The effect of a non-specific gluteal contraction on transient stiffness of the sacroiliac joint as measured by Doppler Imaging of Vibrations

Callum John Isaac Farquharson

A thesis submitted in partial requirement for the degree of Master of Osteopathy, Unitec Institute of Technology, 2013

DECLARATION

Name of candidate: Callum Farquharson

This Thesis/Dissertation/Research Project entitled: **The effect of a non-specific gluteal contraction on transient stiffness of the sacroiliac joint as measured by Doppler Imaging of Vibrations.** Is submitted in partial fulfilment for the requirements for the Unitec degree of Masters of Osteopathy.

<u>Candidate's declaration</u>

I confirm that:

- This Thesis 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. Research Ethics Committee Approval Number: **2011-1232**

Candidate Signature: …………………………………………. Date: 25/02/2013

(Callum Farquharson)

Student number: 1322696

Acknowledgements

Thank you to:

Funding

THESIS ABSTRACT

The complex anatomy and kinematics of the sacroiliac joint (SIJ) has lead to much debate amongst researchers and clinicians, creating a tension between best evidence and clinical practice. A criterion standard quantifying SIJ motion does not yet exist. Doppler imaging of vibration (DIV) is one proposed method of objectively determining SIJ 'stiffness.' The DIV technique has shown validity and intra-session reliability, whereas inter-session reliability has thus far been observed as poor due to substandard equipment and biological variability. Despite these limitations, research utilising the DIV technique has continued. Following the design and manufacture of a suitable vibration generator (VG), this study investigated the intra-session reliability of the new VG including control for participant generated downward pressure on the VG, and to investigate the effect of a force closure movement on SIJ stiffness as measured by DIV. Thirteen healthy participants between the ages of 19-57 years were studied. Intra-session reliability was "very high" (ICC[3,3] = 0.79; 95%CI = 0.59 to 0.90) and the standard error of measurement was calculated as 0.62 TU (95%CI = 0.50 to 0.86). A paired samples t-test showed the non-specific force closure movement had a small, non-significant effect on SIJ stiffness as measured by DIV (mean increase = 2.08TU; 95%CI = -1.18 to 5.34TU; P=0.20). Participant generated downward force on the VG was observed to be constant throughout each session. Without a change in downward force, the changes in transient SIJ stiffness can more confidently be assumed to come from the force closure movement if we accept the current limitations of the DIV technique and small sample size. DIV requires further investigation into its construct validity before the results of any study employing the DIV technique are applied to any form of clinical practice.

Keywords:

Dysfunction, motion, reliability, muscular contraction, force closure, diagnosis.

Table of contents

Introduction to thesis structure

This thesis consists of three parts

1. Literature review
2. Manuscript
3. Appendices

The review of relevant literature provides the theoretical basis and rationale for the study reported in the manuscript. The appendices provide other important documents.

The Doppler Imaging of Vibrations technique utilises a vibration generator. A suitable vibration generator was not commercially avaliable for this study and as a result it was necessary to design and manufacture a specialised vibration generator. Appendix 1 consists of an account of the manufacture of a vibration generator for the purpose of Doppler Imaging of Vibrations.

Section 1: Review of literature

1. Introduction

Low back pain (LBP) is common, affecting 70-85% of people at some stage of life (Andersson, 1999). As a result the topic of LBP has been extensively investigated. Historically, the sacroiliac joint (SIJ) was considered the most common cause of idiopathic low back pain (Albee, 1909). This belief continued until the surgical findings of intervertebral disc (IVD) rupture were first published in 1934 (Mixter & Barr, 1934). Since then, however, it has been shown that symptomatic disc prolapse is found in approximately 1% of patients with low back pain (Bogduk, 1991), and therefore other structures have attracted research interest. Up to 85% of chronic low back pain cases have been termed 'non-specific'; a label used to categorise clinical presentations in which there is an absence of identifiable tissue injury using medical imaging techniques (O'Sullivan, 2005). However, in these non-specific cases, there may be complex interactions of multiple contributing factors including: biological, psychological and social aspects. Although 'non-specific' low back pain may account for a substantial proportion of those people experiencing LBP, the lack of tissue damage in the lumbar region has lead both clinicians and researchers to consider innervated structures from which specific sources of nociception may arise. The SIJ is a known source of nociception and consequently, research has refocused on the anatomy and biomechanics of the joint (Bussey, Yanai, & Milburn, 2004; Cohen, 2005; Laslett, 2008; McGrath, 2004) as well as attempting to quantify the effectiveness of clinical interventions such as manual and manipulative therapies and prescriptive exercises that target the lumbo-sacral spine.

A major barrier to undertaking clinical research in manual diagnosis and treatment of the SIJ is the lack of diagnostic criterion standards for sacroiliac joint motion against which the effectiveness of manual technique could be measured. A substantial amount of research has now been undertaken into manual palpation of the sacroiliac joint (Kmita & Lucas, 2008; McGrath, 2006; Rajendran & Gallagher, 2011), the potential for SIJ structures to generate nociception (Fortin, Kissling, O'Connor, & Vilensky, 1999; Szadek, Hoogland, Zuurmond, Lange, & Perez, 2008; Vilensky et al., 2002), and the effectiveness of manual diagnostic techniques using double blinded anaesthetic injection as the criterion standard (Laslett, Aprill, McDonald, & Young, 2005; Laslett & Williams, 1994; Laslett, Young, Aprill, & McDonald, 2003; McKenzie-Brown, Shah, Sehgal, & Everett, 2005). Despite this increase in both quality and quantity of evidence, much of the manual clinical practice surrounding the SIJ remains predicated on older models of SIJ structure and function (Mitchell & Mitchell, 2001; Peace & Fryer, 2004) that are not well supported by current research (McGrath, 2006). Current approaches to clinical manual evaluation of the SIJ is even considered by some researchers to have limited clinical utility due to the small magnitudes of available sacroiliac movement and recent advances in knowledge of SIJ innervation (Goode et al., 2008; McGrath & Zhang, 2005).

The reproduction of symptoms (especially pain) from manual stress applied to the SIJ, while relevant, is often given less diagnostic importance than findings based on motion palpation by

clinicians working in traditional osteopathic models (Fryer, Johnson, & Fossum, 2010a, 2010b; Fryer, Morse, & Johnson, 2008; Peace & Fryer, 2004). Current assessment and treatment of the SIJ in manual and manipulative medicine is largely based on subjective clinical impression rather than on a robust evidence base. In addition, while pain associated with an anatomical structure can be confirmed by anaesthetic injection, there is no currently accepted criterion standard against which to measure the stiffness or 'laxity' of the joint. Doppler imaging of vibrations (DIV) has been proposed as a method for objectively assessing motion characteristics at the sacroiliac joint (Buyruk, Stam, et al., 1995). Although DIV has been shown to be valid, reliable and safe for use on humans (Buyruk, Snijders, et al., 1995; Buyruk, Stam, et al., 1995), recent investigations have been confounded by methodological inconsistencies and technical challenges with vibration generation equipment used in the DIV techniques (Crossley, 2011; Pender, 2011). Therefore, prior to investigation of inter-session reliability of the DIV technique, intra-session reliability of an improved prototype vibration generator needs to be established. If intra-session reliability of DIV is acceptable, then preliminary data can also be gathered about the efficacy of various clinical interventions (e.g. exercise) on joint stiffness, therefore providing a base for future effectiveness studies. The clinical use of corrective exercise to improve 'joint stability' is already common practice (Ferreira, Ferreira, Maher, Herbert, & Refshauge, 2006) although the mechanisms of action for these techniques are not clear. The efficacy with which certain large pelvic muscles can influence the joint has however, been questioned (McGrath, 2004) and studies investigating these 'force closure' effects on the SIJ are scarce (Richardson et al., 2002; van Wingerden, Vleeming, Buyruk, & Raissadat, 2004).

Therefore, the aims of this thesis were:

1. To address the need for acceptable equipment by developing a new vibration generator.
2. To investigate the intra-session reliability of this newly developed vibration generation equipment.
3. To investigate the effect of a non-specific muscle contraction on sacroiliac joint stiffness as measured by DIV.

Literature reviewed

Literature for this review is current up to 8 November 2012 and was found using the following sources: Google Scholar, EBSCOhost Online Research Databases, PubMed (Medline), ScienceDirect and The Cochrane Collaboration. The search terms were key words selected from the Medical Subject Headings (MeSH) subject areas and other relevant phrases. Hand searches of reference lists in retrieved articles were also undertaken. Authoritative texts were used to support well accepted anatomical and physiological knowledge.

2. Structure and function of the sacroiliac joint

2.1 Osseous anatomy of the SIJ

The articulation between the sacrum and the ilium is a true diarthrodial joint that possesses unique components within its structure when compared to normal diarthrodial joints (Forst, Wheeler, Fortin, & Vilensky, 2006). In addition to hyaline cartilage, the sacroiliac joint has irregular fibrocartilage that increases form closure and resists movement (Drake, Vogl, Mitchell, & Gray, 2010). Form closure is the component of joint stability arising from articular surface congruency (Vleeming, Mooney, & Stoeckart, 2007). It is known that the articular surfaces of the joint change throughout life (Bowen & Cassidy, 1981). In the first decade of life, the convex iliac surface and corresponding concave sacral surfaces permit gliding movements. During the second decade, joint stability increases substantially due to the formation of an iliac ridge and reciprocal sacral grove. Throughout the late second and early third decades a tubercle develops on the articular surface of the ilium, as does a sacral fossa, further restricting joint motion to become uniaxial around this latest bony development (Bowen & Cassidy, 1981). The SIJ is supported by the anterior and posterior sacroiliac ligaments and the interosseous ligament (Drake, et al., 2010). It has also been argued that a significant amount of joint stability is provided by the short anterior sacroiliac ligament and the interosseous sacroiliac ligaments due to their proximity to the joint and resultant mechanical advantage over the long posterior sacroiliac ligament (McGrath, 2010). Removal of either the anterior or posterior sacroiliac ligaments causes an increase in SIJ motion of 10% (Wang & Dumas, 1998), and removal of both the anterior and posterior ligaments causes and increase in SIJ motion of 30% (Wang & Dumas, 1998) to the already small motion of 1-2° of rotation (McGrath, 2004). Wang and Dumas (1998) did not remove the interosseous ligaments describing them as "impossible to tear" (Wang & Dumas, 1998). This description of the interosseous ligament carries the implication that these ligaments are strong and provide a major restraint for SIJ motion.

Historically, the availability of motion at the SIJ and the innervation of the joint has been contentious (Franke, 2003). A variety of studies have now demonstrated the joint possesses small but important mobility (Forst, et al., 2006). In fact, eight different sacroiliac movements have been described by a variety of authors (Cibulka, 2002). SIJ movement is constrained by strong ligaments (Pel, Spoor, Pool-Goudzwaard, Dijke, & Snijders, 2008). Due to its articular congruency and strong ligamentous support of the joint, SIJ function has been described as a mechanism for torsional load attenuation in the bony pelvic ring, enabling a slight 'yield' to twisting forces associated with asymmetric bipedal gait (Adams, Burton, Bogduk, & Dolan, 2006). It is possible that the eight planes of movement described could instead be attributed to the small amounts of movement in all directions of this "force attenuation mechanism."

Muscular structures with contributions to the movement and dynamic stabilisation include the latissimus dorsi through the thoracolumbar fascia, the piriformis and the gluteus maximus (Forst, et al., 2006). It has been stated in clinical texts that the erector spinae neither spans, nor controls this joint (Corrigan & Maitland, 1988). More recently, however, the erector spinae is now thought to produce shear loading in the joint (Snijders, Ribbers, de Bakker, Stoeckart, & Stam, 1998). Furthermore the erectors spinae aponeurosis (ESA) medially, the gluteal aponeurosis laterally and an underlying deep fascial layer combine at the long posterior sacroiliac ligament (LPSL) (McGrath, 2010) and are a good candidates to play a role in stabilising the SIJ through their attachments.

With these considerations, it can be concluded that the SIJ morphology changes with age and has a small but important mobility, making objective clinical assessment of the joint difficult and osteopathic diagnosis and treatment open to investigation.

2.2 Sacroiliac joint innervation

Pain is defined by the International Association for the Study of Pain (IASP) as "an unpleasant sensory and emotional experience associated with actual or potential tissue damage, or described in terms of such damage" (Merskey & Bogduk, 2002). Therefore in the circumstance of actual tissue damage, in order to generate action potentials the brain may perceive as pain, a tissue must possess nociceptive fibres leading to and from nociceptive organs. Histological evidence has shown that the sacroiliac joint capsule and the adjoining ligaments are innervated (Forst, et al., 2006). The sacroiliac joint is therefore capable of producing nociception if these structures are stimulated through mechanical, chemical or thermal deformation, thus supporting the notion that non-physiological sacroiliac joint movement may produce clinical signs. Manual therapy texts describe that reduced range of motion, or hypo-mobility is the cause of dysfunction and therefore may be associated with symptom generation (Ward, 2002). Different theories regarding the consequences of hyper and hypo-mobility in the sacroiliac joint are said to exist (Buyruk et al., 1999), however, these are yet to be researched in a formal way due to the lack of a technique to measure SIJ mobility.

It is well accepted that innervated soft tissue or bone structures around, or connected to, the sacroiliac joint have the potential to produce nociception (Cohen, 2005; Szadek, et al., 2008). Although it must be considered that this is an extrapolation of general anatomical knowledge and individual structures need confirmation of their capacity for nociception (Szadek, et al., 2008). Previously, the sacroiliac joint has been deemed to be devoid of innervation (Fortin, et al., 1999), however, the same authors later reported both myelinated and unmyelinated fibres are present in the posterior ligaments (Vilensky, et al., 2002) and in the dorsal capsule of the sacroiliac joint (Fortin, et al., 1999). Even more recently, calcitonin gene-related peptide (CGRP) and substance P immunoreactive fibres have been found in the anterior capsular ligament and the interosseous ligament, thus providing a physiological and morphological

basis for the origination of nociception from these structures (Szadek, et al., 2008). The segmental origin of the innervation itself has been of similar debate. Most research shows the anterior joint is innervated by the ventral rami between L2-S2, and the posterior joint by the dorsal rami of L4-S3 (Cohen, 2005).

McGrath and Zhang (2005) study investigated the relationship between the lateral branches of the dorsal sacral nerve plexus and the long posterior sacroiliac ligament (LPSL). Twenty-five sides of the pelvis from 16 cadavers were studied. The findings showed that the LPSL is penetrated by the lateral branches of the dorsal sacral rami mostly of S2 and S3, variably of S4 and rarely of S1. Some of the penetrating lateral branches give off nerve fibres that disappear within the ligament providing an anatomical basis for the LPSL as a potential pain generator in the posterior sacroiliac region. This study also provides further confirmatory evidence in support of the hypothesis that soft tissue structures surrounding the SIJ are capable of producing nociception.

2.3 Sacroiliac joint dysfunction

Despite the controversy surrounding the joint innervation, sacroiliac pain has been described as the cause of lower back pain in anywhere from 13-53% of cases (Horton & Franz, 2007) whereas a causative prevalence of 5-30% has been quoted by other authors (Hansen, 2003; Schwarzer, Aprill, & Bogduk, 1995a). To be confirmed as of sacroiliac origin, it is suggested that the pain meets four criteria described by the International Association for the Study of Pain (Meskey & Bogduk, 1994); first, the pain is in the sacroiliac region, second, the joint morphology is normal and free from pathognomonic radiographic abnormalities, third, the pain is reproduced by physical tests that stress the joint and fourth, the pain is eliminated by intra-articular injection (McGrath, 2010; Meskey & Bogduk, 1994). The 'Fortin Finger Test' has been described as a simple screening procedure to predict whether a person with pain perceived as arising from the SIJ is likely to respond to anaesthetic block of the SIJ. The Fortin Finger Test is considered positive if the patient can point to their pain with one finger, consistently in at least two trials, and this area is within 1cm inferiomedial to the posterior superior iliac spine (Fortin & Falco, 1997). A positive result from test has been shown to indicate sacroiliac dysfunction (Fortin & Falco, 1997). It has also been stated that pain from the sacroiliac commonly refers to a 3cmx10cm rectangular region inferior to the posterior superior iliac spine (Fortin, Aprill, & Ponthieux, 1994) although other authors have shown that provocative injection into the SIJ can produce referral patterns indistinguishable from the referral patterns observed from low back pain (Van der Wurff, Buijs, & Groen, 2006).

Sacroiliac dysfunction, however, is an ambiguous term in itself. The term "sacroiliac joint dysfunction" has been used in a clinical context to describe biomechanical disorders of the joint, such as hypo-mobility or 'fixation' (Dreyfuss, Dreyer, Griffin, Hoffman, & Walsh, 1994),

causing pain in the region (Dreyfuss, Michaelsen, Pauza, McLarty, & Bogduk, 1996). Here again we see terms, hypo-mobility and fixation, that are consistent with the manual therapy texts regarding reduced range of motion or stiffness as the pain generator. "Sacroiliac dysfunction" however, has been deemed a misnomer as it is difficult to be sure that it is the joint itself that is causing the pain when a number of known innervated structures refer pain to the sacroiliac region (Nachemson, 1992). Due to the presence of nociceptive fibres in both intra and extra-capsular structures, these should be considered by diagnostic techniques (Szadek, et al., 2008). These studies (Dreyfuss, et al., 1994; Dreyfuss, et al., 1996; Nachemson, 1992) associate pain with dysfunction, an association that is not always reflected in clinical practice where pain provocation is sometimes avoided (Fryer, et al., 2010a). For example, the definition of dysfunction described in the osteopathic texts includes pain as a less significant characteristic of dysfunction using the term tenderness on palpation or sensibility changes as alternatives to pain (Dowling, 1998; Parsons & Marcer, 2005). Osteopathic texts place importance instead on tissue texture changes, asymmetry and range of motion (DiGiovanna, Schiowitz, & Dowling, 2004; Greenman, 2003; Parsons & Marcer, 2005; Ward, 2002).

2.4 Form and force closure

Simple physics and mechanical engineering inform the principles of 'form' and 'force closure' at the SIJ (Figure 1). These principles, when applied to the pelvis, indicate the need for continuous force to be produced by transversely orientated muscles (Snijders, et al., 1998). Snijders et al., (1998), in a comprehensive review of the literature surrounding sacroiliac region muscle activation in varying postures, hypothesised that: a) during decreased periods of spinal load or self-bracing these continuously active, transversely orientated muscles are less active; and b) when spinal load is increased these muscles become more active. In more recent study, it has been stated that gluteus maximus is strongly active when abrupt lower limb loading and subsequent sacroiliac joint stability is required (Hossain & Nokes, 2005). Hossain and Nokes further propose that abnormal force closure of the SIJ, by the gluteus maximus, during the gait cycle may result in LBP symptoms. These authors suggest that the resultant disturbance in force closure would deprive the limb of the important shock absorbing properties of the sacroiliac joint during the gait cycle. It could therefore be useful to investigate if activation of the gluteus maximus and piriformis muscles can cause a transient change in sacroiliac joint stiffness.
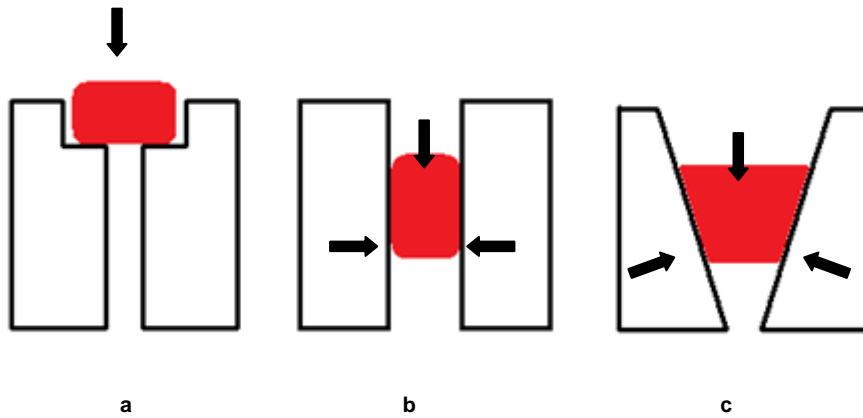
Figure 1. A diagrammatic representation of the principles of form and force closure. a) Form closure, the red object (modelling the sacrum) cannot be moved by any force applied vertically downwards. b) Force closure, the red object will fall unless friction is created by opposite horizontal forces. c) A combination of form and force closure holds the red sacrum in place. Figure adapted from Snijders, et al., (1998)

2.5. Clinical application of force closure

Therapeutic exercise is widely prescribed by practitioners of manual and manipulative therapy (Hayden, van-Tulder, Malmivaara, & Koes, 2005). Although spinal manipulation has been shown to give short term benefit to acute episodes of low back pain (Rubinstein, Terwee, Assendelft, de-Boer, & van-Tulder, 2012), the long term outcomes are similar to that of other interventions (Rubinstein, et al., 2012). Specific muscle training to improve joint stabilisation in the lumbo-sacral spine was popularised in the late 1990s largely through the innovative work of Richardson, Jull, Hodges and Hides (Richardson, 1999) in attempt to provide an explanation for recurrent low back pain (Jull & Richardson, 2000). The approaches to spinal stabilisation described by Richardson et al (2002) are predicated on categorisation of lumbar and abdominal muscles (Bergmark, 1989) based on their role in stabilisation of the lumbopelvic spine. Alterations in muscle firing patterns have been observed in people with chronic low back pain (Hodges, 1999; Jull & Richardson, 2000; Richardson, et al., 2002) and these alterations have been stated to be treated successfully with specific muscle training using a 'stabilisation' model (Richardson, et al., 2002).

Clinicians often use specific muscle exercise as a prescription for the 'stabilization' or 'stiffening' of a 'lax' SIJ diagnosed by palpation and clinical examination (Pool-Goudzwaard, Vleeming, Snijders, Stoeckart, & Mens, 1998; Vleeming, et al., 2007). Various studies have demonstrated that SIJ pain can benefit from specific (Ferreira, et al., 2006; Richardson, et al., 2002) or general exercise prescription (Stuge, Holm, & Vøllestad, 2006; Vleeming, et al., 2007). The mechanisms by which these benefits occur are not fully understood (Chaitow, 2007) but may arise from factors other than improvements in joint stability (McGrath, 2010; Pool-Goudzwaard et al., 2004). The use of specific muscle stabilisation has been investigated by two authors using Doppler imaging of vibrations (DIV) techniques to evaluate SIJ function and will be discussed in section 3.2.3 (Richardson, et al., 2002; van Wingerden, et al., 2004).

3. Clinical assessment of the sacroiliac joint

3.1 Clinical assessment of sacroiliac pain

It is often assumed by practitioners of manual and manipulative therapy that stiffness, or reduced range of motion is undesirable (Brukner & Khan, 2010; DiGiovanna, et al., 2004; Ward, 2002). Yet when a joint is injured traumatically, it may be the over stretching of soft tissue, and subsequent hyper-mobility, that gives rise to clinical symptoms (McGrath, 2004). In the same way, a hyper-mobile joint could potentially put additional mechanical forces on capsule and ligaments causing injury, pain or dysfunction (McGrath, 2004). Current clinical assessment of SIJ stiffness is highly subjective and a more objective measurement approach would allow these assessment techniques to be investigated for validity (Buyruk, Snijders, et al., 1995).

3.1.1 Injection techniques to establish pain generation

Currently, sacroiliac pain is confirmed by an intra-articular analgesic injection (Merskey & Bogduk, 1994). Due to the cost, invasive nature and need for specialist training, this is not a viable option for manual therapists. Clinical provocation tests have been shown to be of diagnostic value when used to reproduce clinical symptoms at the SIJ together in 'clusters' of multiple techniques and interpreted collectively (Laslett, et al., 2005). The validity of these clusters of tests have been verified by intra-articular injection of local anaesthetic (Laslett, et al., 2003). In a systematic review, diagnostic anaesthetic SIJ injections (known as 'diagnostic blocks') were reported to be 'moderately' valid and reliability with a false positive rate of 20% for diagnostic purposes (McKenzie-Brown, et al., 2005). The same review also concludes that there is significantly more evidence regarding SIJ diagnostics than therapy (McKenzie-Brown, et al., 2005). Although these diagnostic blocks are thought to be the most reliable confirmation in sacroiliac pain diagnostics, it is difficult to be certain that the analgesic effects are only occurring within the joint. It has been suggested that the injection is likely to have an effect on both extra- and intra-capsular structures, and thus its diagnostic specificity is lowered (Peace & Fryer, 2004; Schwarzer, Aprill, & Bogduk, 1995b).

3.1.2 Physical assessment of SIJ

Pain is not necessarily a useful correlate of SIJ motion or stiffness in manual and manipulative therapy. Osteopathic texts in particular place importance on motion palpation and asymmetry instead of pain (DiGiovanna, et al., 2004; Parsons & Marcer, 2005; Ward, 2002). Clinical practice however, is not consistent with current research regarding motion palpation and landmark identification (Kmita & Lucas, 2008; Laslett, 2008; McGrath, 2006). This disparity between clinical practice and best evidence is explored in the following paragraphs.

3.1.2.a Motion Testing and Palpation

The SIJ is described as having limited but important motion (McGrath, 2004). Not only has manual testing been unreliable, but due to the complex anatomical structure and varied orientation of the joint, non-invasive three-dimensional kinematic analysis has also proven difficult (Goode, et al., 2008; McGrath, 2006). Due to this difficulty, the three-dimensional and planar movements occurring at the SIJ have been investigated using a variety of techniques both in-vitro and in-vivo. Techniques that have high face validity for accurate measurement of SIJ movements include roentgen stereophotogrammetric analysis (RSA)(Sturesson, Selvik, & Udén, 1989), computerised axial tomography (CAT)(Smidt et al., 1997) and Kirschner wires (Jacob & Kissling, 1995). Roentgen stereophotogrammetric analysis (RSA) involves the implantation of opaque artificial markers onto bony prominences, accurately measuring rotation around a transverse axis (2.5°) and translation (0.7mm) (Sturesson, et al., 1989). Computerised axial tomography (CAT) scan technique has been applied to fresh cadavers and shown approximately three times the amount of rotation (7-8°) and translation (4-8mm) as RSA (Smidt, et al., 1997). The third technique that appears to accurately measure SIJ kinematics uses three-dimensional stereophotogrammetric analysis of Kirschner wires drilled into bony prominences on the sacrum and ilium (Jacob & Kissling, 1995). The average values for total rotation and translation as measured by Jacob and Kissling (1995) were 1.7 ° and 0.7 mm respectively, which is more consistent with RSA than CAT scanning (Jacob & Kissling, 1995). Routinely available imaging techniques such as x-ray or magnetic resonance imaging can be of use in the diagnosis of pathology causing secondary sacroiliac instability, but their usefulness in the detection of the small sacroiliac movements in vivo is limited (Buyruk, Stam, et al., 1995). In a systematic review of three-dimensional analyses of the degree of movement in each plane of motion possible at the sacroiliac joint, it was concluded that sacroiliac motion is limited to amounts of translation and rotation that are minute to the point that clinical assessment methods (eg motion palpation) that use palpation may have inadequate clinical utility (Goode, et al., 2008).

Despite their apparent precision and high face validity, CAT, RSA and Kirschner wires are invasive and involve exposure to ionising radiation making them impractical for routine clinical application (Adhia et al., 2012). Non-invasive techniques such as potentiometers (Perret, Poiraudeau, Fermanian, & Revel, 2001) and inclinometers (Freburger & Riddle, 1999) have been observed to be incapable of measuring movement at the SIJ cited in a review by Goode et al. (2008). Working in a laboratory setting, Bussey et al. (2009; 2004) used a palpation-digitisation method and an electromagnetic tracking system to non-invasively measure movement of the ilium on the sacrum during abduction and external rotation of the femur. They observed between 3° and 4° of rotation around a transverse axis (Bussey, et al., 2004). Despite "large variability" between subjects, the measurements were found to be reliable and the accuracy of palpation in locating the desired bony landmarks was verified by CT scan (Bussey, et al., 2004). Further study by the same research group investigating inter-tester

reliability of the palpation-digitisation method observed an intra-class correlation coefficient (ICC) (≥ 0.97) and standard error of measurement (SEM) of ≤ 2.02 mm which are interpreted as "very high inter-tester and trial-to-trial reliability and accuracy of palpation-digitisation technique" (Adhia, et al., 2012). The authors then conclude that their results support the clinical and research utility of the palpation-digitisation technique for non-invasive kinematic evaluation of SIJ and recommend further research using the technique (Adhia, et al., 2012). In the light of the weight of current research questioning the validity, reliability and relevance of palpation as a diagnostic tool, some clinicians are confused as to why Adhia and colleagues propose the clinical use of the palpation-digitisation method (Ridgeway & Silvernail, 2012). Adhia and colleagues respond to this critique by restating their results and outlining their reasoning behind the avocation of the clinical use of palpation-digitisation (Bussey, Milosavljevic, & Adhia, 2012). Although their reasoning and examples of clinical application of the results appear logical, the claims need a stronger evidence base as current research into the validity and reliability of palpation of the SIJ is not favourable (Kmita & Lucas, 2008; Laslett, 2008; Levangie, 1999; McGrath, 2006; Rajendran & Gallagher, 2011).

3.1.2.b Pain Provocation

Manual therapists rely on observation and palpation of bony land marks to assess the sacroiliac joint (Walker, 1992). The reliability of these subjective clinical tests has been questioned by a number of studies (Buyruk, et al., 1999; Buyruk, Stam, et al., 1995; Van-der-Wurff, Meyne, & Hagejier, 1999, 2000). Of seven sacroiliac provocation tests studied, five showed acceptable inter-rater reliability with Kappa statistics ranging in value from 0.52 to 0.88 (P < 0.001) (Laslett & Williams, 1994). More recent study investigating similar tests observed "fair to substantial" levels of inter and intra-rater reliability of individual SIJ provocation and motion tests, and "substantial to excellent" levels of inter and intra-rater reliability of composite tests (Arab, Abdollahi, Joghataei, Golafshani, & Kazemnejad, 2009). The improvement of inter and intra-rater reliability of SIJ provocation tests through the use of composite tests has also been observed by Paatelma, Karvonen and Heinonen (2010). Laslett and Williams (1994) nominated five SIJ provocation tests that appeared to have reasonable face validity and these were subsequently investigated for validity in follow up studies. Authors observed that composites of three tests, in the absence of centralisation during repeated movement testing, have a "clinically useful" sensitivity (93%), specificity (89%) and positive likelihood ratio (+LR = 6.97) (Laslett, et al., 2003). Although some SIJ tests have shown acceptable levels of inter-rater reliability (Kokmeyer, van der Wurff, Aufdemkampe, & Fickenscher, 2002; Laslett & Williams, 1994) studies have shown that these tests alone cannot predict the results of diagnostic injection (Dreyfuss, et al., 1996; Maigne, Aivaliklis, & Pfefer, 1996; Slipman, Sterenfeld, Chou, Herzog, & Vresilovic, 1998). Since their earlier seminal work (Laslett & Williams, 1994), Laslett and colleagues have conducted a study investigating the differences in validity of provocation tests individually and in combination, compared to double blinded diagnostic injection (Laslett, et al., 2005). They

conclude that composites of SIJ pain provocation tests are valuable to clinical diagnosis of the painful SIJ. Three or more out of six tests or any two of four selected tests were reported to have the best predictive power in relation to results of intra-articular anaesthetic block injections. When all six provocation tests do not provoke familiar pain, the SIJ can be "ruled out" as a current source of LBP (Laslett, et al., 2005). Again it must be considered that these tests are intending to confirm pain not investigate the motion characteristics of the SIJ. In addition, there has been recent commentary regarding the clinical utility of composite SIJ provocation tests in light of contemporary anatomical evidence from detailed dissection of the joint (McGrath, 2010). McGrath (2010) proposes an alternate hypothesis to explain the apparent predictive validity of clusters of SIJ provocation tests. In light of contemporary anatomical studies that have observed previously unknown multiple innervation of the SIJ (McGrath & Zhang, 2005), McGrath argues that SIJ pain provocation tests may not reproduce pain by stressing SIJ tissues such as the joint capsule, inflamed articular surfaces or ligaments. Rather, the reproduced pain may be a result of mechanical palpation pressure over superficial nerves arising from the lateral branches of the dorsal sacral nerve plexus which are found in close proximity to the long posterior sacroiliac ligament – the same area palpated during SIJ provocation tests (McGrath, 2010; McGrath & Zhang, 2005). It could be argued that pain reproduction is useful in a clinical setting, but importantly, the reproduction of symptoms (e.g. pain) during clinical examination does not explain the aetiological factors involved in symptomology.

3.1.2.c Somatic Dysfunction and palpation

It is important to note that many of the provocation tests described above are intended to confirm that the sacroiliac joint is painful, and do not assess the joint for dysfunction or stiffness. Osteopathic texts give an indication of what diagnostic tests are taught to osteopaths but not necessarily what is used in practice (Fryer, et al., 2008; Peace & Fryer, 2004). Three recent studies have investigated what techniques osteopaths use to assess the sacroiliac joint (Fryer, et al., 2010a, 2010b; Fryer, et al., 2008; Peace & Fryer, 2004). These studies have established that osteopaths use pain provocation tests in conjunction with a variety of osteopathic models, and orthopaedic testing to assess the sacroiliac joint in clinical practice (Fryer, et al., 2010a, 2010b; Fryer, et al., 2008; Peace & Fryer, 2004).

In 2004 a survey of 168 Australian osteopaths aimed to determine what clinical tests were used and the effect experience had on the tests used (Peace & Fryer, 2004). All 953 osteopaths listed in the Yellow Pages were sent a questionnaire and the response rate was calculated at 18% but estimated at 30% due to repeat addresses. Respondents reported the use of bony land mark symmetry, SIJ motion and pain provocation tests to assess the SIJs. Over 94% of respondents place importance on the use of static palpation of bony land marks while existing evidence shows inter-examiner reliability of palpation of bony landmarks indicative of somatic dysfunction to be low or less than acceptable for the test to be used clinically (Fryer, McPherson, & O'Keefe, 2005; Kmita & Lucas, 2008). In addition to low inter-

examiner reliability, palpation of pelvic asymmetry has not shown a positive correlation with low back pain (Levangie, 1999). The extent of osteopaths' experience appeared to influence their selection of landmark palpation. As experience increased, osteopaths tended to move away from using the anterior superior iliac pine (ASIS), inferior lateral angle and sacral base, and moved toward using the gluteal folds and ischial tuberosities. This apparent experience effect indicates a move away from the land marks used by conventional approaches such as the model proposed by Mitchell, Moran, and Pruzzo, (1979) towards less advocated, uncommon, or "other" tests as practitioner experience increased. The study also showed that all but 14% of osteopaths surveyed use pain provocation tests, which are not advocated by any author in major osteopathic texts (DiGiovanna, et al., 2004; Greenman, 2003; Ward, 2002). The authors raise the lack of a valid "gold standard" against which SIJ provocation tests can be assessed. Motion tests were used more than pain provocation but less than static bony palpation. Peace and Fryer (2004) accept the likelihood of response bias in that osteopaths interested in the SIJ and who place clinical importance on its diagnostic value, are more likely to respond to such a questionnaire than those who feel SIJ assessment is less important to osteopathic diagnosis.

Another similar study, by the same lead author (Fryer, et al., 2008), investigated the assessment and treatment approaches of osteopathic physicians in the United States (US) to the spinal and sacroiliac joints. This study used a web-based survey as opposed to the traditional mail used in the 2004 study of Australian osteopaths. The study showed a slightly higher response rate of 22%. Assessment procedures were divided into the subgroups; asymmetry, SIJ motion and pain provocation. Pelvic landmarks used most commonly to assess asymmetry were the ASIS (87%), sacral base (82%), PSIS (81%), sacral sulci (78%), and iliac crests (77%). SIJ motion testing was used less commonly than static bony palpation. American physicians reported using the same motion tests as Australian osteopaths but tended to incorporate osteopathy in the cranial field more than their Australian counterparts. The SIJ pain provocation tests were the least used of the three assessment subgroups, but American physicians used provocation tests approximately four times more commonly than Australian osteopaths.

A third study, again by the same lead author (Fryer, et al., 2010a) investigated the SIJ assessment procedures performed by osteopaths in the United Kingdom (UK). A web-based questionnaire was used and sent to all 2700 osteopaths registered by the General Osteopathic Council with a current email address. Of 2700 invitations, 520 osteopaths responded (56% male, 44% female) with a wide range of practice experience (range = 0-36y; mean = 11.6 ± 9.7). Provocation of sacroiliac pain (82%), reduced range of joint motion (79%) and tenderness around the sacroiliac joint (80%) were most frequently and most highly regarded as indicative of pelvic and sacroiliac somatic dysfunction (p < 0.001). Bony asymmetry was not as highly regarded by UK respondents as the Australian and US groups studied but percentage agreement was still high at 75%. Pain provocation was regarded as

the most clinically important SIJ test by the UK respondents despite its lack of advocacy by osteopathic texts. The high reported useage of pain provocation tests may indicate a response bias in the direction of osteopaths who are interested in research or hold strong beliefs about the SIJ. Respondents in the UK (32%) and Australian (30%) appeared to use osteopathy in the cranial field to assess the pelvis and sacroiliac joints to a far lesser degree than US osteopathic physicians (61%) (Fryer, et al., 2008; Peace & Fryer, 2004). It must be noted that the response rates in both this study and the US study (Fryer, et al., 2008) are calculated from the number of eligible registrants with email addresses not from the total number of eligible participants. This means the sample is a significantly smaller proportion of practicing osteopaths than the response rate suggests, contributing to possible response bias.

These three studies (Fryer, et al., 2010a; Fryer, et al., 2008; Peace & Fryer, 2004) were not designed with the intent of comparison. With this caveat in mind, useful inferences can still be drawn from the results. All these studies use the term "sacroiliac dysfunction", and discuss the use of pelvic landmarks and pain provocation tests in a clinical setting. Both the osteopaths included in these studies and the authors therefore associate pelvic asymmetry and pain as contributing factors to sacroiliac dysfunction. SIJ pain is not necessarily related to SIJ stiffness and although the aforementioned studies investigated pain provocation, landmark palpation and motion assessment, no reference to perceived joint stiffness or restriction was made. The Mitchell model, however, does use motion palpation to infer which sacroiliac joint is stiff (Mitchell & Mitchell, 2001). These studies found the most commonly used diagnosis and treatment model by respondents is that described by Mitchell, first published in 1979 (Mitchell, Moran & Pruzzo, 1979). The Mitchell model, advocated by many osteopathic texts (Chaitow & DeLany, 2002; DiGiovanna, et al., 2004; Ehrenfeuchter & Sandhouse, 2002; Greenman, 2003; Mitchell & Mitchell, 2001; Parsons & Marcer, 2005), uses motion testing to identify the side of the 'lesion' and static palpation of bony prominences to determine the type of lesion. The type of lesion then determines which side is treated with a muscle energy technique (Mitchell & Mitchell, 2001). The Australian study states that there is currently no "gold standard" for assessing SIJ dysfunction (Peace & Fryer, 2004). From these three studies it is apparent that osteopaths surveyed in Australia, the US and the UK, used palpation of bony landmarks, motion testing and pain provocation tests when assessing the SIJ. The use of bony palpation and motion tests as described by Mitchell and advocated by most osteopathic texts, does not appear to have declined despite the availability of contrary evidence such as that reported by Kmita & Lucas (2008) or Rajendran and Gallagher (2011). Furthermore, the inclusion of pain provocation tests which are not found in osteopathic texts, suggests osteopaths sampled in Australia, the US and the UK have an awareness of wider manual therapy literature but individually select what evidence to incorporate into their practice. It was noted in all three countries studied that some osteopaths responded to open ended questions with the notion that they never intend to induce pain (Fryer, et al., 2010a, 2010b; Fryer, et al., 2008; Peace & Fryer, 2004), which appears more

consistent with osteopathic texts (DiGiovanna, et al., 2004; Ehrenfeuchter & Sandhouse, 2002; Greenman, 2003; Mitchell & Mitchell, 2001). If clinical practice is to become more consistent with current research, then a tool to objectively measure SIJ motion needs to be developed. This could, in the future be used to investigate the efficacy of clinical motion testing.

3.2 Doppler imaging of vibrations

To address the need for an objective measurement of sacroiliac joint stiffness, Colour Doppler Imaging of Vibrations has been suggested and applied to human pelvises in-vitro and in-vivo (Buyruk, Snijders, et al., 1995; Buyruk, Stam, et al., 1995). The technique is predicated on the premise that a joint will dampen a force translating through it (Buyruk, Stam, et al., 1995). Vibrations applied to the anterior superior iliac spine (ASIS) are transmitted through the pelvis and would be dampened by the SIJ creating a difference in vibration intensity between the ilium to which the vibrations were applied and the sacrum. The amount of dampening is postulated to represent the laxity of the joint; the stiffer the joint the less it would dampen the vibration. The Doppler function of an ultrasound machine is routinely used to measure the intensity of movement in a tissue, most often blood flow. Therefore, if a vibration, applied to the ASIS, is dampened by the SIJ, then the ilium will be vibrating at a higher intensity than the sacrum due to the loss of force. Doppler mode consists of a function that enables the operator to increase or decrease the colour flow (CF) percentage. The CF percentage represents the signal power required to see the vibrations in a given tissue (Allan, 2006). A high CF percentage is required to see coloured pixels displayed on the ultrasound image over a tissue with a low intensity vibration and a low CF percentage would enable only tissues with high intensity vibration to be shown as colour pixels on the ultrasound monitor. DIV uses the difference in CF percentage to represent the stiffness of a joint in threshold units (TU). This difference is obtained by subtracting the CF percentage seen when colour Doppler pixels are observed over the PSIS only, from the CF percentage seen when colour Doppler pixels appear over both the sacrum and PSIS. DIV has been shown to have intra-individual reproducibility, inter-individual variability and be non-invasive (Buyruk, Snijders, et al., 1995).

3.2.1 Critique of the DIV technique

The validity and reliability of the DIV technique has been reviewed by de Groot, Spoor & Snijders (2004). The review identified five key assumptions in DIV that appear to be incorrect: 1) energy loss in propagation ensures vibration intensity reduction across a joint; 2) joint stiffness is proportional to the conducted vibration intensity; 3) vibration intensity changes during one measurement session are negligible; 4) vibration phase differences across a joint can be ignored; and 5) threshold units are a measure for the velocity (squared) of the vibrating bone. Another assumption is that no resonance is occurring at 200Hz. de Groot and colleagues analysed the changes observed in stiffness values (TU) recommending that changes in stiffness should only be considered significant if they are greater than 2.0TU for an average of three measures. The authors conclude that the DIV technique "is promising" with established reliability and clinical relevance, but recommend that good quality validity study of the DIV technique is necessary. Validity studies into the DIV technique would involve access to cadavers and be technically difficult requiring specialised skill sets. Validity studies involving live human participants would be invasive. Such studies require large amounts of funding and specific resources.

Although de Groot's review highlights fundamental assumptions regarding the validity of the DIV technique, the authors fail to mention any methodological flaws in the technique such as patient positioning and the lack of control for patient generated downward force on the VG. Mens, Damen, Snijders & Stam (2006) offer an alternative to the fundament assumption raised by de Groot et al., that vibrations are not necessarily conducted through the bone alone. Mens et al., propose instead that vibrations may be transmitted through the surrounding soft tissues and that SIJ stiffness is dependent on the tone of these tissues and therefore, DIV may indirectly measure SIJ stiffness in this way.

3.2.2 Early use of DIV

The initial study into Doppler Imaging of Vibrations (DIV) explored proof of concept in cadavers (Buyruk, Stam, et al., 1995). This study used four embalmed female pelvises (age range; 92-97y), resected from L4 to mid-femur keeping all superficial layers intact as well as all muscles and ligaments while removing the pelvic organs. Four kilograms of metal was used to mimic the mass of the legs and trunk. Two pelvises were used to explore optimum vibration frequency which was observed to be 200Hz. The remaining two specimens were used to investigate validity of the DIV technique. Each of the two pelvises was imaged with no intervention and the stiffness value in threshold units was found. Screws were then inserted to fix each SIJ and the pelvises were tested again before having the screws removed and ligaments transected. It was observed that one of the specimen's stiffness increased significantly with fixation whereas the other observed no change. Following the transection of the ligaments, both specimens showed a decrease in stiffness to above that observed pre-intervention. The authors report no issue in cutting the ligaments but fail to report what ligaments were transected. The specific ligaments cut could have an effect on the amount of movement available at the joint, with other authors describing the interosseous ligaments as being "impossible to tear" (Wang & Dumas, 1998). Buyruk and colleagues conclude that DIV is objective and repeatable, providing significant intra- and inter-individual differences, despite only assessing four joints. The small scale of this study is acceptable as it aimed to provide proof of concept and establish if DIV is safe for human application. Buyruk and colleagues recommended in-vivo application due to the apparent safety of the DIV technique although it is not clear how a cadaver study can provide safety data for live humans.

The DIV technique was first investigated in-vitro by Buyruk and colleagues, on a sample of 14 healthy female participants (Buyruk, Snijders, et al., 1995). The aim of this follow on study was to further investigate DIV as an objective method for the evaluation of pelvic stability. Buyruk and colleagues state that there is no current objective measure for determining motion at the SIJ despite an accepted etiological relationship between pain and pelvic stability. To be included participants were required to be female, have no history of lower back or pelvic problems for a period of a year, and no regular use of alcohol or pain killers. The use of a

very specific sample contributes to higher internal validity, but limits further generalisation. The authors show a sound rationale for their stated aim due to the subjectivity, poor reliability and observer experience-based nature of current clinical assessments. The number of subjects used in the study is low. However, it is an in-vivo pilot study and thus the use of a smaller number of participants is acceptable. Authors state that participants were in a prone position and it was ensured that all the large muscles that can stabilise the sacroiliac joint were relaxed. Although the authors report the use of parametric statistical analysis they do not report whether their data satisfied the assumptions of normality. The authors draw conclusions that are appropriate for their method and results. They report the observation of satisfactory intra-individual reproducibility and inter-individual variability and no significant difference between the left and right SIJ. They report awareness of a number of variables such as the oral contraceptive pill and strong pain killers that could possibly create a bias for, or against, the result and suggest they are controlled for in future studies. The authors do not, however, make reference to the direction of bias that oral contraceptive pill (OCP) may have on ligament laxity. It is now known that the OCP can cause increased ligament stiffness which may be extrapolated to the SIJ ligaments (Martineau, Al-Jassir, Lenczner, & Burman, 2004).

Buyruk and colleagues later completed a cross-sectional comparative analysis of SIJ stiffness in peripartum pelvic pain patients (Buyruk, et al., 1999). DIV measurements were performed on a group of participants diagnosed by an independent physician with peripartum pelvic pain (PPPP) (n=56) and on a control group (n=52) who reported no history of idiopathic pelvic or low back pain before, during or after pregnancy. The PPPP group and the control group were of similar age range and mean age. The equipment set up was consistent with the authors' previous studies using DIV. The authors observed no significant difference in mean stiffness between the PPPP group and controls, but did observe a "highly significant" (P<0.00001) difference between groups in relation to asymmetry. The PPPP group were reported to have shown a much larger asymmetry of stiffness (mean=3.38TU) than controls (mean=0.78TU), but no relationship between location (left-right) of pain and stiffness was observed. The main conclusion from the study was stated to be the left-right asymmetry observed in the PPPP group. The authors found that a variety of stiffness values were present amongst healthy people. This variety of normative stiffness values is a result that is not consistent with manual and manipulative therapy literature which cites both hypo-mobility(Vitanen, Kokko, Lehtinen, Suni, & Kautiainen, 1995) and instability (Walheim, Olerud, & Ribbe, 1984) as pathological. Asymmetric shock absorption has also been cited as a possible cause of SIJ pain by clinicians (Grieve, 1983). Buyruk and colleagues, dismiss asymmetric shock absorption due to the prevalence of pain complaints while sitting and standing when shock absorption is not occurring. More contemporary thinking in light of best evidence, has now termed the SIJ a "force attenuation mechanism" (Adams, et al., 2006) which is consistent with shock absorption and may warrant further research into asymmetric shock absorption as a possible aetiological factor in SIJ pain.

3.2.3 Use of DIV in pregnancy related pelvic pain

The DIV technique was used by Damen and colleagues, to investigate pregnancy related pelvic pain (PRPP) (Damen et al., 2001; Damen et al., 2002). The first of these studies used DIV to test for asymmetric laxity of the SIJs following the use of a cluster of techniques to classify 163 pregnant females at 36 weeks gestation into PRPP+ve (n=63) or PRPP-ve (n=90) groups (Damen, et al., 2001). Participants were classified as being PRPP+ve or PRPP-ve based on the results of a visual analogue scale (VAS) and a pain drawing. Damen and colleagues observed no significant difference in mean SIJ laxity between PRPP+ve (mean=3.4TU) and PRPP-ve (mean=3.0TU) groups. The mean left-right difference was significantly higher ($P<0.05$) in the PRPP+ve group (2.2 ± 1.7TU) than in the PRPP-ve group (0.9 ± 0.9TU). Asymmetry of SIJ laxity was noted in 37% of the PRPP+ group compared to 4% of the PRPP-ve group. It was noted that participants who had a significant left-right difference in SIJ laxity also showed a positive correlation with high scores on pain scales and positive clinical SIJ dysfunction tests. The authors conclude that increased SIJ laxity is not associated with PRPP, whereas asymmetric laxity of the SIJs is associated with 'moderate or severe' PRPP. While cross sectional studies such as this show an association between SIJ asymmetry and local pain, they do not address whether asymmetry is causative or a result of SIJ pain.

The second of these studies (Damen, Buyruk, et al., 2002), investigated the prognostic value of the DIV laxity measurements taken in the first study (Damen, et al., 2001) described above. Of the 163 participants in this first study, 123 returned for re-examination at 8 weeks postpartum and were included in this prospective cohort study. Dropout rates were approximately equal in the PRPP+ve and PRPP-ve groups. SIJ asymmetry was defined as a left-right laxity difference of ≥3 TU. No differences were found in laxity between DIV measurements at 36 weeks gestation and at 8 weeks postpartum. The authors report that for participants with 'moderate to severe' pelvic pain during pregnancy, asymmetric SIJ laxity is a positive predictor of the persistence of PRPP into the postpartum period in 77% of cases (sensitivity=65%; specificity=83%). The authors conclude by stating that asymmetric SIJ laxity during pregnancy is a predictor of PRPP persisting postpartum. The authors do not appear to have considered the possibility that an asymmetric foetus presentation could be unevenly loading the vibration generator, creating a false positive left-right asymmetry measurement. Further, at the time of this study, inter-session reliability of the DIV technique had not been investigated. Subsequently, intersession reliability has been observed to be poor (Pender, 2011). Therefore, any differences in DIV stiffness measurements between the session at 36 weeks gestation and at 8 weeks postpartum cannot be separated from natural variations in joint stiffness.

3.2.4 Reliability of DIV

Following the completion of their first study into PRPP described above, Damen, Stijnen, Roebroeck, Snijders, & Stam (2002), observed that there was no existing literature regarding the inter-tester reliability of the DIV technique. Intra- and inter-tester reliability of five novice testers and one experienced tester were investigated on 10 healthy female participants. Intra-class correlation coefficients (ICC) were observed to range from ICC = 0.53 to 0.80 for novice testers and 0.75 to 0.89 for the experienced tester. The authors state that they are 95% certain that a left-right difference greater than 2.8TU is above the 95th percentile in healthy females and suggest that a difference of ≥ 3.0TU is not within the normal range for healthy women. The authors conclude that both novice and experienced testers can reliably access the SIJ using DIV and that experienced testers can significantly detect smaller variations in SIJ stiffness as measured in TU. Importantly, Damen and colleagues recommend that the mean of three repetitions are used for each measurement of SIJ stiffness to improve reliability.

In a recent study Crossley (2011) investigated the reliability of novice observers assessing threshold levels in pre-recorded videos of the DIV technique. This task is the key decision in the DIV technique that requires testers to make subjective judgments about Doppler pixel colour intensity. Threshold levels are the CF percentage values when coloured pixels appear first over the ilium, and then over both the ilium and sacrum. The later is subtracted from the former to give a stiffness measurement. Intra-observer reliability ranged from 'moderate' (ICC = 0.48, 95% CI = -0.04 to 0.81) to 'very high' (ICC = 0.99, 95% CI = 0.99 to 1.0) whilst inter-observer reliability was 'very high' (ICC = 0.99, 95% CI = 0.99 to 1.0). Crossley concluded that video recordings of DIV can be reliably assessed by novice observers, indicating that measurement error in the DIV technique is unlikely to be attributable to rater error. Reliability of rating pixel density is one key cognitive aspect of intra-session reliability of the DIV technique which can be done well, independently of psychomotor skills, such as ultrasound probe alignment and positioning. Crossley's study allows future studies to confidently take screen shots of threshold values for later analysis eliminating the hassle of video cameras.

Another recent study aimed to test the reliability of the DIV technique to assess SIJ stiffness in a normal population (Pender, 2011). Pender investigated intra and inter-session reliability using a custom built vibration generator and thirteen healthy participants. This was the first study to investigate inter-session reliability of the DIV technique. Patient positioning and equipment set up was consistent with previous literature. Interclass correlation coefficients (ICC) with 95% confidence intervals (CIs) were used to calculate intra and inter-session reliability. 'Excellent' ICC scores with 'substantial' to 'almost perfect' CIs for intra-session reliability scores were observed. Inter-session reliability was observed to have 'less than acceptable' to 'acceptable' ICC scores with 'poor' to 'fair' agreement CIs. The author concludes that the DIV technique using a custom build VG in a normal population showed a satisfactory level of intra-session reliability but a less than satisfactory level of inter-session

reliability. Technical modifications are recommended to the VG if it is to be used in future studies.

3.2.5 Application of force closure in DIV

At the SIJ, both mobility and stability are achieved through a dynamic combination of form and force closure (McGrath, 2004; Pel, et al., 2008). Investigating what can affect the closure of the SIJ was therefore the next step in stiffness measurement by DIV. Two studies have shown that the application of a pelvic belt results in an increase in SIJ stiffness as measured by DIV (Damen, Spoor, Snijders, & Stam, 2002; Mens, et al., 2006). The first of these pelvic belt studies, by Damen, Spoor, Snijders, & Stam (2002), aimed to investigate the effect of a pelvic belt on SIJ stiffness as measured by DIV in a healthy female population (n=10). These authors applied a pelvic belt in a low position (at the level of the pubic symphysis) and a high position (below the ASIS) at two different tensions (50N and 100N). They observed a decrease in SIJ laxity with the application of the belt in the high position, and that changes in belt tension did not influence SIJ laxity further. A follow up study by Mens, Damen, Snijders and Stam (2006), aimed to show in-vivo proof that clinical application of a pelvic belt can affect SIJ stiffness as measured by DIV in women with PRPP. A pelvic belt was applied to 25 women with PRPP in both the high and low positions previously described. Both positions are concluded significantly decreased SIJ laxity ($P<0.001$), with the high position of the belt decreased SIJ laxity (mean = 1.3 ± 1.7TU) by a significantly larger degree than the low position (mean = 0.6 ± 1.0TU) (P=0.006). The authors conclude by stating that application of a pelvic belt significantly decreases SIJ laxity. While summarising the authors question the validity of DIV and acknowledge the limitations of the technique as identified by de Groot, Spoor and Snijders (2004) before making their conclusion. They do not, however, take into account the recommendations of de Groot and colleagues that changes in SIJ stiffness should only be considered significant if the change is greater than 2.0TU.

As discussed in section 2.5, clinical practice in manual and manipulative therapy utilises the prescription of exercise to improve force closure in the pelvic region. Thus far, only two studies have directly assessed the affect of muscular contraction on force closure of the SIJ as measured by DIV. Richardson and colleagues., (2002) investigated the effect of transversus abdominis (TA) contraction on SIJ laxity compared to other abdominal contractions. DIV was used to assess SIJ laxity in 13 healthy participants who could perform TA contraction patterns in isolation. A significant decrease in SIJ laxity with both types of muscle contraction pattern (mean difference = 1.73; $P<0.001$) is reported, with larger decreases observed during the TA contraction pattern (mean difference = 0.56; $P<0.026$). The authors conclude that contraction of the TA significantly decreases SIJ laxity. There is, however, no mention of control for participant breathing or downward force on the VG in this study. Therefore, the authors cannot confidently attribute the decreases in laxity observed to the muscle contraction as opposed to changes in downward force on the VG. They have also

termed changes less than 2.0TU in SIJ stiffness "significant" apparently ignoring recommendations of de Groot, Spoor and Snijders (2004).

The second, and only other, study in this area by van Wingerden and colleagues., (2004) used DIV in a pilot study consisting of 6 female subjects (mean age=22 ± 2.6y) that aimed to verify the effectiveness of muscular contraction as a method of force closure effecting the stiffness of the SIJ in vivo. Electromyography (EMG) was used to ensure the selected muscles (erector spinae, biceps femoris, gluteus maximus and latissimus dorsi) were contracting when required. Like all other DIV studies known, the changes to participant position on the equipment set up due to muscle contraction is not controlled for in the methods. The authors do not describe in any way the movements or static positions used by participants to achieve contraction of the desired muscle. The study showed that SIJ laxity decreased by approximately 50% with muscular contraction of erector spinae, biceps femoris and gluteus maximus. This 50% decrease was calculated from a decrease in mean threshold value of 2.7, 2.7 and 2.5TU respectively of the mean relaxed threshold difference of 5.2TU. Being that the difference observed by van Wingerden and colleagues is greater than 2.0TU it can be considered significant based on recommendations of de Groot, Spoor and Snijders (2004). van Wingerden and colleagues, conclude that their study has enhanced the understanding of how muscles dynamically influence joint stiffness. From a sample of 6 young females the authors appear to make speculative generalisations about the implications their SIJ stiffness findings have to all joints in general to the manual joint testing world. The small sample size of this study limits its applicability to the population and therefore further study into muscle contraction as a method of increasing force closure of the pelvis is necessary. For example, these authors dismiss any possible force closure effect of the latissimus dorsi based on being able to recruit only a single participant who was able to contract this muscle in isolation. The authors discuss the possible mechanism by which SIJ stabilisation is achieved by muscle contraction or co-contraction, but again do not discuss the effect of these contractions on the participants positioning and consequent effect on downward force on the VG.

4. Conclusion

From this review, it is clear that there are many contentious issues in the literature surrounding the sacroiliac joint (SIJ). The innervation is multiple and varied but the joint and surrounding tissues are considered capable of generating pain. SIJ pain can be confirmed by anaesthetic injection and composites of SIJ provocation tests may be able to predict the results of diagnostic injection if certain limitations are accepted. There are two main approaches to clinical diagnosis and manual testing of the SIJ: pain provocation and motion testing-palpation. The relationship between pain provocation and motion testing-palpation is not yet well understood and currently motion testing-palpation approach is the alternative to, or partial compliment of, pain provocation. Palpation of SIJ motion and pelvic landmarks are considered unreliable, and mobility testing is considered difficult to evaluate accurately in a clinical setting. DIV is a technique that has been suggested as an objective technique for the measurement of SIJ stiffness. Thus far the DIV technique has been observed to be valid with excellent intra-session reliability but poor inter-session reliability. Substandard equipment has been cited as a barrier to further study. Furthermore, the variable of patient generated downward force on the vibration generator has not been controlled or discussed in any studies reviewed. This particularly affects a study that uses the DIV technique and claims to have verified muscular contribution to force closure of the pelvis. For such a claim to be valid the effect of force closure on the force the participant applies to the VG must be controlled for.

Therefore, the aims of this investigation are reported in the following sections. Section 2 is a Manuscript which includes two aims that were 1) to establish intra-session reliability of the DIV technique with the newly developed VG; and 2) to investigate the effects of force closure on SIJ stiffness as measured by the DIV technique with the addition of control for participant generate downward force on the VG. Appendix 1 includes a third aim that was to develop a vibration generator (VG) suitable to allow further study into the DIV technique.

5. References

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Section 2: Manuscript

Section 2: Manuscript

The effect of a non-specific gluteal contraction on transient stiffness of the sacroiliac joint as measured by Doppler Imaging of Vibrations

Callum John Isaac Farquharson

Department of Osteopathy

Unitec Institute of Technology

Private Bag 92025 Auckland

New Zealand

Email: callum.farquharson@gmail.com

Tel: +64 9 815 4321 x8197

Abstract

The complex anatomy and kinematics of the sacroiliac joint (SIJ) has lead to debate amongst researchers and clinicians, creating a tension between best evidence and clinical practice. Doppler imaging of vibration (DIV) is one proposed method of objectively determining SIJ 'stiffness' and may show potential to reduce this evidence/clinical practice tension. Despite showing validity and intra-session reliability of SIJ stiffness measurement, inter-session reliability has thus far been observed as poor. The aim of this study was to investigate the intra-session reliability of a new vibration gnerator (VG) including control for participant generated downward pressure on the VG, and to investigate the effect of a force closure movement on SIJ stiffness as measured by DIV. Thirteen healthy participants between the ages of 19-57 were studied. Intra-session reliability was "very high" (ICC[3,3] = 0.79; 95%CI = 0.59 to 0.90) and the standard error of measurement was calculated as 0.62 TU (95%CI = 0.50 to 0.86). A paired samples t-test showed the non-specific force closure movement had a small, non-significant effect on SIJ stiffness as measured by DIV (mean increase = 2.08TU; 95%CI = -1.18 to 5.34TU; P=0.20). Participant generated downward force on the VG was observed to be constant throughout each session. Without a change in downward force, the changes in transient SIJ stiffness can more confidently be assumed to come from the force closure movement if we accept the current limitations of the DIV technique and small sample size. DIV requires further investigation into its construct validity before the results of any study employing the DIV technique are applied to any form of clinical practice.

Keywords:

Dysfunction, motion, reliability, muscular contraction, force closure, diagnosis.

1. Introduction

Low back pain is a common musculoskeletal complaint, affecting 70-85% of people at some stage of life (Andersson, 1999). Due to this high prevalence, the lower back, and the areas surrounding it have been extensively reviewed. Many structures have been implicated in the aetiology of low back pain including: the intervertebral disc (Bogduk, 1991; Mixter & Barr, 1934), the zygapophyseal joints (Bogduk, 2012), dysfunction of the deep stabiliser muscles (Hides, 2004; Hodges, 1999; Richardson et al., 2002), and the sacroiliac joint (SIJ) (Schwarzer, Aprill, & Bogduk, 1995).

Examination, diagnosis and treatment of the SIJ is commonly described in manual and manipulative therapy texts (Chaitow & DeLany, 2002; Vleeming, Mooney, & Stoeckart, 2007; Ward, 2002). Despite popularity amongst clinicians, researchers have questioned the validity and reliability of manual diagnosis and treatment of the SIJ (McGrath, 2006), on the basis that even identication of pelvic landmarks appears problematic (Kmita & Lucas, 2008). To be considered a potential aetiological factor, contributing to LBP, the SIJ must be established as a source of nociception. Innervation of the SIJ has been established to be both complex in origin (Fortin, Kissling, O'Connor, & Vilensky, 1999; Szadek, Hoogland, Zuurmond, Lange, & Perez, 2008) and variable between individuals (McGrath & Zhang, 2005). The SIJ has been confirmed as a source of nociception using double blinded anaesthetic injection (McKenzie-Brown, Shah, Sehgal, & Everett, 2005). Despite being the current criterion standard for pain confirmation at the SIJ, the face validity of the injection itself is still questioned (Kokmeyer, van der Wurff, Aufdemkampe, & Fickenscher, 2002; Schwarzer, et al., 1995). When multiple manual provocation tests are applied in 'clusters,' they have been shown to predict the results of anaesthetic injection with increasing sensitivity and specificity if three or more of six tests are clustered together (Laslett, 2008; Laslett, Aprill, McDonald, & Young, 2005).

In addition to a pain provocation approach, there is another line of clinical thinking, common in osteopathy, that uses SIJ motion testing and joint palpation (McGrath, 2004). SIJ motion testing and positional palpation are used extensively within clinical osteopathic practice in the UK (Fryer, Johnson, & Fossum, 2010a, 2010b), USA (Fryer, Morse, & Johnson, 2008) and Australia (Peace & Fryer, 2004), despite having questionable validity and reliability (Kmita & Lucas, 2008; McGrath, 2006). The original studies quantifying SIJ motion (Jacob & Kissling, 1995; Smidt et al., 1997; Sturesson, Selvik, & Udén, 1989) have been systematically reviewed, and motion at the SIJ was concluded to be limited to minute amounts of rotation and translation (Goode et al., 2008). It is the minute motion at the SIJ that has lead researchers to question the clinical usefulness of motion testing and palpation (Kmita & Lucas, 2008; McGrath, 2006). As an alternative to palpation and motion testing, researchers have suggested that the SIJ functions as a force attenuation mechanism utilising this minute motion in all directions and should be treated as such in a clinical setting (Adams, Burton, Bogduk, & Dolan, 2006).

An objective measurement tool that tested motion at the SIJ would be useful in reducing the gap between current research and clinical practice. The original methods used to quantify SIJ motion are invasive and impractical for use in clinical settings (Adhia et al., 2012). One proposed objective measurement tool for SIJ stiffness is Doppler Imaging of Vibrations (DIV); a process by which vibration intensity lost across the SIJ is measured by Doppler ultrasound (Buyruk, Stam, et al., 1995). Despite the use the term 'SIJ stiffness' by current DIV studies (Buyruk, Snijders, et al., 1995; Buyruk et al., 1999; Buyruk, Stam, et al., 1995), by measuring the amount of vibration energy lost in the joint, the technique could be considered consistent with current evidence regarding SIJ function as a force attenuation mechanism. For the purpose of measuring SIJ 'stiffness,' DIV has been observed to be objective and reproducible in-vitro (Buyruk, Stam, et al., 1995) and to show excellent intra-session reliability (Buyruk, Snijders, et al., 1995; Damen, Stijnen, Roebroeck, Snijders, & Stam, 2002; Pender, 2011) while being considered non-invasive and safe (Buyruk, Snijders, et al., 1995; Buyruk, Stam, et al., 1995). Inter-session reliability of the DIV technique, however, has been observed to be less than acceptable when used to measure SIJ 'stiffness' in a healthy sample (Pender, 2011). Equipment limitations and biological variation are cited as possible confounding factors influencing intersession reliability, and the development of new vibration generation equipment has been recommended to continue further study (Pender, 2011).

A recent study using the DIV technique has investigated the effect of muscular contraction on the stiffness at the SIJ (van Wingerden, Vleeming, Buyruk, & Raissadat, 2004). Muscular contractions that provide support for a joint are referred to by these authors and by the wider manual therapy world as force closure and give a joint congruency when combined with form closure (Vleeming, et al., 2007). van Wingerden et. al.(2004), reported a strong "stiffening effect" of the SIJ as measured by DIV and concluded this to be a result of muscular contraction. An alternative hypothesis for the stiffening effect observed by these authors may lie within changes to downward pressure on the VG due to the muscular contractions.

The aim of this study is therefore to, further investigate intra-session reliability of the DIV technique for the purpose of measuring SIJ 'stiffness,' and to investigate the effect of force closure on SIJ stiffness including control for participant generated downward force on the vibration generator.

2. Methods

2.1 Participants

Thirteen participants were recruited by convenience sample in response to posters around the Unitec Campus, and the AUT School of Physiotherapy. Asymptomatic participants (n=13; age: 30.5y ± 12.6; height: 176.6cm ± 8.1; weight: 76.1kg ± 11.8) volunteered to participate in this study. Volunteers without any history of trauma, pathology or surgery to the sacroiliac or low back regions were included. No age or gender restriction was set in order to promote sample diversity. Participants were provided with detailed written and verbal information regarding the procedures in this study. The study was approved by the Unitec Research Ethics Committee (UREC 2011.1232).

2.2. Equipment
2.2.1 Vibration generation

A vibration generator (VG) was custom designed and built for this study (Appendix 1). The VG produced stable, sinusoidal oscillations at 200Hz and less than 0.05mm in amplitude, consistent with previous studies utilising the DIV technique to investigate similar aims (Buyruk, Snijders, et al., 1995; Buyruk, et al., 1999; Buyruk, Stam, et al., 1995; van Wingerden, et al., 2004). The VG included a load cell (Model: C2G1-T; Max capacity: 6kg; Tanaka Electronic Co. Ltd, Japan) to continuously measure participant generated downward force during data collection.

2.2.2 Ultrasound Imaging

Doppler ultrasound images were generated using a 12-5 MHz, 55mm linear array transducer and a Philips ultrasound machine (Philips IU22, Medical Systems Company, Eindhoven, Netherlands). The machine was in B-mode and in the manufacturer presettings of 'musculoskeletal' and 'spine.' Ultrasound gel (Aquaflex ® Ultrasound Gel Fair-field, USA) was used to improve signal penetration through the skin. Static images were captured using the inbuilt software on the Philips Ultrasound unit and stored for later analysis.

2.2.3 Set up

A notebook computer running Labchart 7 (Version 7.2.1, AD Instruments Pty Ltd., NSW) was interfaced with the loadcell (Model: C2G1-T; Max capacity: 6kg; Tanaka Electronic Co. Ltd, Japan) via a data acquisition system (PowerLab 26T, ML856, AD Instruments Pty Ltd., NSW). LabChart was used to record the participant generated downward force for later analysis. The participant was positioned such that they were able to watch the screen as a form of bio-feedback while performing the force closure movement described below in 2.3. Measurement procedures. The internal clock on the notebook running LabChart and the ultrasound unit

were synchronised. The synchronisation allowed the data from the oscillator to be matched to the corresponding Doppler ultrasound image.

2.3. Measurement procedures

Participants lay prone on two-plinths set up in a perpendicular arrangement (Figure 1). The use of two plinths allowed the vibration generator (VG) to contact the ASIS through the face hole while also allowing the participant to view the notebook computer screen while all large pelvic muscles were relaxed. A pillow was used to raise their ankles and allow the large pelvic muscles to relax. The transducer was positioned over the participant's sacroiliac joint space. The joint space was found using palpation of the posterior superior iliac spine (PSIS) and visualised with ultrasound imaging. From the PSIS the transducer was rotated to 45 degrees of the sagittal plane and moved towards the midline until both the PSIS and sacrum were visible (Figures 2a and 2b). Following visual identification of the SIJ joint line, the Doppler function was turned on. A vibration of 200Hz generated by the VG was then applied to the ipsilateral anterior superior iliac spine (ASIS).

Doppler Imaging of Vibrations (DIV) relies on the premise that the difference in vibration frequency between the sacrum and ilium is due to the loss of energy through the joint's mobile tissues (Buyruk, Snijders, et al., 1995). The loss of energy across the SIJ is represented by the difference in colour flow (CF) percentage across two images. A large difference in CF percentage is proposed to represent a stiff joint, whereas a small difference would be indicative of minimal vibration attenuation and therefore represent a stiff joint (Buyruk, Stam, et al., 1995). The CF percentage is a value given to the signal power at which the transducer receives signals from tissues in motion. The operator increased the CF percentage until the vibration was shown in coloured Doppler pixels over the PSIS alone. Doppler image 1 (Figure 2a) of the SIJ was captured and saved for later analysis. The CF percentage was then further increased until coloured Doppler pixels were displayed over both the PSIS and sacrum. Doppler image 2 (Figure 2b) of the SIJ was captured and saved for later analysis. The difference between the CF percentage values of image 1 and image 2 has been referred to in previous studies as the difference in threshold units (TU) and used to represent the stiffness of the SIJ (Buyruk, Snijders, et al., 1995; Buyruk, et al., 1999; Buyruk, Stam, et al., 1995). Participants were asked to hold their breath in comfortable expiration while each image was taken to further prevent changes to downward pressure on the oscillator, which may have occurred through trunk and/or abdominal movement during respiration. Changes to downward pressure on the VG resulting from inspiration were clearly shown by the output from the load cell in the data gathered on LabChart (Figure 3). Ultrasound images (such as Figures 2a and 2b) were taken during a period of static downward pressure on the VG as confirmed by the display in LabChart.

As described above each measurement was calculated as the difference between two ultrasound images. Three 'measurements' were completed and stored for later processing. This was repeated four times, giving four sets of data T1, T2, T3 and T4, (each an average of three measurements) referred to as stiffness value points. Each set of three measurements were separated by a period of 150 seconds. The fourth set of measurements was captured with the addition of the force closure movement. The VG was turned off for the standardized period of 150 seconds between each of the stiffness value points.

Before the measurements at stiffness value four (T4) were taken, participants were allowed a familiarisation period to practice an isometric gluteal contraction without changing the downward pressure observed on the VG. The instruction given to guide the contraction was "squeeze your buttock muscles together." This will be referred to as the "force closure movement." The prescription of therapeutic exercise for posterior pelvic muscles with the intent to stabilise the SIJ is common practice within manual and manipulative therapies (Pool-Goudzwaard, Vleeming, Snijders, Stoeckart, & Mens, 1998; Vleeming, et al., 2007). Investigation of the transient effect of large pelvic muscle contraction is necessary to give plausibility to the muscular stabilisation of the SIJ concept.

Figure 1. Equipment set up showing participant position and perpendicular plinth arrangement. The vibrations are applied to the ASIS through the face hole of the grey plinth at the level of the ASIS obscured by the participant. (Reproduced with permission of Scott Pender)

Figure 2a) An example of the first image captured (Image 1) in each stiffness measurement. The transducer is positioned at 045 degrees to the mid saggital line over the PSIS. The colour flow (CF) percentage of Image 1 is subtracted from the CF percentace of Image 2 (figure 2b) to give the SIJ stiffness in threshold units (TU). The operator increased the CF percentage until the vibration was shown in coloured Doppler pixels over the PSIS alone and an image was captured (figure 2a). The CF percentage was then further increased until coloured Doppler pixels were displayed over both the PSIS and sacrum and the second image is captured (figure 2b).
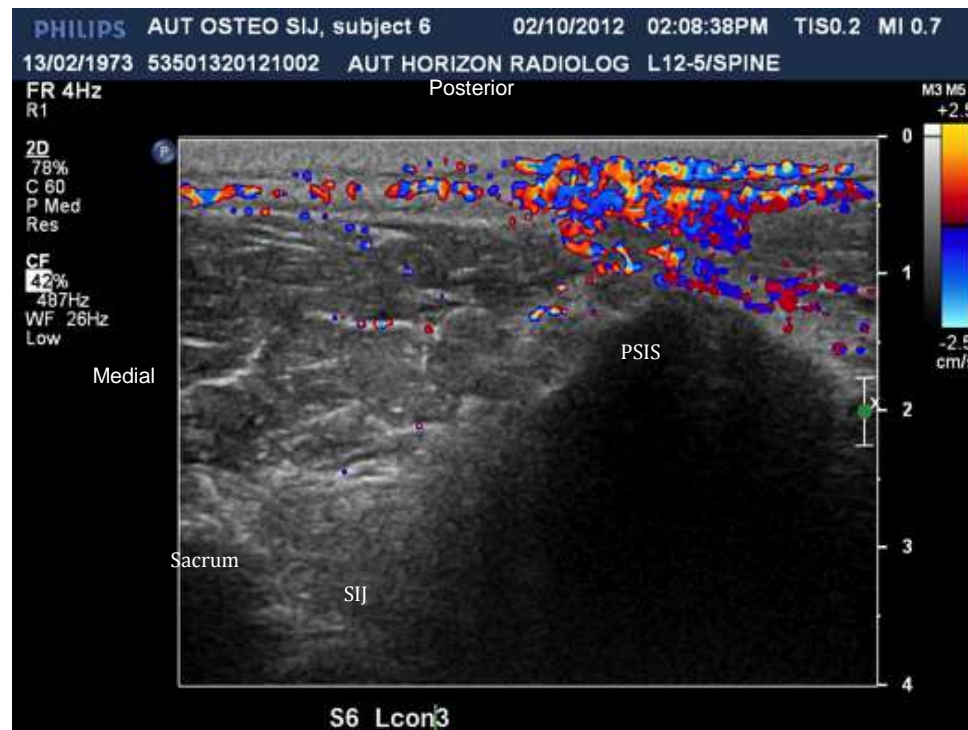
Figure 2b) An example of the second imaged captured (Image 2) in each stiffness measurement. Image 2 is used to calculate SIJ stiffness as described in the caption of Figure 2a.
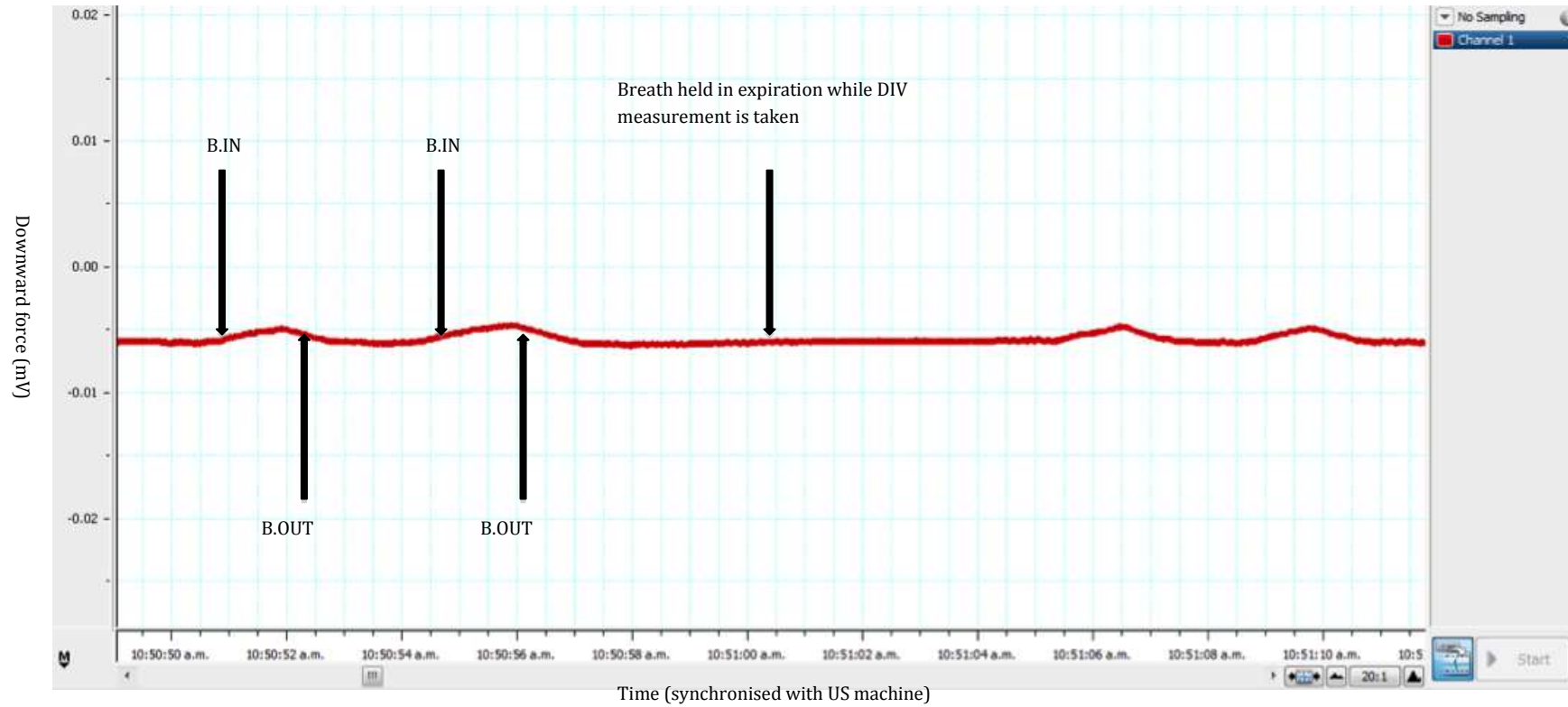
Figure 3) LabChart data showing the effect of respiration on downward force on the vibration generator (VG) and the consistency of this force during Doppler Imaging of Vibrations (DIV) measurement if breathing is controlled. B.IN= breath in, B.OUT= breath out.

2.4 Data analysis

2.4.1 Data Extraction

The CF percentage and the precise time of capture were extracted from each image. The CF percentages were tabulated in a spreadsheet. The time each image was taken was used to extract the corresponding downward force data from LabChart. This data was then entered into the spreadsheet alongside the CF percentages. Each 'measurement' was calculated as the difference in CF percentage between image 1 and image 2 and expressed in threshold units (TU). Each of the four sets of three 'measurements' ware averaged to give stiffness values (T1, T2, T3, T4) in threshold units. The average of T1, T2 and T3 (X_{T1-3}) was found for comparison with T4.

2.4.2 Statistical analysis

Data was explored by visual inspection of P-P and Q-Q plots. Skewness and kurtosis and the Shapiro-Wilk statistic were calculated. Levene's test for homogeneity of variance was calculated.   Three aspects of the data were analysed: i) Intrasesssion reliability of the first three stiffness values (T1, T2, T3) was calculated using an intra-class correlation coefficient (ICC[3,3]). Descriptors for the magnitude of the ICC coefficient were based on those of Hopkins (Hopkins, 2002); ii) To quantify measurement error of the stiffness values the standard error of measurement was calculated (Hopkins, 2007b); iii) One-way ANOVA was used to investigate the difference between the downward force at each of the four stiffness value points and a paired samples t-test was used to calculate the effect magnitude of the force closure movement between X_{T1-3} and T4. $P<0.05$ was considered statistically significant. Further interpretation of the difference in SIJ stiffness between non-contractile (X_{T1-3}) and contractile (T4) states was undertaken using magnitude based inferences as described by Hopkins (Hopkins, 2007a). Hopkins' spreadsheet for deriving mechanistic inferences from a p value were used to estimate the magnitude of the effect statistic (Hopkins, 2007a). Due to the limited avaliability of trials showing effect sizes for specific exercise on SIJ stiffness (Ferreira, Ferreira, Maher, Herbert, & Refshauge, 2006), the threshold values for postive and negative effects of the observed test statistic when making mechanistic inferences were based on the most approximate effect size observed from spinal manipulation for acute LBP of 0.4 (Rubinstein, Terwee, Assendelft, de-Boer, & van-Tulder, 2012). Except for the calculation of the standard error of measurement all analysis was conducted using IBM SPSS Statistics (v.20, IBM Corp., NY). Values are presented in the text as mean ± SD.

3. Results

From 13 healthy volunteers (n=8 males, 5 females; age: 30.5y ± 12.6, height; 176.6cm ± 8.1: weight; 76.1kg ± 11.8), 25 sacroiliac joints were investigated using DIV. The right SIJ of participant 2 was excluded due to data corruption. The data was normally distributed and there was no significant difference in the homogeneity of varience between groups (Levene's statistic P>0.05).

The intrasession reliability of the SIJ stiffness values (T1, T2, T3) was "very high" (ICC[3,3] = 0.79; 95%CI = 0.59 to 0.90). The standard error of measurement was 0.62 TU (95%CI = 0.50 to 0.86) and there was no significant difference between measures in the absence of the force closure movement at T1, T2 and T3 (One-way ANOVA; df=2; F=1.258; P=0.290), therefore the mean of T1, T2 and T3 was used to represent the stiffness value without force closure (X_{T1-3}).

Analysis revealed that there were no significant differences in the mean magnitude of participant generated downward force between T1, T2, T3,T4 (One-way ANOVA; df=3; F=0.111; P=0.953) see Table 1.

Table 1. Participant generated downward force as measured by the VG

Stiffness value	*n*	Mean force (N)	SD (N)	95% CI for Mean		Minimum Force (N)	Maximum Force (N)
T1	25	26.51	6.42	23.86	29.16	7.86	33.77
T2	25	26.75	5.95	24.29	29.20	10.51	35.76
T3	25	26.67	6.57	23.96	29.38	9.18	39.95
T4	25	27.52	8.03	24.21	30.84	10.02	40.17

Notes: T1 = Stiffness value 1; T2 = Stiffness value 2; T3 = Stiffness value 3; T4 = Stiffness value 4; n = Number of joints; N = Newtons

There was a small non-significant increase in stiffness between the values measured in the absence of the force closure movement (18.04 ± 4.57TU) and with the addition of force closure (15.96 ± 9.36TU) (Paired samples *t*-test, *t*=1.32, df=24, *P*=0.20; mean difference = 2.08TU, 95%CI = -1.18 to 5.34TU; Cohen's *d*=0.46).

Further interpretation of the contrast between stiffness values with, and without, addition of the force closure movement using Hopkins' mechanistic and clinical inferences are reported in Table 2. Threshold values for the observed effect statistic were chosen based on the effect size commonly oberved in spinal manipulation outcome studies of *d* ~ 0.4 (Rubinstein, et al., 2012).

Table 2. Mechanistic chances according to Hopkins (2002)

P value	Observed effect statistic	Threshold value for effect statistic		Chances the true value of the effect statistic is:		
		Benefit	Harm	Beneficial or substantially positive	Negligible or trivial	Harmful or substantially negative
0.2	0.46	0.4	-0.1	56.8 %	37.2%	6.1%
0.2	0.46	0.4	0.0	56.8%	33.2%	10.0%
0.2	0.46	0.6	0.0	34.6%	55.4%	10.0%

Notes: P values and effect statistics are based on results. Threshold values are based on assumptions as described in text.

4. Discussion

This study aimed to investigate the effect of a force closure movement on sacroiliac joint stiffness as measured by Doppler Imaging of Vibrations while controlling for participant generated downward force on the vibration generator (VG). Although reliability of DIV has been previously investigated (Crossley, 2011; Pender, 2011) the development and use of a new vibration generator for this study warranted confirmation of satisfactory reliability and quantification of measurement error of the DIV technique using this device before investigating the effect of force closure movements. The findings of this study concluded very high intra-session reliability of SIJ stiffness measurements using the DIV technique. Furthermore, the experimental set up specifically monitored the influence of participant generated downward force on the VG to ensure that potential fluctuations in downward force, due to relaxed respiration and active muscle contraction, were not a confounding factor in the DIV measurements. The findings of this study also concluded that the magnitude of the downward force of the pelvis against the VG was stable and consistent throughout each session.

Previous authors have shown that, for the purpose of measuring SIJ stiffness, the DIV technique is reproducible in cadavers (Buyruk, Stam, et al., 1995) asymptomatic populations (Buyruk, Snijders, et al., 1995), in peripartum pelvic pain patients (Buyruk, et al., 1999; Damen et al., 2001; Damen et al., 2002; Damen, Spoor, Snijders, & Stam, 2002), as well as showing intra-session reliability between raters (Crossley, 2011) and within stiffness measures (Damen, Stijnen, et al., 2002; Pender, 2011) while being considered harmless to humans (Buyruk, Snijders, et al., 1995; Buyruk, Stam, et al., 1995). Other studies have investigated the effect of force closure on transient SIJ stiffness (Richardson, et al., 2002; van Wingerden, et al., 2004). However, none of the studies listed above have reported any control for participant generated downward force on the VG in their methods or discussion. This is an important point as the possibility exists that participant generated downward force on the VG could directly influence apparent changes in DIV measures, and by inference, SIJ stiffness values. During pilot trials for this study the authors noticed that large changes in DIV measures occurred (specifically Doppler pixel distribution and CF percentage), as a result of changes in downward pressure on the vibration generator. For example, the small force changes due to relaxed respiration had an observable effect (figure 3). In this study each participant maintained comfortable expiration during DIV measurements and a load cell was used to monitor the downward force on the VG throughout the session. As reported above, the downward force was not significantly different and remained constant throughout each session.

Doppler Imaging of Vibrations (DIV) relies on the premise that the difference in vibration frequency between the sacrum and ilium is due to the loss of energy through the joints mobile tissues (Buyruk, Snijders, et al., 1995). This premise also assumes that the vibration is

occurring in the bone (Buyruk, Stam, et al., 1995). The images obtained in this study are consistent with those in previous studies (Crossley, 2011; Pender, 2011), but nonetheless, the Doppler pixels are seen in the soft tissue above the corresponding bony prominences. Therefore, muscle contraction that increases tension in the soft tissues may reduce vibration attenuation in the soft tissues in the same way a 'stiff' joint is proposed to do. This presents a possible confounding variable in that changes in DIV measurements during periods of increased force closure may be due a number of factors: 1) increased stiffness across the SIJ; 2) a change in the vibration attenuation properties of the soft tissues contracting around the SIJ; 3) a combination of both. In addition we observed that the pressure with which the operator pressed the ultrasound transducer onto the skin also had an impact on the Doppler pixel density displayed on the screen. The operator was made aware of this and controlled the source of error by resting the transducer on the skin with no additional downward force, holding it only to maintain the necessary alignment.

Clinicians often use specific muscle exercise as a prescription for the 'stabilization' or 'stiffening' of a 'lax' SIJ diagnosed by palpation and clinical examination (Pool-Goudzwaard, et al., 1998; Vleeming, et al., 2007). It has been shown that SIJ pain may benefit from specific (Ferreira, et al., 2006) or general exercise prescription (Stuge, Holm, & Vøllestad, 2006; Vleeming, et al., 2007). These mechanisms are not fully understood (Chaitow, 2007) but may arise from factors other than improvements in joint stability (McGrath, 2010; Pool-Goudzwaard et al., 2004). Rather than prescribe a specific individual muscle contraction, a general isometric gluteal contraction was employed for a number of reasons. Firstly there is evidence that the rectus femoris, erector spinae and gluteus maximus all have a significant force closure effect on the SIJ, whereas the latissimus dorsi has no effect (van Wingerden, et al., 2004). In addition, recent anatomical evidence has shown that other muscles in the gluteal region (e.g. gluteus medius and minimus) have potential to contribute to force closure of the SIJ due to their attachment to the long posterior sacroiliac ligament via the gluteal aponeurosis (McGrath, Nicholson, & Hurst, 2009; McGrath & Zhang, 2005). Due to this disparity a non-specific force closure movement that is inclusive of a number of muscles with potential force closure effects, gives the highest chance of changes to joint stiffness in light of best evidence.

The use of the term 'sacroiliac stiffness' is popular amongst clinicians where it is used as a descriptor of palpated findings (Chaitow, 2007). However, in this instance, stiffness is not synonymous with the engineering or mechanical meaning of 'stiffness.' These terms are easily confused and furthermore, contemporary evidence has lead researchers to suggest that 'stiffness' is a poor descriptor of SIJ mechanics (McGrath, 2004) for the following reasons. The potential for changes in sacroiliac 'stiffness' is challenged by some authors, who liken the small movement capabilities of the SIJ to that of a "rubber shock absorber" (Adams, et al., 2006; McGrath, 2004, 2010). The term 'force attenuation properties' could be used in

place of 'stiffness' as the SIJ is widely considered a force translator between the lower limbs and the axial skeleton (Adams, et al., 2006; Vleeming, et al., 2007). Use of the term 'force attenuation properties' could apply well to the DIV process as the technique is designed to measure the dampening effect SIJ tissues have on the vibrations passing through it (Buyruk, Stam, et al., 1995). 'Stiffness' was still used throughout this study to remain consistent with previous study in the area.

A small difference in SIJ 'stiffness,' as measured by DIV, was observed during the force closure movement. When interpreted using Hopkins' mechanistic inferences by inputting a conservative positive-negative effect threshold, a high probability of a 'trivial' effect was observed (55.4%). Due to the limited availability of trials reporting effect sizes for specific exercise on SIJ stiffness, the threshold values for positive an negative effects were based on the approximate effect size observed from spinal manipulation for acute LBP of 0.4 (Rubinstein, et al., 2012). A systematic review of specific stabilisation exercise for spinal and pelvic pain reported that specific stabilisation exercise was at least equally as effective as spinal manipulation (Ferreira, et al., 2006). When positive/negative effect values are used to approximate the effects observed in spinal manipulation studies (Rubinstein, et al., 2012) the probability of a trivial effect becomes 33.2% and the probability that the effect will be 'positive' rises to 56.8%. In both of these instances the probability of a 'negative' effect is 10.0%. In this study it must be remembered that a 'positive' effect corresponds to a stiffening of the SIJ and a 'negative' effect corresponds to a loosening of the SIJ during the application of a force closure movement. This does not mean that the authors believe a stiffening of the SIJ to be positive in a clinical setting, but rather 'positive' in that it was the expected effect from a force closure movement. In other terms the high p-value (0.2) indicates the possibility that the small effect observed is due to a Type II error and more data would be required to definitively show if the small effect observed was significant or not.

Data collected in this study was within one session. Although intra-session reliability of the DIV technique has been shown (Buyruk, Snijders, et al., 1995; Damen, Stijnen, et al., 2002; Pender, 2011), intersession reliability has been observed to be poor (Pender, 2011). The absence of intersession reliability is a substantial barrier to clinically interesting studies such as the relationship between 'stiffness' or asymmetry as measured by DIV and various types of low back region pain, and physical examination correlates. Further work which investigated the normative fluctuations in joint 'stiffness' would be a valuable to future inter-session reliability studies. Until such a time, studies can focus on intra-session data collection and could investigate the force closure effect of specific muscle contraction with the control for participant generated downward force. It would also be of interest to compare the results of DIV with that of 3D palpation digitization, as proposed by Bussey, Yanai and Milburn (2004), or other proposed kinematic analysis techniques.

5. Conclusion

A non-specific force closure movement had a small to moderate effect on transient SIJ stiffness as measured by DIV. Participant generated downward force on the VG was observed to be constant throughout each session. Without a change in downward force, the changes in transient SIJ stiffness can more confidently be attributed to the force closure movement if we accept the current limitations of the DIV technique. DIV requires further investigation into its construct validity before its potential use as an explanatory variable in clinical effectiveness studies.

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Section 3: Appendicies

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Appendix 1

Design and manufacture of a suitable vibration generator for use in Doppler Imaging of vibrations

1. Introduction

Doppler Imaging of Vibrations (DIV) is a technique developed as an objective assessment tool for joint stiffness (van Wingerden, Vleeming, Buyruk, & Raissadat, 2004). The DIV technique utilises a vibration generator (VG) that produces a constant, high frequency vibration that is applied over a bony prominence and the transmission of vibration across a joint is detected using Doppler ultrasound. The DIV has, to date, been almost exclusively used to assess sacroiliac joint (SIJ) stiffness. When used at the SIJ, the vibrations are applied to the anterior superior iliac spine (ASIS). The transmission of these vibrations through the SIJ is measured by the difference in vibration intensity of the ilium and sacrum, i.e. the sacrum is assumed to vibrate at a lower frequency due to the force attenuation properties of the SIJ. This difference in vibration intensity is hypothesised to represent a measurement of SIJ stiffness (Buyruk, Snijders, et al., 1995; Buyruk, Stam, et al., 1995). The DIV technique was developed in 1995 and has been reported to be safe and non-invasive (Buyruk, Snijders, et al., 1995; Buyruk, Stam, et al., 1995). These studies used an industrial Derritron VP3 vibrator (Buyruk, Snijders, et al., 1995; Buyruk et al., 1999; Buyruk, Stam, et al., 1995; van Wingerden, et al., 2004) that could not be obtained for local study. A frequency of 200Hz was observed to maximise Doppler image clarity (Buyruk, Stam, et al., 1995). Previous investigation in our research group has investigated the intra-rater reliability Crossley (2011) and the inter and intra-session reliability of the DIV process Pender (2011).

Previous study has concluded that both inter and intra-rater reliability was acceptable (Crossley, 2011) as was intra-session reliability of the stiffness measurements (Pender, 2011). Whereas inter-session reliability of the stiffness mesurements was less than acceptable and difficult to interpret due to wide confidence intervals (Pender, 2011). Crossley and Pender recommend that a more robust vibration generator may have benifited their studies by ensuring more consistent application of vibration to the ASIS and within and across all measurement sessions. For the purpose of DIV a suitable VG would accurately mimic the vibrations used in previous studies (200Hz and of less than 0.05mm in amplitude) but also to enable modification or tuning of frequency and amplitude if desired. The device used by Crossley (2011) and Pender (2011) (Figure 2.a), employed an audio speaker-like system to produce vibrations in the same way as the Derritron VP3 vibrator. Formative discussion with consulting mechanical engineers (P. Barnes, personal communication, October 13, 2011) suggested that the use of an audio speaker to produce vibrations under load is likely to be unstable over periods of extended use as would be required in DIV. More specifically, the possibility of creep occuring in the speaker membrane was considered an undesirable

characteristic and one that would explain the apparent instability of vibration produced by the VG of Crossley and Pender (2011). Further consideration of device requirements indicated that the production of vibration using mechanical generation using an electric motor with an offset load produce the stable sinusoidal oscillations required for DIV.

Therefore, the aim of this development project was to design and manufacture a device capable of producing stable oscillations at 200Hz fit for the DIV process.

2. Methods

An iterative process of prototype development and testing was employed in collaboration with mechanical and electrical engineers at Wellington Drive Technologies (Auckland, New Zealand). The approach was to develop an initial mock up prototype and then conduct product development iterations until the device requirements of the study were met.

2.1 Procedures

2.1.1 Mock-up and first prototype

An initial mock-up was produced to test the use of an offset load to produce vibrations. Following proof of this concept a first prototype was produced. During preliminary testing, it was observed that the participant generated downward pressure on the VG varied with alterations in participant position due to relaxed respiration. Therefore the design was modified further to incorporate a load cell to enable apprpriate control of this variable.

2.1.2 Final prototype

The load cell was interfaced with a notebook computer through PowerLab and results were gathered in a data acquisition system (PowerLab 26T, ML856, AD Instruments Pty Ltd., NSW) and recorded in LabChart 7 (v7.2.1, AD Instruments Pty Ltd., NSW). The frequency and amplitude of the vibration produced by the VG was calculated using LabChart's inbuilt spectral analysis (Fast Fourier Transform) function (Figure 1).
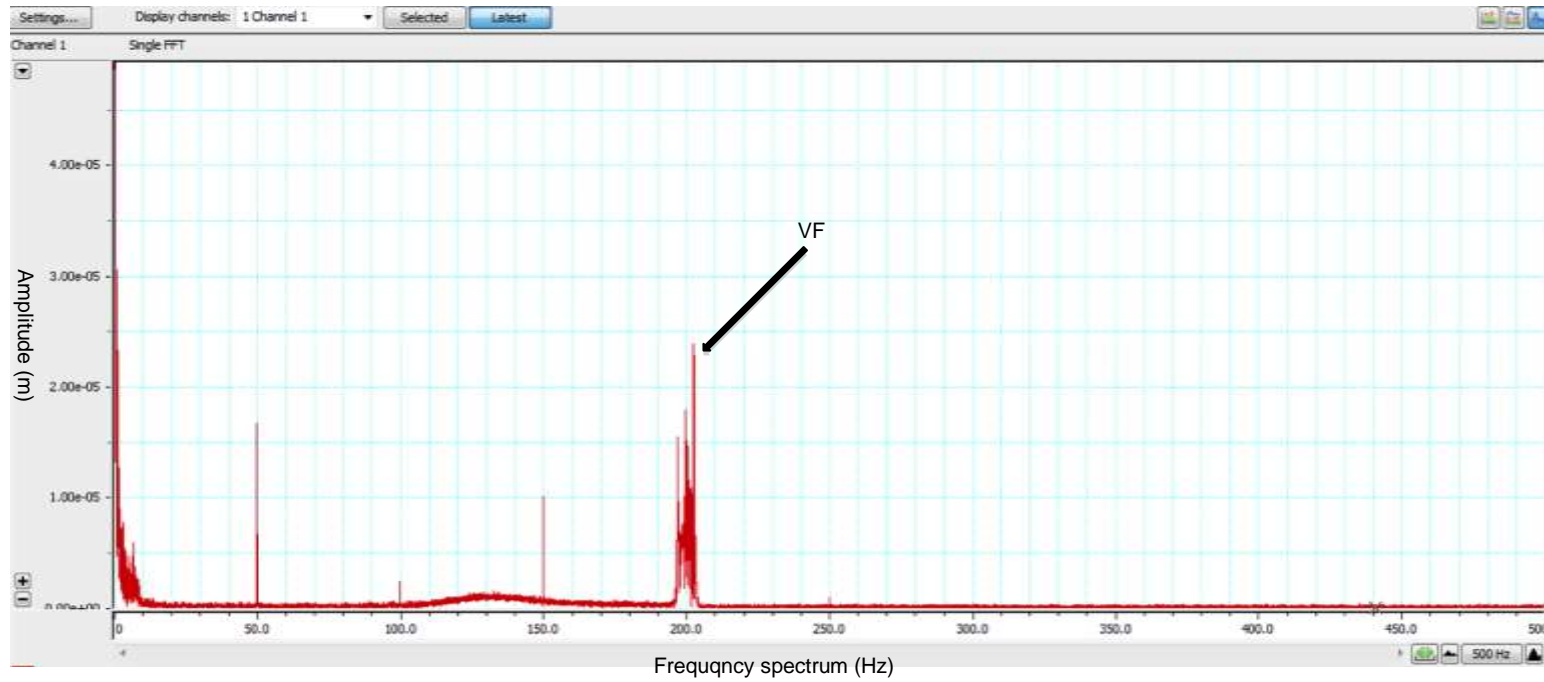
Figure 1. A screen shot from LabChart showing the vibration frequency at 200Hz, and the amplitude at a maximum of 2.0e-05m or 0.02mm. VF=vibration frequency

3. Results

3.1 Mock-up

The use of an offset load to generate vibrations was piloted (Figure 2.B). A small electric motor salvaged from an electric toothbrush (characteristics unknown) was used with a cut down wing-nut as an off-set load. The motor was attached to the undersurface of a wooden frame and mounted to a base with springs allowing free motion of the motor and offset load. In initial piloting sessions the mock-up produced stable vibrations and acceptable Doppler images for the lower oscillation frequency. It was decided that a prototype VG would be built based on the mock-up concept. In the mock-up phase the effect of participant generated downward pressure onto the VG on the Doppler image was noted. Obvious changes in the appearance of the image with downward forces changes due to respiration were apparent. Simple domestic metric scales (T61, Terillion, Croissy-sur-Seine, France) were used to provide an indication of the magnitude of downward force to between 20 to 50N. Review of the DIV literature, however, revelaed that no previous study had controlled for downward pressure on the VG, and therefore, at this stage it was assumed that the changes in ultrasound display would no longer occur when the first prototype VG producing vibrations at 200Hz was used.

3.2 First prototype

Computer aided three dimensional design and a fused deposition moulding (FDM) machine (FDM Vantage X, Stratasys, Minnesota, USA) were used to produce the first prototype (Figure 2c and 2e). A brushless electric motor (YM2774 DC Motor 12 V 4.9KG 18800RPM-max, Jaycar Electronics, Auckland, New Zealand) was used. The offset load was a fly wheel with an adjustable mass attached. The VG was able to produce vibrations at 200Hz confirmed by a laser tachometer:

Raw tachometer output as 11983 RPM (revolutions.min^{-1}, 11983/60=199.72 (2dp) revolutions.s^{-1}, or ~200Hz).

Further testing showed that the vibrations produced by the first prototype enabled capture Doppler images of satisfactory quality. The patient generated downward force on the VG still, however, appeared substantial. Increases in downward force due to breathing were observed to increase the density of Doppler pixels on the ultrasound dysplay which may be interpreted by the DIV technique as a 'stiffer' SIJ.

3.3 Final prototype

Due to the apparent impact of patient generated downward force on the images produced, the prototype VG was customised to include a single point load cell (Model: C2G1-T; Max capacity: 6kg; Tanaka Electronics Co.Ltd, Japan) in place of the springs (Figure 2f). The output from the load cell was processed by a data acquisition system (PowerLab 26T, ML856, AD Instruments) and recorded in Labchart 7 (Version 7.2.1, AD Instruments) on a notebook computer for later analysis. From the LabChart output both the vibration frequency (200Hz) and amplitude (0.02 mm) were calculated (figure 1). Replacement of the springs was accompanied by minor structural defects but these were rectified with light weight aluminium plate reinforcing (figure 2d).

Figure 2a

Figure 2b

Figure 2c

Figure 2d

Figure 2e

Figure 2f

Figures 2a through 2f show the development process from mock-up to final prototype (left to right from top to bottom). Designed by Andrew Lee and Peter Barnes of Wellington Drive Technologies in conjunction with the author. Manufactured by Andrew Lee and Bernard Yan of Wellington Drive technologies.

4. Discussion

The aim of this development project was to develop a vibration generator (VG) suitable to the needs of ongoing investigation using DIV techniques, and comparable to previous studies in the same area (Buyruk, Snijders, et al., 1995; Buyruk et al., 1999; Buyruk, Stam, et al., 1995; van Wingerden, et al., 2004). The final VG produced stable vibrations at 200Hz at less than 0.05mm amplitude. The addition of a load cell allows for the control and investigation of participant generated downward force. One limitation of the current version of the VG is the capacity of the load cell. Measured values were towards the upper limit of the load cell's capacity and an improvement would be to substitute the 6kg load cell with a higher capacity model (eg 15kg). The 15kg load cells are available in identical sizes to the current cell and could be substituted without further modifications to the VG. The electric motor used could also be upgraded with the addition of a more robust shaft and bearing set to withstand the demands of an offset load. Such a motor replacement could also occur without further modification to the VG. These upgrades would enhance the durability and consistent function of the VG.

5. Conclusions

A suitable VG was produced for the purpose of investigations using Doppler Imaging of Vibrations. The vibration characteristics align the device with that used in previous studies. The final prototype also incorporated a load cell interfaced with a notebook computer, allowing the users to control for participant generated downward force.

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Appendix 2

Participant information and consent forms

Unitec
NEW ZEALAND
Te Whare Wānanga o Wairaka

Participation Information Sheet – A methodological study of sacroiliac joint stiffness measurement

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Who am I?

My name is Callum Farquharson and I am a senior student of osteopathy undertaking post graduate research. I am interested in researching the method used to investigate the potential relationships between pelvic biomechanics, muscle activation and low back pain.

What we are doing?

You are invited to participate in a study investigating the method used to objectively assess sacroiliac joint stiffness (the sacroiliac joint is a large joint located at the back of your pelvis)

This research study will investigate the use of 'Colour Doppler imaging of Vibration' to measure relative stiffness of the sacroiliac joints and to investigate the methodological approach to how these vibrations are applied and then used to measure joint stiffness.

By taking part in this research you will be helping to contribute to research in the field of diagnosis and treatment of low back pain, and the development of a new technique in measuring joint function.

Taking part in the study

We require male and non-pregnant female participants over 18 years of age.

After you have read and understood the information sheet, and if you are interested in participating, please contact the principal researcher (Callum Farquharson) via email, phone or in person (see details below). Upon receipt of your interest, you will be contacted to discuss what is involved and determine if you are available to participate on one of the data collection session dates. If you are willing and available to participate, you will be invited to AUT North Shore campus or Clinic 41 Unitec for data collection. We will provide a map for parking and venue details.Upon arrival we will explain the procedures with you again, and gain your written consent. Giving consent does not stop you from changing your mind if you wish to withdraw from the study. You can withdraw from this study at any stage, including withdrawing your data up until 1 week *after* the data collection session.

During the first part of the consultation, you will be required to complete a medical questionnaire, and take part in a brief discussion of medical history and a physical examination (observing bending movements of you back) with the principal researcher Callum Farquharson. All information you provide will be kept confidential and securely stored with limited access.

The next stage of the process involves a measurement of sacroiliac joint stiffness using an ultrasound machine to measure the levels of vibration transfer across the joint. The vibrations applied are of maximum 200Hz and less than 1.0mm in amplitude. This may feel like a mild 'buzzing' sensation against your pelvis. The vibration is applied to a bony prominence on the front of the hip bone and are produced by a machine that is similar to the vibration from a mobile phone. This vibration is harmless and painless, however, should any discomfort be felt by the participant then the process will be stopped immediately upon request. A trained ultra-

sonographer using a Colour Doppler ultrasound machine (also harmless to humans) will calculate joint stiffness. This may involve removing or movement of outer garments of clothing to gain access to the joint (located at the small of the back) so that an ultrasound transducer may be applied to bare skin. Modesty will be maintained by the use of a drape when necessary.

The measurement process above will be repeated three times followed by a short interval of a few minutes. Three more measurements will then be taken in the same way. Following another short break a familiarisation process will commence designed to allow the participant some time to become confident contracting some muscles around the pelvis while watching a screen through the face hole. Three more stiffness measurements will then be taken. During the procedures you will be asked to report on the presence of discomfort and measurement will be stopped if any is felt.

Confidentiality

Your name and information that may identify you will be kept completely confidential. All information collected from you will be stored in a lockable cabinet at either the researcher's home office or in one of the supervisors' office. Electronic data derived from the study will be stored on a password protected file and only the researcher and supervisors will have access to this information. Information will be stored for a minimum of five years. All data derived from the research will be anonymous. Anonymised data derived from the study may also be used for future study. A copy of the final report will be available in the Unitec library. All participants will be welcome to view this. Summaries and recommendations may be published in research journals.

Yes, I'm interested – who do I contact?

If you would like to participate in this study please contact Callum Farquharson. Your participation is greatly appreciated.

Information and concerns

Please contact us if you would like further information or have any concerns about the research study. You can contact Callum Farquharson or relevant supervisors:

Primary Researchers:	Supervisors:
Callum Farquharson	**Rob Moran**
Email : callum.farquharson@gmail.com	Email: rmoran@unitec.ac.nz
	Phone: 09 815 4321 ext 8197
Mobile : 0210316282	Mobile: 021 073 9984

Thank you for reading the information sheet – please keep it for your records

UREC REGISTRATION NUMBER: 2011-1232
This study has been approved by the UNITEC Research Ethics Committee from 16-11-2011 to 16-11-2012. If you have any complaints or reservations about the ethical conduct of this research, you may contact the Committee through the UREC Secretary (ph: 09 815-4321 ext 7248). Any issues you raise will be treated in confidence and investigated fully, and you will be informed of the outcome.

Unitec
NEW ZEALAND
Te Whare Wānanga o Wairaka

Participation Consent Form – A methodological study of sacroiliac joint stiffness measurement

I have seen the Information Sheet about this study. I have read and understand the information sheet given to me. I have had the opportunity to discuss any queries or concerns regarding this study with Callum Farquharson or his supervisors and am satisfied with explanations given.

I understand that that taking part in this study is my choice. I don't have to be part of this if I don't want to and I understand that I may withdraw from this study at any stage up until 1 week after the data collection session. I also understand that withdrawing will not affect my access to any services provided by Unitec, New Zealand.

I have been informed that measurements of sacroiliac joint stiffness will be taken by a trained ultrasonographer. A vibration will be applied to the front of my pelvic bones and recorded via the ultrasound machine. For this assessment I am aware that I will be asked to reposition outer layers of my clothing so that the top of my hips and small of my back are accessible to the ultrasonographer. I understand that I will also be required to contract the muscles around my hip for a short period of time while further measurements of stiffness are taken.

I understand that all the information that I give will be stored securely on a computer for a period of 5 years and that any information reported will not identify me in any way. I give permission for the data from this study to be retained and combined with other future studies provided that my identity remains anonymous.

I understand that I can see the finished research document. I have had time to consider everything and I give my consent to be a part of this study.

I know whom to contact if I have any questions or concerns about this study.
The principal researcher is:
Callum Farquharson
Email : callum.farquharson@gmail.com
Mobile : 0210316282

Participant Name: …………………………..

Participant Signature: ………………………….. Date: ……………………………

Study explained by: …………………………..

Signature: …………………………. Date: ……………………………
Thank you for participating in this research

UREC REGISTRATION NUMBER: 2011-1232
This study has been approved by the UNITEC Research Ethics Committee from 16-11-2011 to 16-11-2012. If you have any complaints or reservations about the ethical conduct of this research, you may contact the Committee through the UREC Secretary (ph: 09 815-4321 ext 7248). Any issues you raise will be treated in confidence and investigated fully, and you will be informed of the outcome.

Appendix 3

UREC approval

Callum Farquharson
39 Rame Road
Greenhithe
Auckland, 0632

21.11.11

Dear Callum ,

Your file number for this application: 2011-1232
Title: The intra-session reliability of instrumented sacroiliac joint stiffness measurement and the effect of force closure on sacroiliac joint stiffness.

Your application for ethics approval has been reviewed by the Unitec Research Ethics Committee (UREC) and has been approved for the following period:

Start date: 16.11.2011
Finish date: 16.11.2012

Please note that:

1. The above dates must be referred to on the information AND consent forms given to all participants.

2. You must inform UREC, in advance, of any ethically-relevant deviation in the project. This may require additional approval.

You may now commence your research according to the protocols approved by UREC. We wish you every success with your project.

Yours sincerely,

Scott Wilson
Deputy Chair, UREC

cc: Rob Moran
Cynthia Almeida