both the left and right SIJs were taken and recorded in each participant (Buyruk at al, 1995a).

Buyruk at al. validated DIV of the SIJ in a series of studies (1995a, 1995b and 1999). The first being an in-vitro study of 4 embalmed human specimens ranging in age between 92 and 97 years. The aim of which was to demonstrate a proportional relationship between joint stiffness and transmission of vibration through the SIJ. Joint stability was increased in the cadavers by fixing the joint with screws. Supporting ligaments were cut to reduce the stability of the joint. The researches concluded that they were able to demonstrate proportional differences in joint stability and vibration transmitted through the joint (Buyruk et al, 1995a).

The technique was then applied to fourteen healthy, asymptomatic female volunteers, aged between 20 and 40 years of age (Buyruk et al, 1995b). Statistical analysis demonstrated that the method could successfully discriminate inter-individual variations in joint stiffness. T-test demonstrated no significant intra-individual differences of left to right sides (p=0.44) in this asymptomatic group.

DIV was further applied to a group of Peripartum Pelvic Pain (PPPP) participants (n=56, ages 24-54 years) and compared to a healthy control group (n=45, ages 24-42) (Buyruk et al., 1999). The inclusion criterion for the PPPP experimental group was the existence of pelvic and/or back pain during at least the first three months after delivery. A similar distribution of SIJ stiffness was seen in both the experimental and control group, the patients did not show significant differences in joint stiffness or laxity. However, there existed a statistical significance between the groups with regards to absolute difference of SIJ stiffness between the left and the right (P<0.001), patients showing a far greater level of asymmetry than the controls. This experimental group was specifically chosen based on their predisposition for altered SIJ stiffness caused by strain in ligaments in the pelvis and lower spine resulting from a combination of hormonal effects, muscle weakness and the weight of the foetus (Buyruk et al., 1999). Based on these findings it appears that *SIJ dysfunction* might be most accurately described as *a difference in motion from one SIJ compared to the other in the same subjec*t. Since this time no further research was conducted using DIV by this particular research group, which is of interest considering the seemingly successful initial findings.

There is a degree of confusion in the literature regarding the assessment procedure for DIV of the SIJ images and the calculation of what Buyruk et al. (1995) refers to as "Threshold Units". The development of an assessment protocol for calculation of Threshold Levels and Threshold Units would inform the use of DIV in future research. There were also practical limitations to the protocol used in the series of studies by Buyruk et al (1995a, b and 1999). The equipment used was highly expensive (Vibratron 2000, estimated at $7000 US), a factor that may limit clinical usefulness.

Two years later a second research group picked up the evaluation of DIV of the SIJ. Damen et al. (2002c) examined the inter-rater reliability of measuring SIJ laxity using DIV in 10 healthy female subjects. In assessing inter-observer reliability they were able to determine 'the degree to which observers gave consistent estimates of the same phenomenon' (Domholdt, 2000). Reliability and measurement error were assessed from repeated measures, by five testers on two occasions as well as by one experienced tester. Intra-class correlation co-efficients ranged 0.53 to 0.80 for all five testers, and from 0.75 to 0.89 for the one experienced tester. Damen et al. (2002c) concluded that 'DIV is a reliable technique for SIJ laxity measurement in healthy subjects, when performed by an experienced tester. The work of Damen et al. (2002c) is of interest as it highlights the need for some element of clinical experience in assessing DIV.

Damen et al. went on to use DIV of the SIJ technique in a series of studies (2001, 2002b, 2002c) applying DIV to a symptomatic group. Damen et al. selected a group similar to that of Buyruk et al (1999), pre (2001) and post-partum (2002a) pelvic pain patients, due to the increased likelihood that SIJ dysfunction was involved. In these studies Damen et al. (2001 and 2002a) found that left to right asymmetry of SIJ laxity was greater in those subjects suffering pelvic pain compared to a no pain control group. The findings of Damen et al supported the work of Buyruk et al. (1999) in finding that dysfunction is best defined as motion asymmetry.

Richardson et al. (2002) used the technique to demonstrate the effect of abdominal muscle activity patterns on SIJ laxity. A total of 13 healthy individuals performed two muscle activity patterns, a 'drawn-in' pattern to contract the TVA and an abdominal brace to globally contract the abdominal musculature (Richardson et al., 2002). In all individual's joint laxity decreased, with the reduction being greater in the drawn-in pattern. This supports the concept that laxity can be altered by muscular activity and that the DIV technique is sensitive enough to register these changes.

Other research groups have used DIV to assess different physical phenomena. Faber et al. (2000) expanded the technique to assess the first tarsometatarsal joint. In this study vibration was applied to the head of the first metatarsal in 46 feet of 23 healthy subjects and picked up by a transducer at both sides of the tarsometatarsal joint. Faber et al. (2000) demonstrated reliable measures that were hypothesized to relate totarsometatarsal joint mobility. This conclusion supports Buyruk et al.'s contention that loss of vibrational energy is proportional to joint laxity.

DIV has been shown to be harmless to humans and therefore may be safely used as a clinically relevant measure of the SIJ (Buyruk et al., 1995a).Only three research groups have investigated DIV, a small amount considering the possible utility of the technique. Researchers applying the technique might consider why this is the case.

The use of DIV to assess laxity of the SIJ does suffer from some limitations and has received criticism in the literature. In a review of DIV of the SIJ, De Groot et al. (2004, pg. 366) concluded that 'the reliability of the technique has been shown to be good and that the technique has shown clinical relevance, although the technique has not been thoroughly validated'. De Groot et al. (2004) challenges the assumption of Buyruk et al (1995b), that the difference in threshold levels between the sacrum and the ilium represented the loss of energy over the SIJ. De Groot et al. (2004) also concludes that it has not been proven that the measured vibration relates to the bony surfaces and not just the overlying soft tissue.

In any testing protocol reproducibility of test results relies on several factors.Domholdt, (2000, pg 233) indicate that "most test-retest reliability calculations reflect some combination of instrument errors, and true subject variability". The within-session reliability relies upon the accuracy of the test measure (i.e. DIV of the SIJ) including the skill of the operator in applying the technique and the skill of the operator in interpreting the test results (i.e. assigning Threshold Levels). Likewise, the between-session reliability relies on the biological stability of the function in question (i.e. SIJ motion). It would inform future development of the DIV of the SIJ technique to know which of these factors makes the most considerably contribution to loss of reliability.

A standardized protocol for interpreting DIV of the SIJ images needs to be established in order to further validate the technique and verify previous reliability studies. Value will be added if this technique can be reproduced using a more cost effective method, making it more clinically accessible.

Evidence supporting the reliability and validity of a cost effective protocol utilising DIV of the SIJ would help support its use as an accessible criterion standard for assessing SIJ motion/dysfunction. DIV of the SIJ may provide a non-invasive, reliable and valid criterion standard for the assessment of SIJ motion that may be used to validate current manual therapy tools applied to the SIJ. Results may provide a rationale for assessment and treatment of mechanical lower back pain.

There is a rationale for a study that investigates the ability of an observer to make judgments regarding the Threshold Level in DIV of the SIJ. Control of additional sources of variation in reliability could be achieved (operator error in applying the technique and subject variability), by having observers rate DIV of the SIJ video images or 'clips'. Therefore, the aim of the investigation reported in Section 2 of this thesis was to examine one aspect of the DIV technique, the judgment of 'Threshold Level' scores for bony prominences in DIV images'. Assessing the intra- and inter-rater reliability of observers assessing Threshold Levels for DIV of SIJ using video clips.

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Section II

Manuscript

Observer Reliability assessing ‘Threshold Levels’ in color Doppler imaging of vibration of the sacroiliac joint video clips

James Crossley
Department of Osteopathy
Unitec Institute of Technology
Private Bag 92025 Auckland
New Zealand

Email: jcrossley50@hotmail.com
Tel: +64 9 815 4321 x8197

Abstract

The concept of sacroiliac joint (SIJ) motion dysfunction is an area of contention in manual therapy. Manual methods of assessing the SIJ have been constrained by poor reliability and a lack of an agreed ‘gold standard’. Doppler Imaging of Vibration has been proposed as one alternative method of evaluating SIJ motion. The aim the study was to determine the intra-rater and inter-rater reliability of a group of observers scoring ‘Threshold Levels’ using pre-recorded video clips of Doppler Imaging of vibration (DIV) of the SIJ. 12 observers of varied clinical experience ranked 12 repeated and randomly assorted DIV clips. Intra-observer reliability ranged from ‘moderate’ to ‘very high’. Inter-observer reliability was ‘very high’ indicating that observers can reliably assess ‘Threshold Levels’ for DIV of the SIJ in pre-recorded video clips. The present study demonstrates that observers can make reliable judgments regarding Threshold Levels of DIV of the SIJ using video clips. Further research is required to establish the validity of the technique. This may include work demonstrating correlation with alternative measures of SIJ laxity/stiffness.

1. Introduction

The sacroiliac joint (SIJ) is widely accepted as a potential pain generator in cases of low back pain (Bogduk, 1995), and is estimated to be the source of nociception for approximately 19% of all LBP (Manchikanti et al., 2001). The biomechanical model of lower back pain emphasises the role of joint restriction in predisposing mechanical stress on the umbo-pelvis (O'Sullivan, 2005). Whilst the sacroiliac joint has been identified as one potential site of mechanical restriction, the concept of sacroiliac motion dysfunction is an area of considerable confusion and contention in manual therapy.

The SIJ is inherently stable (Vleeming, 1990a and b), having to withstand large compressive forces during weight bearing (O'Sullivan and Beales, 2007). As a result, movement at the SIJ is small, measuring an average of 2.5 degrees of rotation in non-weight bearing and 0.2 degrees in weight bearing using roentgen stereophotogrammetric analysis (Tulberg et al., 1998; Sturesson et al. 1989; Jacob and Kissling, 1995;Vleeming et al. 1992; Sturesson et al. 2000). Complex anatomy, anatomical location and lack of motion have lead to several contentious issues surrounding the SIJ. Areas for discussion have included; the functional significance of SIJ movement; the ability of clinicians to manually assess SIJ pain (Laslett and Williams, 1994, Dreyfuss et al., 1996, Hilde et al., 2005, Laslett et al., 2005, McGrath, 2010), alignment (Potter and Rothstein, 1985, Tullberg et al., 1998) and motion (Dreyfuss et al., 1996;Potter and Rothstein, 1985; Cibulka et al., 1999; Hungerford et al., 2004).

Manual methods of assessing the SIJ have been constrained by poor reliability and a lack of an agreed 'gold standard' (Van der Wurff et al., 2000, Laslett et al., 2005). The only credible reference standard for SIJ mobility is radiostereometric x-ray analysis, taken during flexion and extension with metal markers embedded into the sacrum and ilia (Sturesson et al, 2000). This technique whilst reliable is highly invasive, posing obvious clinical drawbacks (e.g. low compliance, risk of infection). The development of a reliable and accessible technology based criterion standard for assessing SIJ motion is required.

Previous researchers have presented and validated a measurement technique utilising Doppler Imaging of Vibration (DIV).This technique may provide an alternative method of evaluating SIJ motion (Buyruk et al. 1995a, 1995b, 1999). DIV uses vibration transmitted through the SIJ, between the iliac and sacral bones. Intensity of vibration is detected by Colour Doppler Imaging and is used to indicate joint “stiffness” (Buyruk et al., 1995a). Buyruk et al. (1999) proposed that the difference between vibrational feedback from the medial and lateral aspect of one SIJ was representative of joint motion. One of the first studies was an in-vitro study of 4 embalmed human specimens and then applied to 14 healthy, asymptomatic female volunteers, aged between 20 and 40 years of age (Buyruk et al., 1995b). A later study investigated a group of Peripartum Pelvic Pain patients, in which patients demonstrated significantly greater levels of absolute difference of SIJ stiffness between the left and the right ($P<0.001$) compared to a pain free control group.

Apart from Buyruk’s research group, only one other research group has used DIV to investigate the SIJ. Damen et al. (2002a) examined the inter-rater reliability of measuring SIJ laxity using DIV in 10 healthy female subjects, and found DIV to be a reliable technique when performed by an experienced tester. Damen et al. used DIV of the SIJ applied to pre (2001) and post-partum (2002b) pelvic pain patients, selected due to the increased likelihood that SIJ dysfunction was involved. Damen et al (2002b) found that left to right asymmetry of SIJ laxity was greater in those subjects suffering pelvic pain compared to a control group.

In clinical examination, the reproducibility of diagnostic test results are dependent on several different types of measurement error including: instrument and technical error; biological stability of the trait being assessed; and operator skill and judgement. Within-session reliability relies on the accuracy of the test measure (i.e. DIV of the SIJ) including the skill of the operator in applying the technique (operator skill) and the skill of the operator in interpreting the test results (i.e. operator judgement in assigning Threshold Levels). Likewise, between-session reliability relies on the biological stability of the trait in question (i.e. SIJ motion). It would inform future development of DIV of the SIJ technique to identify the relative contribution to measurement error from biological, technical and operator sources. If the biological variability within subjects can be experimentally controlled (e.g. by using video clips) then measurement errors can be directly attributed to sources other than biological variability.

Therefore, this study will examines only aspect of the DIV technique, the judgment of ‘Threshold Level’ scores for bony prominences in DIV images. The aim of this research project was to determine the intra-rater and inter-rater reliability of a group of blinded observers scoring Threshold Levels using pre-recorded video clips of Doppler Imaging of Ultrasound of the sacroiliac joint.

2. Methods

2.1. Design

A blinded test-retest design was used to examine the intra- and inter-rater reliability for identifying 'Threshold Level' in DIV of SIJ video clips.

2.2. Participants

All participants were recruited from the campus of Unitec Institute of Technology and AUT University. There were two groups of participants, 'Subjects' recruited for purposes of obtaining primary data (DIV clips); and 'Observers' recruited to rate DIV video clips.

2.2.1. Subjects

A sample of 12 subjects was recruited using convenience sampling through word of mouth and poster advertising. To enhance the extent to which subjects would be representative of patients normally seen in a clinical setting, the inclusion criteria were defined broadly so that a range of morphologies, gender and ages were recruited. People with and without musculoskeletal symptoms were included.

Inclusion and exclusion criteria

To qualify for the study participants were required to comfortably lie prone for the duration of the procedure (approximately 30 minutes). For safety purposes participants were excluded if they were pregnant.

Information regarding the presence, or absence, of musculoskeletal symptoms was deemed unnecessary as subjects were recruited solely for the purpose of producing raw data in the form of DIV video clips. In the present study no conclusions are being made about the clinical relevance of the findings of joint stiffness or laxity.

2.2.2. Observers

A sample of 12 observers were recruited using convenience sampling through word of mouth. Participants were selected based on the level of clinical experience, and included observers with ultrasonography qualifications, postgraduate students of osteopathy or physiotherapy, and those with no formal clinical or health training. A range of clinical experience will allow conclusions regarding the impact of experience on reliability.

Inclusion and exclusion criteria

Participants were excluded if they had any visual impairment that may have impeded their ability to visually assess the DIV of the SIJ video clips.

2.2.3. Ethics

All study participants provided written informed consent.The Unitec Research Ethics Committee approved the study (Ref. No. 2010-1024).

2.3. Equipment

2.3.1. Vibration generation

Vibration was generated and amplified using a custom made ‘vibration generator’ (Fig. 1) and power amplifier. Vibration was controlled using a signal generator (Dick Smith Electronics, VIC, Australia). The vibration generator and signal generator were set to 150 Hz with amplitude of approximately 0.1mm.

2.3.2.Ultrasound Imaging- Doppler

All images were made using an Ultrasound machine (Philips IU22, Medical Systems Company, Eindhoven, The Netherlands) with a 12-5 MHz, 55mm, linear array transducer. Aquaflex® Ultrasound Gel (Fair- field, USA) was applied directly to the participants’ skin overlying the posterior aspect of the sacroiliac joint, ensuring optimal transducer contact and signal penetration. Philips Q-lab Software (Release 5.0) was employed for data quantification from the images taken from the ultrasound unit, and the Philips inbuilt software was used to capture and store video and still images for later analysis.

2.4.Procedures

2.4.1.Collection of primary data

Two clinical treatment tables were arranged so that the head hole of one of the tables could be used to project the vibration generator(see Fig. 1). The vibration generator was positioned on a heavy height adjustable table under the treatment plinth to enable the ‘piston’ of the device to protrude above the level of the table and contact the targeted anterior superior iliac spine (ASIS). The signal generator and power amplifier were positioned adjacent to the treatment table. The subject was instructed to lie prone with their target ASIS positioned over the piston of the vibration generator.

The sonographer introduced themselves to the subjects and reviewed the procedure. Warm coupling gel was applied to the SIJ region, to allow efficient ultrasound transmission from the transducer device to the SIJ. A test run of the vibration generator was conducted in order to make sure the participant was (1) positioned correctly; and (2) the amplitude and frequency of the vibrations were not uncomfortable for the participant. Buyruk et al., (1995b) states that vibration propagates with a spherical distribution from the pelvis to the SIJ. Subsequently, whilst care was taken to ensure an accurate contact, the position of the piston of the vibration generator on the bony ASIS contact is not critical.The participants were instructed to relax and breathe normally. The subject was asked to maintain a relaxed position free of any conscious muscular contraction to reduce the influence of muscular force closure on SIJ laxity.

The following protocol, as described by Pender et al. (2011, unpublished data), was used to assess ‘Threshold Level’ for the iliac and sacral aspects of the SIJ:

1. The transducer was applied in transverse section over the medial aspect of the posterior superior iliac spine
2. The fifth lumbar spinous process was visualized in normal grey scale and the scan plane adjusted until the sacrum, ilium and SIJ were visible
3. Depth and focus were optimized to improve image quality
4. The vibration generator was switched on after notifying the participant, and Doppler Colour mode was activated

5. The sonographer familiarised themselves with bony landmarks (ilia, sacrum and sacroiliac joint line) on the monitor
6. The sonographer steadily increased the sonophoric gain by adjusting the gain dial.
7. Doppler signals reached a 'Threshold Level' at either the sacral aspect of the joint or the iliac aspect of the joint when the elements were displayed in colour as opposed to grey on the monitor
8. A Threshold Level was established for both the sacral aspect of the joint (including the joint line) and the iliac aspect producing two Threshold Level scores for each SIJ

An example DIV of the SIJ 'raw' image is provided (Fig. 3)

A series of continuous DIV video clips were produced of approximately 15 seconds in duration. To achieve this, a recording was taken as the level of gain was gradually increased, so that the Threshold Level for both the sacral and iliac aspects of the joint were achieved at some point in the 15-second interval. In all cases this was achieved at a variable point of time within the clip and was not predetermined by the sonographer.

2.4.2.Image processing

Each clip was processed to remove labels and other cues on the image that may be used for identification of the video clip. Frames in which images were repeated were removed so that every frame contained a change in the colour density of at least 1 pixel. A clear indication of which joint was being viewed, left or right SIJ, was added (see Fig. 4). The label left/right was shown because a sonographer would have access to this information at the time of recording in a clinical setting so it was considered appropriate to provide this information to the observers when they scored the DIV clips. Each clip had a timer and a counter attached that was covered from the observer when each clip was viewed to minimise bias based on the timing of each clip. Each clip was presented to observers using a standard video player (QuickTime, v. 6.0, Apple Inc.)

A series of videos was arranged using 12 clips. Each clip was repeated twice, then coded [see Appendix] and randomly ordered using the website http//www.random.org (using options 'Number' – 'Sequence Generator') to produce 24 randomly assigned clips.

Observers were not aware of the order in which each clip was presented or that each clip was repeated twice.

2.4.3.Development of training tutorial

A protocol for scoring the Threshold Level for DIV of the SIJ was agreed upon based on discussion within the research group and on interpretation of the original works of Buyruk et al. (1995a,b, 1999). The protocol included four discrete steps that would allow two scores to be obtained, one for the Threshold Level for the iliac aspect and a second for the combined sacral aspect and joint line.

These four steps were;

1. Confirm view is of left or right SIJ
2. Identify major bony landmarks (ilium, sacrum and joint line)
3. Identify 'target zone' based on where significant colour is appearing on or near bony landmarks (includes two points, one for the ilia and a second for the combined sacrum and joint line)
4. Identify image scores based on the first red pixel of color appearing in the target zone

This protocol is expanded upon in the training tutorial [see Appendix].

2.4.4. Observer training and orientation

A slideshow tutorial was produced to consistently introduce the protocol to each observer. The tutorial presentation was made to each observer separately. The tutorial was designed to provide the following information: an introduction to Doppler Ultrasound, an overview of the DIV of the SIJ technique, an overview of the relevant anatomy, a tutorial instructing each observer how to determine which SIJ they were looking at (left or right), how to identify the relevant bony landmarks on the video clip, how to identify their 'target zone' and how to score each image. The tutorial also included opportunities to view and score the Threshold Level of example clips which were not used other than for training purposes. Each of the 12 Observers was shown the slideshow tutorial by one of two different researchers. Each observer had the opportunity to ask questions and discuss the protocol until they were satisfied and confident they could reproduce the protocol accurately and rate DIV of the SIJ clips without assistance, at which point they conducted the assessment. [Appendix 3 for Slideshow tutorial]

2.4.5. Reliability data collection

Each observer independently scored 24 clips (12 clips repeated twice). An assistant started each clip, and instructed the observer to watch the clip to completion. The observer could then control the clip as required prior to indicating a Threshold Level score for both the iliac and the sacral aspects of the joint. This is consistent with the procedure a sonographer follows in the original protocol in which they can alter Doppler gain until satisfied that a correct Threshold Level has been reached. The assistant recorded observer scores on a data collection sheet, ensuring the examiners were not aware of the scores they indicated during the process.

2.5. Data analysis

To estimate intra- and inter-rater reliability for the judgement of identifying Threshold Levels in DIV of the SIJ clips, interclass correlation coefficients were calculated. For scores of intra-rater reliability for identifying Threshold Level in the same bone (ilia or sacrum), a 2-way mixed model ANOVA for absolute agreement ($ICC_{2,1}$, using a single measurement) was used. For identifying inter-rater reliability scores in identifying Threshold Level in the same bone (ilia or sacrum) a 2-way mixed model ANOVA for absolute agreement ($ICC_{2,k}$, where k=2 and measurements are the average of 2 measures) was used. 95% confidence intervals were calculated for all estimates. Hopkins' descriptors were used to interpret levels of agreement (Hopkins, 2000). An ICC of ≥ 0.80 with a lower confidence interval boundary$\geq$ 0.60 was operationally defined as the minimum for satisfactory reliability. The SPSS statistical package was used for all calculations (SPSS v18.0, SPSS Inc, Chicago, IL).

3. Results

Five out of 12 observers had ‘acceptable’ levelsof intra-rater reliability when identifying Threshold Level for the sacral aspect of the joint. Three out of 12 observers had acceptable levelsof intra-rater reliability when identifying Threshold Level for the iliac aspect of the joint. The intra-rater reliability scores for the sacrum and ilium are displayed in Figure 1 and 2 respectively.

The intra-observer reliability for identifying Threshold Level for the sacral aspect of the joint ranged between ‘high’ ($ICC_{2,1}$ = 0.51, 95% CI = -0.01 to 0.82) to ‘very high’ ($ICC_{2,1}$ = 0.98, 95% CI = 0.93 to 0.99).

The intra-observer reliability for identifying Threshold Level for the iliac aspect of the joint ranged between ‘moderate’ ($ICC_{2,1}$ = 0.48, 95% CI = -0.04 to 0.81) to ‘very high’ ($ICC_{2,1}$= 0.99, 95% CI = 0.99 to 1.0).

The inter-observer reliability for identifying Threshold Level for the sacral aspect of the joint was ‘very high’ ($ICC_{2,2}$ = 0.92, 95% CI = 0.83 to 0.97). Scores ranged from ‘insubstantial’ ($ICC_{2,2}$ = -1.26, 95% CI = -7.30 to 0.37) to ‘very high’ ($ICC_{2,2}$ = 0.98, 95% CI = 0.92 to 0.99).

The inter-observer reliability for identifying Threshold Level for the iliac aspect of the joint was ‘very high’ ($ICC_{2,2}$= 0.88, 95% CI = 0.75 to 0.96). Scores ranged from ‘less than chance agreement($ICC_{2,2}$ = -0.2, 95% CI = -3.10 to 0.65) to ‘very high’ ($ICC_{2,2}$ = 0.99, 95% CI = 0.99 to 1.0)

Individual comparisons for intra- and inter observer reliability scores are shown in Table 1.

4. Discussion

The aim of this study was to determine the intra- and inter-rater reliability for scoring 'Threshold Level' in DIV of the SIJ 'video clips'.Intra-observer reliability ranged from 'moderate' to 'very high' and from 'high' to 'very high' for the iliac and sacral aspects of the joint respectively. Inter-observer reliability was 'very high' for both sacral and iliac aspect of the joint, indicating that observers can reliably assess Threshold Levels for DIV of the SIJ in pre-recorded video clips.

Doppler imaging of vibration was first described applied to the SIJ by Buyruk et al. (1995a) using embalmed human pelvises.The reliability of the technique has been demonstrated by subsequent research. Buyruk et al. (1995b) investigated the Intra-examiner reliability using healthy human subjects, demonstrating that DIV could successfully discriminate inter-individual variations in joint stiffness. Damen et al. (2002) further investigated the intra-rater and inter-rater reliability of the technique in a small group (n=5) of examiners with varied levels of clinical experience. Damen et al. (2002) found that reliability ranged from 'moderate' to 'high' (ICCs ranging from 0.53 to 0.80 for all five testers and 0.75 to 0.89 for one experienced tester) and concluded that DIV is a reliable technique for assessing SIJ laxity measurement in healthy subjects, when performed by an experienced tester (Damen et al., 2002). Pender et al. (2011, unpublished data) replicated the work of Buyruk et al. (1995b) analysing intra- and inter-session reliability of DIV applied to the SIJ, using one examiner and their own custom made vibration generator. Whilst the reported studies demonstrate that DIV is a reliable technique, the present study considers the relative sources of errorwhen evaluating measures of reliability.

Domholdt, (2000) indicates that all measurements can be influenced by instrument error, intra-rater, inter-rater, and inter-subject reliability. In DIV, these factors include: changes in the biology of the subjects between measurements with regards to the target characteristic (SIJ laxity); the effect of testing itself (e.g. potential influence of vibration on the SIJ); changes in the instrumentation (e.g. faults or changes with the vibration generator); changes in the application of measurement (e.g. changes in application force of the vibration piston; or contact points and subsequent effects on vibration transmission); and changes in the operator, including the effect of learning; subtle changes in interpretation of criteria, and the impact of cognitive fatigue in conducting a large number of experimental measures. Partitioning the relative sources of reliability error may inform the technical development of DIV applied to the SIJ.

The present study, performed alongside the work of Pender et al. (2011, unpublished data), contributes to evidence of reliability by evaluating the contribution of observer judgment. Video clips were used to control error originating from biological variability (SIJ laxity) and changes in instrumentation and operator error. The findings indicate that observer judgement, in the context of evaluating video clips, is not a major source of measurement error. By interpreting the data concomitantly with that of Pender et al. (2011), conclusions may be drawn regarding the relative contribution of the differing sources of measurement error to DIV of the SIJ.

It should be highlighted that the present findings only contribute towards validity in as much as reliability is a requisite of validity (Hopkins, 2000). Work to validate DIV was performed by Buyruk et al. (1995a) on embalmed pelvises. Construct validity of the DIV technique has been demonstrated by showing differences in symmetry of SIJ laxity in pregnancy related pelvic pain compared to normal control subjects (Buyruk et al., 1999, Damen et al., 2001 and 2002a). Regardless of some work towards validity, De Groot (2004) highlighted the need for further research to validate several assumptions of the technique. These include; that differences in Threshold Levels actually represent a loss of vibration across the SIJ; and that vibration is occurring in bone related to the joint, rather than in soft tissue. These assumptions have yet to be thoroughly addressed in the literature, however, investigating reliability is a pre-requisite to undertaking this work.

Some technical limitations may have contributed to less than perfect reliability in the present study. In several of the recordings it appears that the physical changes (e.g. abdominal distension; chest expansion/contraction) with inspiration and expiration were affecting the contact force of the vibration generator on the bony prominence. Changes in Threshold Level induced with breathing may reduce the reliability of measures. Future protocols should control for the impact of breathing by ensuring that the participant maintains a full inspiration and breath-hold while Threshold Levels are determined.

It was noted that despite a consistent observer-training program, a key factor influencing intra-observer reliability may have been differences in application of the scoring protocol. Buyruk et al. (1995b, 1999) did not clearly describe their protocol with respect to interpreting Threshold Levels. A basic protocol to interpret Threshold Levels was developed for the purpose of the present study. To increase inter-observer reliability, the effect of training could be enhanced by: further refining the protocol; delivering the training in a highly prescribed manner; and by using group training and feedback sessions to facilitate 'calibration' of ratings between observers.

Discrepancies in rating may be partly attributed to inconsistencies in the DIV images produced. Bony landmarks were not clearly defined in every clip. Images were less clear in subjects with increased levels of subcutaneous adipose tissue. The morphology and somatotype of the person being assessed may influence accuracy of measurement and it may be that somatotypes are more reliably assessed. There was insufficient data to draw clear statistical conclusions about the influence of subject morphology on reliability. The impact of subject morphology on reliability should be further researched.

In some cases vibration was detected in an area first interpreted by the observer as a bony sacral or iliac landmark. In these cases observers were asked to identify a more superficial point as their 'target area'. In some subjects vibration was not observed in target areas identified as bone, in these cases the observer was forced to rate the presence of signal in more superficial tissue. An assumption of the protocol is that when Doppler signal is registered only at superficial tissue, and is not visualised on the bone, that vibration is still occurring at sacral or iliac bone. Whether vibration was reaching bony landmarks as expected or whether landmarks were incorrectly identified remains unclear and needs clarification. Secondly, whilst the expectation was that Threshold level would be reached firstly on the ilium, due to the spherical nature of the vibration transmission (Buyruk et al, 1995b), this was not always the case in the clips produced. There were instances in which Threshold Level was reached at the sacrum prior to the ilium. Inconsistency in DIV images highlights issues of validity that require more investigation.

5. Conclusion

The present study demonstrates that observers can make reliable judgments regarding Threshold Levels of DIV of the SIJ using video clips. Further research is required to establish the validity of the technique, including work to demonstrate correlation with alternative measures of SIJ laxity/stiffness.

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Figure and Tables

Observer 1.	Observer 2.	Observer 3.	Observer 4.	Observer 5.	Observer 6.	Observer 7.	Observer 8.	Observer 9.	Observer 10.	Observer 11.	Observer 12.		
											0.99 (0.99 –1.0)	Ilia	Obs.12 .
											0.98 (0.92 – 0.99)	Sacrum	
										0.96 (0.86 – 0.99)	0.34 (-0.47- 0.77)	Ilia	Obs.11 .
										0.87 (0.60 – 0.96)	0.66 (-0.19 – 0.9)	Sacrum	
									0.76 (0.35 – 0.92)	0.56 (-0.26 – 0.87)	0.71 (-0.08 – 0.92)	Ilia	Obs.10 .
									0.57 (0.07 – 0.85)	0.32 (-1.7 – 0.81)	0.86 (0.45 – 0.95)	Sacrum	
								0.38 (-0.26 – 0.78)	0.36 (-1.37 – 0.82)	0.54 (-0.25 – 0.86	-0. 08 (-3.32 – 0.70)	Ilia	Obs. 9.
								0.48 (-0.08 – 0.82)	-0.24 (-2.73 – 0.63)	-0.55 (-3.61 – 0.53)	-1.02 (-4.20 – 0.39)	Sacrum	
							0.84 (0.55 – 0.95)	-0.09 (-1.35 – 0.62)	0.52 (-0.33 – 0.85)	0.14 (-0.35 – 0.62)	0.79 (0.15 – 0.94)	Ilia	Obs. 8.
							0.98 (0.93 – 0.99)	-0.90 (-0.88 – 0.56)	0.77 (0.08 – 0.94)	0.30 (-1.17 – 0.79)	**0.90** (0.66 – 0.97)	Sacrum	
						0.82 (0.52 – 0.95)	0.22 (-0.38 – 0.70)	0.49 (-0.51 – 0.85)	0.54 (-0.26 – 0.86)	**0.89** (0.63 – 0.97)	0.35 (-0.66 – 0.79)	Ilia	Obs.7.
						0.97 (0.91 – 0.99)	0.33 (-0.27 – 0.75)	0.29 (-1.80 – 0.80)	0.71 (-0.11 – 0.92)	0.14 (-1.00 – 0.71)	0.45 (-3.1 – 0.82)	Sacrum	
					0.46 (-0.15 – 0.80)	0.87 (0.53 – 0.96)	0.87 (0.53 – 0.96)	0.28 (-0.56 – 0.75)	0.54 (-0.28 – 0.86)	**0.91** (0.71 – 0.96)	0.33 (-0.40 – 0.76)	Ilia	Obs. 6.
					0.57 (-0.01 – 0.85)	0.60 (-0.15 – 0.88)	0.70 (0.01 – 0.91)	-0.39 (-3.84 – 0.60)	0.82 (0.36 – 0.95)	0.83 (0.42 – 0.95)	0.86 (0.49 – 0.96)	Sacrum	
				0.74 (0.34 – 0.92)	0.16 (-0.33 – 0.63)	-0.10 (0.87 – 0.61)	0.86 (0.54 – 0.96)	-0.18 (-2.18 - - 0.63)	0.47 (-0.72 – 0.84)	0.09 (-0.49 – 0.61)	0.85 (0.49 – 0.96)	Ilia	Obs.5.
				0.72 (0.30 – 0.91)	0.79 (0.30 – 0.94)	0.57 (-0.26 – 0.87)	0.86 (0.48 – 0.96)	-0.43 (-2.61 – 0.54)	0.87 (0.59 – 0.96)	0.44 (-1.20 – 0.84)	**0.93** (0.76 – 0.98)	Sacrum	
			0.92 (0.76 – 0.98)	0.70 (-0.07 – 0.92)	0.34 (-0.34 – 0.76)	0.51 (-0.34 – 0.76)	0.87 (0.52 – 0.96)	-0.20 (-3.10 – 0.65)	0.74 (0.10 – 0.92)	0.25 (-0.50 – 0.76)	**0.89** (0.65 – 0.97)	Ilia	Obs.4.
			0.98 (0.93 – 0.99)	**0.95** (0.84 – 0.99)	0.87 (0.56 – 0.96)	0.47 (-0.30 – 0.83)	**0.90** (0.67 – 0.97)	-0.76 (-3.66 – 0.44)	0.88 (0.59 – 0.96)	0.57 (-0.59 – 0.88)	**0.98** (0.94 – 0.99)	Sacrum	
		0.85 (0.59 – 0.96)	**0.93** (0.77 – 0.98)	0.77 (0.20 – 0.93)	0.32 (-0.33 – 0.75)	0.42 (-0.39 – 0.80)	0.79 (0.28 – 0.94)	0.08 (-2.04 – 0.73)	0.76 (0.16 – 0.93)	0.26 (-0.43 – 0.73)	**0.93** (0.78- 0.98)	Ilia	Obs. 3.
		0.60 (0.11 – 0.86)	**0.93** (0.74 – 0.98)	**0.96** (0.87 – 0.99)	0.77 (0.18 – 0.96)	0.53 (-0.26 – 0.85)	0.78 (0.18 – 0.94)	-0.59 (-3.96 – 0.53)	0.88 (0.59 – 0.97)	0.43 (-1.24 – 084)	**0.88** (0.60 – 0.97)	Sacrum	
	0.8 (0.47 – 0.94)	**0.94** (0.79 – 0.98)	**0.89** (0.62 – 0.97)	**0.90** (0.68 – 0.97)	0.17 (-02 – 0.64)	0.24 (0.48-0.72)	**0.90** (0.68 – 0.97)	-0.12 (-1.95 – 0.65)	0.51 (-0.55 – 0.86)	0.12 (-0.44 – 0.63)	**0.91** (0.60 – 0.96)	Ilia	Obs. 2.
	0.86 (0.33 – 0.92)	**0.91** (0.66 – 0.96)	**0.96** (0.87 – 0.99)	**0.97** (0.90 – 0.99)	0.78 (0.30 – 0.94)	0.51 (-0.26 – 0.85)	**0.96** (0.76 – 0.98)	0.45 (-2.20 – 0.51)	0.87 (0.53 – 0.96)	0.48 (-0.89 – 0.85)	**0.96** (0.88 – 0.99)	Sacrum	
0.48 (-0.04 – 0.81)	0.66 (-0.03 - 0.90)	0.84 (0.46 – 0.95)	0.80 (0.35 – 0.94)	0.56 (-0.27 – 0.87)	0.57 (-0.22 – 0.87)	0.70 (0.06 – 0.91)	0.43 (-0.42 – 0.82)	0.80 (-3.02 – 0.75)	0.77 (0.20 – 0.93)	0.59 (-0.17 – 0.86)	**0.85** (0.51 – 0.96)	Ilia	Obs.1.
0.51 (-0.01 – 0.82)	0.88 (0.42 – 0.97)	0.78 (0.22 – 0.94)	0.85 (0.49 – 0.96)	0.85 (0.49 – 0.96)	0.76 (-0.06 – 0.92)	0.66 (-0.14 – 0.90)	0.71 (-0.06 – 0.92)	-1.26 (-7.30 – 0.37)	0.78 (0.16 – 0.94)	0.46 (-1.51 – 0.82)	0.87 (0.48 – 0.96)	Sacrum	

Table 1. Inter-observer and intra-observer correlation coefficients for identifying Threshold Level for the sacrum and ilium in DIV of the SIJ clips.

Note: Light grey shading indicates intra-observer scores; Cells shaded darker grey with bold type indicate ICC estimates that not less than 0.80 with a lower boundary not les than 0.60

Figures

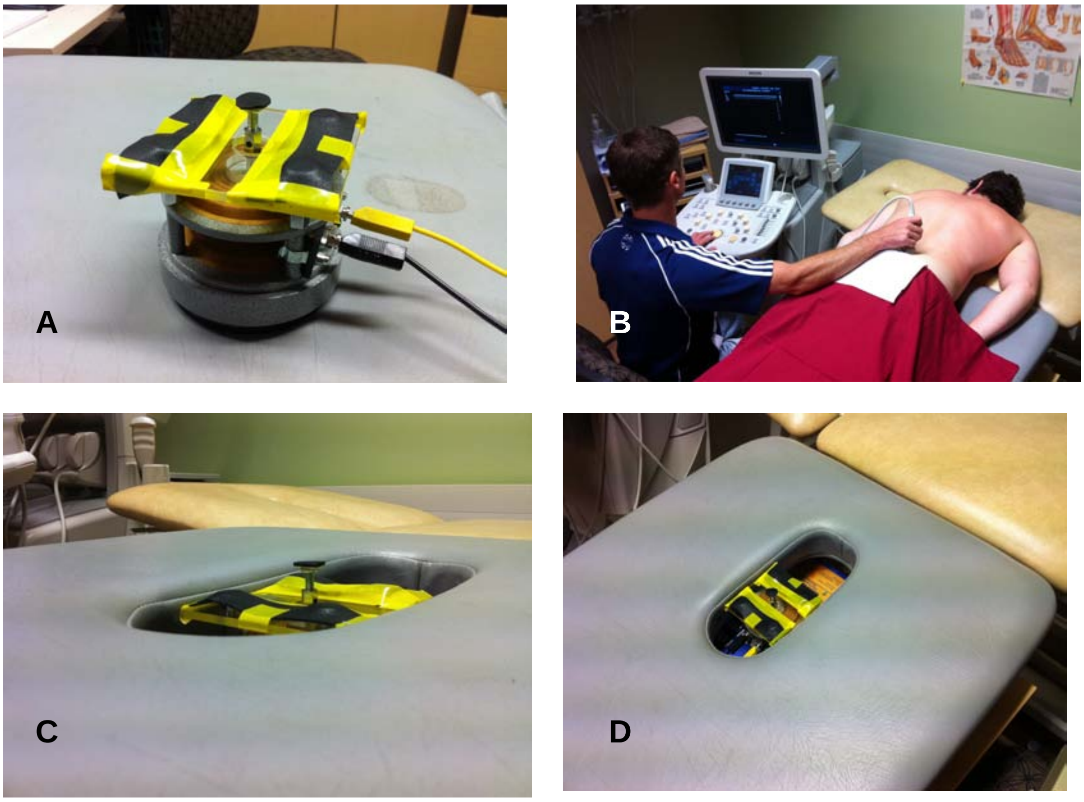

Fig. 1.(A) Vibration Generator in situ, note black protective padding on the base and on top of the 'piston' (B) Subject positioning (C and D) Vibration Generator projecting through height adjustable plinth, note how the 'piston' can project above the height of the plinth.

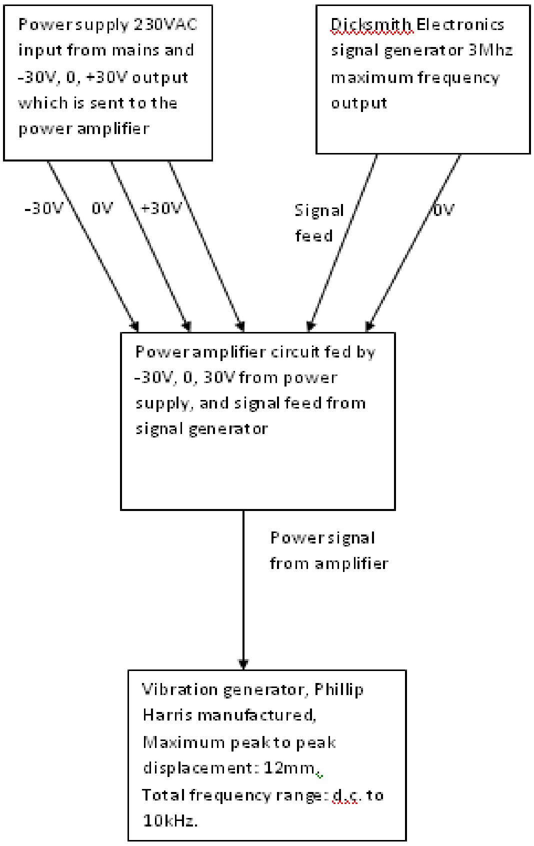

Fig. 2. Schematic of Vibration Generator, power amplifier and signal generator.

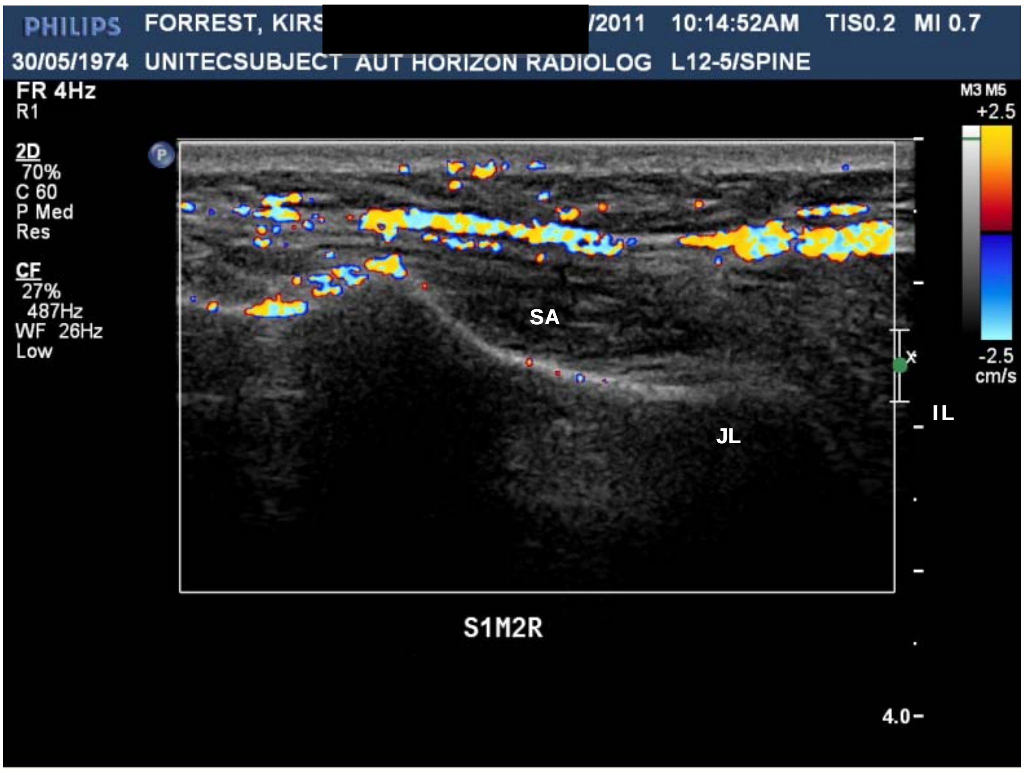

Fig. 3.Example of a typical raw image taken of the over the right sacroiliac region. The colour represents directional movement detected by the Doppler Ultrasound device. Abbreviations: IL = ilium, JL = Joint Line, SA = Sacrum)

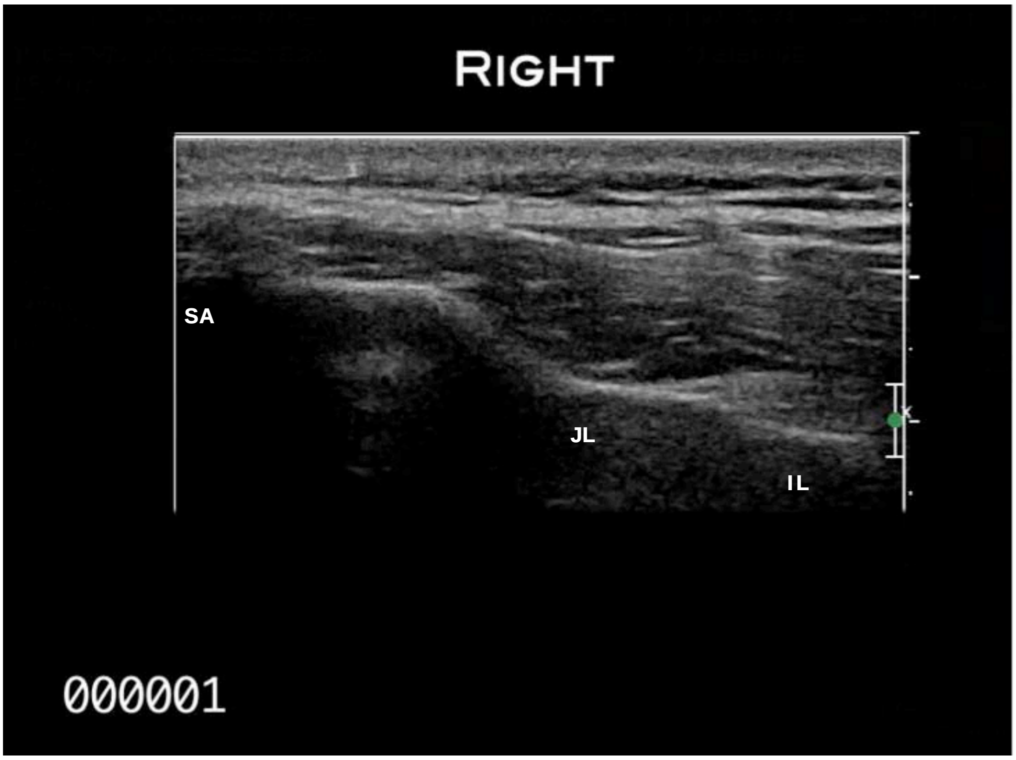

Fig. 4. Example of a typical processed image, taken of the over the right sacroiliac region to show. The colour represents directional movement detected by the Doppler Ultrasound device. Abbreviations: IL = ilium, JL = Joint Line, SA = Sacrum)

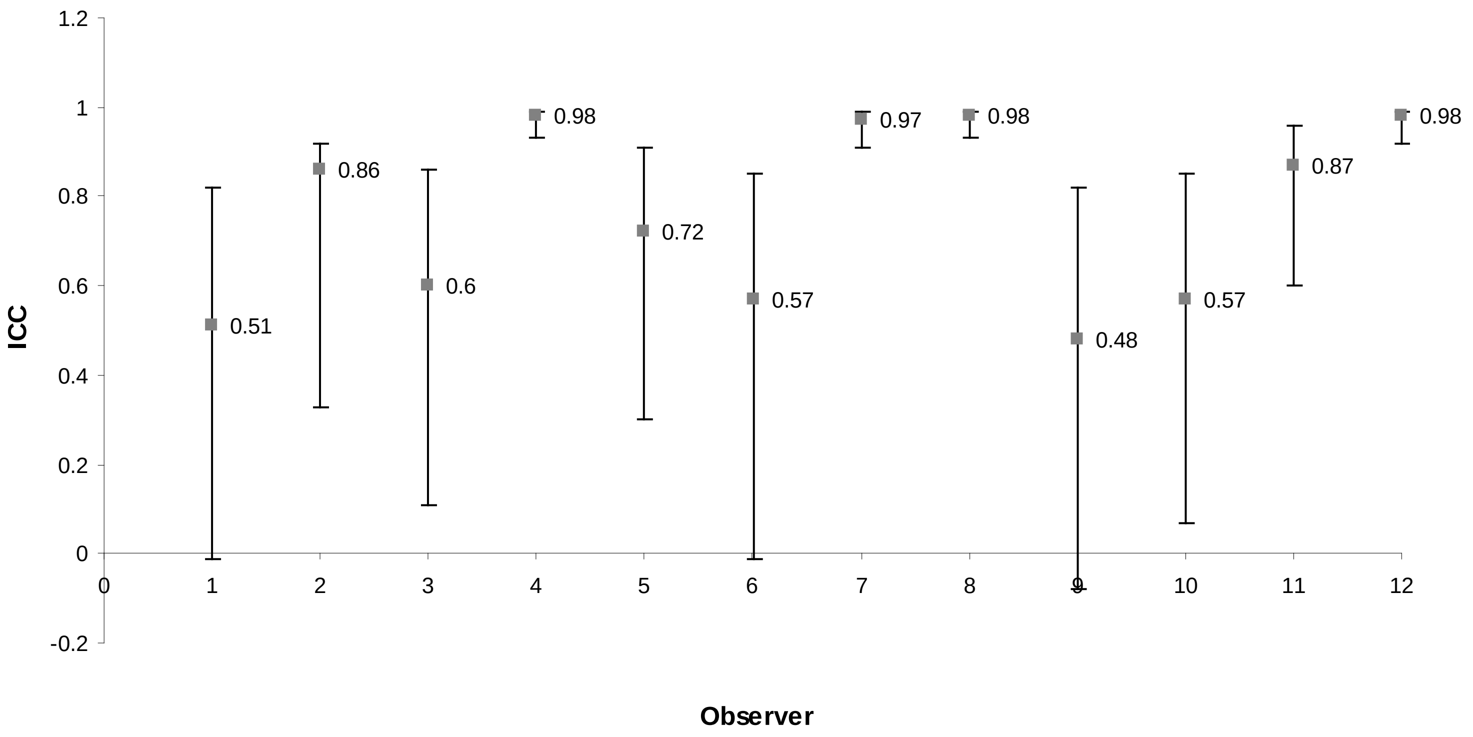

Fig. 5. Correlation coefficients (ICCs) for intra-observer reliability for observers identifying Threshold Level for the sacrum in DIV of the SIJ clips. Error bars represent ± 95% CI.

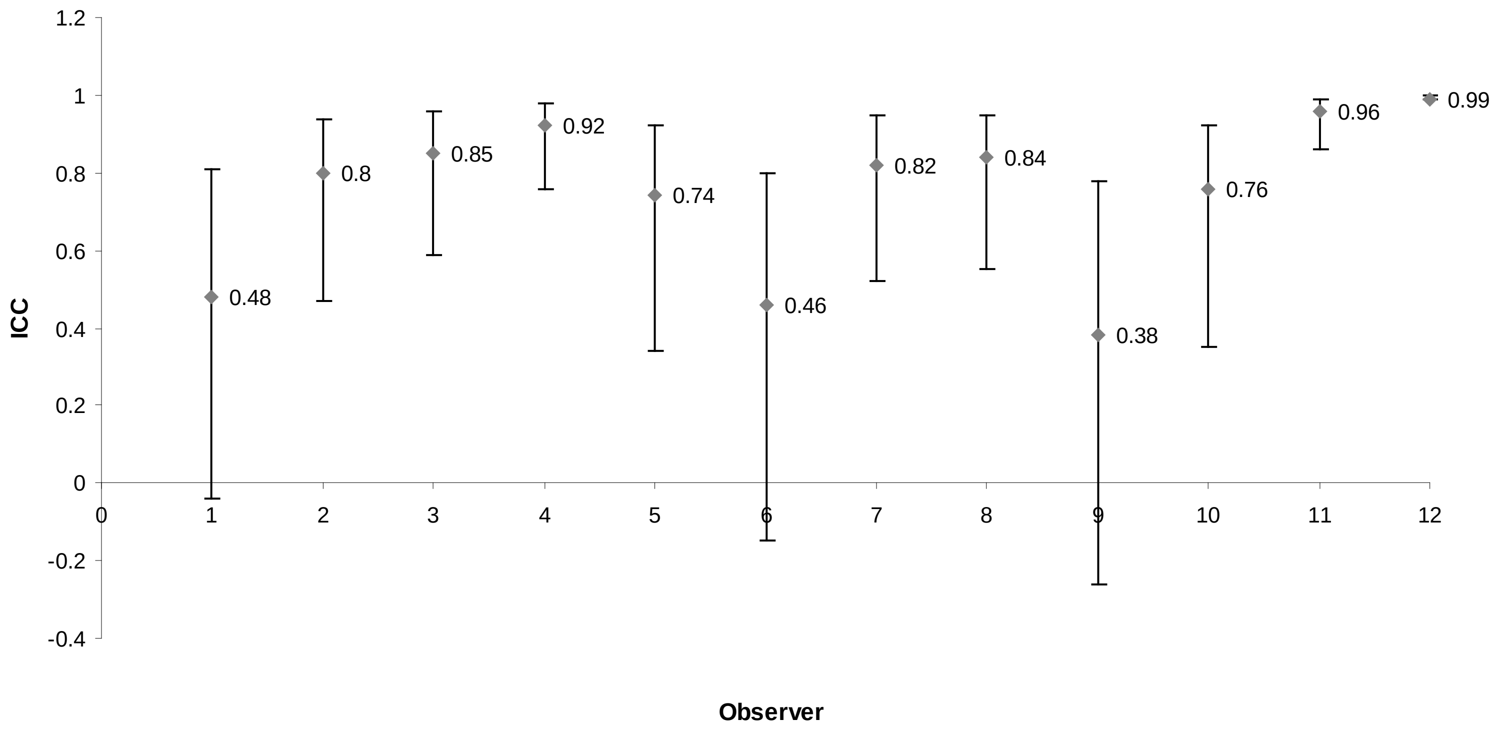

Fig. 6. Correlation coefficients (ICCs) for intra-observer reliability for observers identifying Threshold Level for the ilia in DIV of the SIJ clips. Error bars represent ± 95% CI.

Section III: Appendices

Appendix 1: Ethics – Information Sheet

Appendix 2: Ethics – Consent Form

Appendix 3: Operator Training Tutorial