# UNIVERSITY OF SOUTHAMPTON

FACULTY OF HEALTH SCIENCES

**Coccydynia in Taiwanese Women: Biomechanical and Physiological Study**

by

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Thesis for the degree of Doctor of Philosophy

November 2010

**Abstract**

Coccydynia is a form of back pain and occurs more commonly in women than in men, and is a particular clinical problem seen in Taiwan. Understanding of the condition is limited and it cannot be isolated from other dysfunctions in the lumbopelvic region. It is proposed that neuromuscular alterations that occur in low back pain (LBP) could also occur in coccydynia and forms the topic of this thesis. The aims of this study were to explore neuromuscular and musculoskeletal changes in Taiwanese women with coccydynia. A total of 55 Taiwanese women, aged 23-65 years were studied in three groups: healthy young participants in Southampton (n=18, aged 23-35 years); patients with coccydynia in Taiwan (n=20 aged 23-65 years) and healthy older women in Taiwan (n=17, aged 35-65 years). Three techniques were used to investigate musculoskeletal changes in coccydynia: rehabilitative ultrasound imaging (RUSI), 3-dimensional motion analysis (using the VICON system) and surface electromyography (sEMG).The reliability of the developed experimental protocols was first established at the University of Southampton and then the protocols were replicated for he main study in Taiwan.

Patients had thicker resting transversus abdominis (TrA) muscles than healthy participants but showed less thickness change during a functional task, indicating reduced ability to contract the muscle. Differences between patients and healthy groups from motion analysis and EMG studies were found and indicate that neuromuscular alterations occur in coccydynia. In six case studies, a six week intervention using a pelvic belt, patients reported improvements in symptoms and function but there were no changes in the objective tests of musculoskeletal function.

The contributions of this preliminary work to knowledge include: (1) provision of normal reference data of muscle morphology in Taiwanese women of different ages; (2) a possible effect of age on muscle contractile ability; (3) objective evidence of changes in musculoskeletal function in patients with coccydynia, specifically muscle morphology, motor control and biomechanical changes; (4) evidence of the feasibility of using RUSI as an appropriate tool to detect differences in the lumbopelvic muscles between patients with coccydynia and healthy participants; (5) Reliability of inter-recti distance measurement on RUSI at rest and during contractions in patients with coccydynia and healthy participants; (6) the pelvic belt may be a potentially effective intervention in the management of pain in coccydynia.

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## DECLARATION OF AUTHORSHIP

I, San-Pei Chen, declare that the thesis entitled ***Coccydynia in Taiwanese women: biomechanical and physiological study*** and the work presented in the thesis are both my own, and have been generated by me as the result of my own original research. I confirm that:

- this work was done wholly or mainly while in candidature for a research degree at this University;
- where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated;
- where I have consulted the published work of others, this is always clearly attributed;
- Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work;
- I have acknowledged all main sources of help;
- where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself;
- None of this work has been published before submission.

**Signed:** ……………………………………………………………………………..

**Date:**………………………………………………………………………………….

## Acknowledgements

This is a long journey, which I started in October 2007, and which will end in 2010. However, this will not signify the conclusion of my study life; it simply means that I am moving on to a new stage in my life, and prospective career. I would like to express my wholehearted gratitude to my family; I could not have progressed to PhD level without their unwavering support. Massive appreciations for my supervisors, Professor Maria Stokes, Dr. Paul Chappell and Professor Robert Allen, who have been like my family during the course of my studies in the United Kingdom. They have always provided wise counsel, and enlightened and motivated me whenever I felt discouraged, or was in a difficult place. When I was panicking, or feeling depressed and aimless, they helped me to see the light at the end of the tunnel.

The successful execution of the main study in Taiwan must be attributed to the invaluable assistance of the China Medical University (CMU) and Hospital at Taichung (CMUH) City in Taiwan. A sincerest thank you to Dr. Li-We Chou: the study could not have been accomplished without his assistance in negotiating with the factories and other staff, regarding the borrowing of facilities. Thanks to all my colleagues in the CMUH, for helping me to recruit participants. I am extremely grateful to all of my friends, who have always encouraged me, and who continued to send their wishes overseas in order to support me, and help me get through this tough time. Finally, I want to thank all of my participants. Without their participation, this study could never have been carried out.

## LIST OF ABBREVIATION

**A**

Active draw-in maneuver (ADIM)

Anterior superior ischial spine (ASIS)

Active straight leg raising (ASLR)

**B**

Body mass index (BMI)

**C**

China Medical University (CMH)

China Medical University Hospital (CMUH)

Cross-sectional area (CSA)

Central nervous system (CNS)

Computed tomography (CT)

**E**

External obliquus abdominis (EO)

Erector spinae (ES)

**G**

Greater trochanter (GT)

**I**

Intra-class correlation coefficient (ICC)

Intra-abdominal pressure (IAP)

Internal obliquus abdominis (IO)

Inter-rectus distance (IRD)

**L**

Low back pain (LBP)

Lumbar multifidus (LM)

Long-standing groin pain (LSGP)
Limitation of agreement (LOM)

**M**

Magnetic resonance imaging (MRI)

Maximum voluntary isometric contraction (MVC)

Maximum voluntary effort (MVE)

**N**

Neutral zone (NZ)

**P**

Pelvic floor muscles (PFMs)

Pelvic girdle pain (PGP)
Postpartum Pelvic Girdle Pain (PPPGP)

Posterior superior ischial spines (PSIS)

**R**

Rectus abdominis (RA)

Range of motion (ROM)

Rehabilitation ultrasound imaging (RUSI)

**S**

Sacroiliac joint (SIJ)

Surface electromyography (sEMG)

Standard deviation (SD)

Smallest detectable change (SDC)

Standard error measurement (SEM)

Sacral multifidus (SM)

**T**

Transversus abdominis (TrA)

Transcutaneous electrical nerve stimulation (TENS)

**V**

Visual analogs scale (VAS)

**W**

Waist-to-hip (WHR)

# Chapter 1: Introduction

## 1.1 The Reasons to initiate an observational study in Taiwanese women with coccydynia

Coccydynia, also known as tailbone pain, is a common complaint, predominantly in women. Thiele (1963) and Fogel (2004) both reported that the incidence of coccydynia was five times greater in women than in men. The prevalence of coccydynia in the western world is relatively low, and there is little research involving this demographic; thus, figures for prevalence and incidence are lacking. So far, no official reports have been composed which are relevant to epidemiological research on coccydynia. A study in France observed 208 patients over two years from 1996-1998(Maigne et al., 2000a). According to several orthopaedists at the China Medical University Hospital (CMUH), the average number of patients with coccydynia was 14% (7 coccydynia cases out of 50 patients per orthopaedist) of their outpatients in October 2006, and most patients were women. Effective interventions, including conservative treatment or surgery, are not evident to date (Jones et al., 1997, Laycock and Haslam, 2003, Hodges and Eck, 2004, Johnson and Rochester, 2006). To physicians and allied health professionals, the cycle of pathogenesis is complex and the limited understanding of coccydynia restricts the development of treatment intervention.

Prior to taking up doctoral studies, the researcher had worked in the fields of orthopaedics and women's health physiotherapy for over three years. She observed that coccydynia was a common complaint within the female population, and this discomfort could not be fully cured. Coccydynia, as observed, frequently coexists with other orthopaedic dysfunctions in the lumbopelvic region, such as, low back pain and also urine incontinence in some patients. However, no formal reports or studies supported the author's concerns. The review papers only stated the possible factors which may induce or worsen the symptoms, but did not discuss the correlations among these co-existing dysfunctions. The investigator wished to conduct research to identify the neuromuscular mechanism of coccydynia, and to understand the alterations that underlie dysfunctions, such as altered motor control, decreased strength, or reduced functional capacity. In particular, the study proposed to investigate this condition in Taiwanese women. If patients with coccydynia showed insufficient support of the lumbopelvic region, a pelvic belt might offer an external compression force to help correct the alignment of the sacroiliac joints, and indirectly relieve the symptoms of coccydynia. Anecdotal evidence suggests that Taiwanese women tend towards a more sedentary lifestyle than western women. This lifestyle involves prolonged sitting postures, which may increase stress over the pelvic region and potentially lead to coccydynia. Poor posture and insufficient muscular control of the lumbopelvic local system may also constitute possible factors for the incidence of coccydynia (Laycock and Haslam, 2003). Additionally, the most popular form of transport in Taiwan is that of a motor scooter, which could potentially lead to cumulative trauma directly over the coccygeal region. However, to date, the above assumptions are not supported by evidence from scientifically reliable studies.

### 1.2 The techniques used and protocol development

Based on the consideration of biomechanics, the position of the coccyx is relevant to the function of the sacroiliac joints and lumbar spine, and may affect the surrounding muscle activity. Neuromuscular dysfunction was found to be present in patients with lower back pain (Hodges and Richardson, 1996, Hodges and Richardson, 1999a, Hodges, 2001, Richardson et al., 2002, Richardson et al., 2004a) and is proposed that similar dysfunction may occur in coccydynia. Tests including ultrasound imaging, motion analysis (VICON), and surface electromyography (sEMG) can be used to evaluate neuromuscular performance between healthy groups and patient groups. Ultrasound imaging is an increasingly popular tool used for assessing the morphology and function of muscles, at rest and during contraction real-time. The sEMG is a method used for inspecting muscle activation. The VICON technique is a type of optical motion capture system, to provide the characteristics of motion during a specific task. These three techniques were selected for the present study to see if differences existed between patients and healthy participants, which could be used to interpret the possible biomechanical mechanism for coccydynia. The investigator was trained in the applied techniques, which were then rehearsed, and the experimental protocols were developed in Southampton, prior to data collection in Taiwan.

A reliability study was conducted between March and June 2008, to examine the repeatability of the three techniques. To standardise the experimental protocols, a reliability study of the level of contraction in abdominal muscles was carried out in March 2009 in Southampton. The purpose of this additional study was to further standardise the protocols for ultrasound imaging. During an active straight leg raising (ASLR) task, the subjects were requested to do the task whilst slightly drawing-in their abdomens and contracting their gluteal muscles. If the level of contraction could be shown to be controlled during the ASLR, the ultrasound test could be considered more reliable.

### 1.3. Data collection

The pilot study was carried out in Southampton and ethical approval for the study was obtained in January 2008. Data collection for the pilot study commenced from March and finished in June 2008 (see Appendix 13.1.1). To standardise the experimental protocols, the different levels of contraction in abdominal muscles were considered a necessary element. An extra 15 participants were recruited to take part in a study on thickness changes of TrA muscles at different levels of contraction, in March 2009 (see Appendix 13.1.5). This protocol was also applied with patients. Because of a lack of older Taiwanese participants in Southampton, only young participants could be recruited for the pilot study in the UK. Older healthy participants were recruited for the main study in Taiwan, to become an age-matched control group, which could be used for comparison with the patient group who were older. The main study was executed in the China Medical University and Hospital, Taichung, Taiwan between July and December 2009, involving older controls and patients. The ethical application for the study in Taiwan was submitted to the Institute Review of Board at the China Medical University Hospital (CMUH) and approval was obtained in July 2009. It was valid for one year (see Appendix 13.1.7).

### 1.4. Overview of the thesis

This PhD thesis begins with the background of coccydynia. The biomechanics of the lumbopelvic region, with the theorisations and speculations regarding the lumbopelvic region, based on biomechanical and physiological theory and studies, are presented in Chapter 2. Chapter 3 introduces the techniques used to evaluate the dysfunction in the lumbopelvic region and the decision-making for the three main techniques applied in these studies. Chapter 4 details the methodology applied in these studies and the protocols for the pilot work in Southampton and the main study in Taiwan are discussed herein. The outcome measurements and analysis strategies are also described in this chapter. The findings of the three techniques are discussed in separate chapters: Chapter 5: Ultrasound Imaging; Chapter 7: Motion Analysis; and Chapter 8: Electromyography (EMG). The research regarding the levels of contraction of the abdominal muscles for patients and healthy participants is presented in Chapter 6. Chapter 9 presents six case studies of the application of a pelvic belt for treating coccydynia. Finally, Chapter 10 provides general discussion and commentary on the findings of the studies and their relationship with existing literature, as well as clinical implications. Chapter 11 features the conclusion and proposals for the future resolution of any unanswered questions.

## Chapter 2: Background of coccydynia and biomechanics of the lumbopelvic region

Coccydynia, also known as tailbone pain, is described as: "pain in or around the coccyx" and is considered as a symptom not a disease itself(Wray et al., 1991, Ryder and Alexander, 2000, Laycock and Haslam, 2003, Johnson and Rochester, 2006).The condition occurs approximately five times more frequently in women than in men (Thiele, 1963, Fogel et al., 2004), but the prevalence of patients in Asian and in Western societies is unclear.

### 2.1. Coccydynia

Coccydynia was first described by Simpson in 1859(Simpson, 1959), and Churchill's Illustrated Medical Dictionary (Koenigsberg, 1989) gave coccydynia alternative terms such as; coccygalgia, coccyalgia, coccygodynia and coccyodynia. These terminologies were used as keywords in this thesis to search PubMed, and the search criteria were restricted in language only. The articles were checked and arranged into reviews, interventions and case studies (See Figure 2.1.). This condition is considered as a type of lower back pain but how it affects neuromuscular performance in the lumbopelvic region is unclear. Herein, the relevant information was reviewed from the presenting symptoms to interventions.

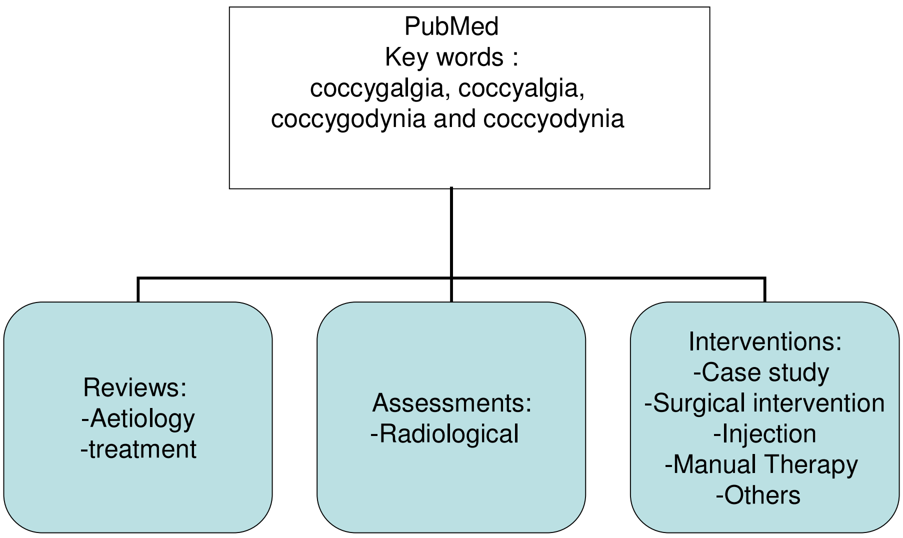



**Figure 2.1. Flow-chart of papers search for the literature review**

#### *2.1.1 Symptoms and classification of coccydynia*

The symptoms of coccydynia result from inflammation of musculoskeletal tissues. Coccydynia is defined as: "pain in and around the coccyx that does not significantly radiate, which is made worse by sitting or by standing up from the sitting position."(Maigne et al., 2000a). If patients suffer coccydynia as a result of acute original trauma, the pressure on the tip of coccyx induces pain (Thiele, 1963). Figure 2.2 magnifies the painful area in coccydynia: the tip of coccyx and the tender triangular region.

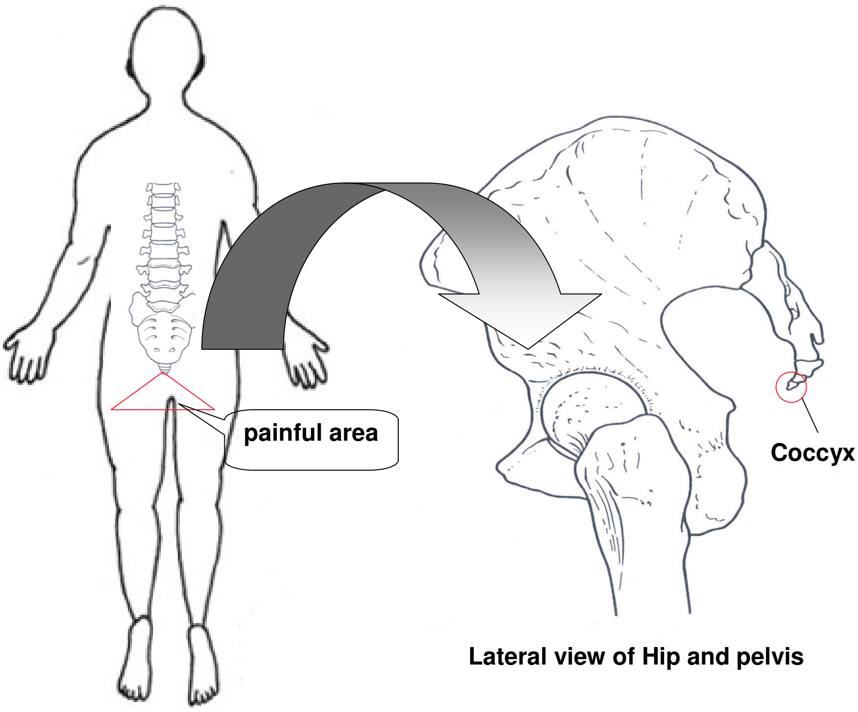



**Figure 2. 2. The pain distribution of coccydynia: tip of the coccyx and the common painful triangular area around the coccyx. Modified from 'The source of Medical Illustration' which provides figures free from copyright restrictions.**

The mechanism of coccydynia is unknown; therefore the classification is based on the time course of the disorder, the characteristics of the pain, the medical history and the anatomic characteristics of the coccyx. The most common sources of acute pain are the coccygeal discs or joints and acute local trauma related to a fall into a sitting position. Childbirth is also a common aetiology. If pain persists for more than two months it is considered chronic, but the disorder is often viewed as idiopathic (Maigne et al., 2000a, Andres and Chaves, 2003). This classification is very subjective and is based on the duration of symptoms, but it is very convenient for clinical practice.

Kim and Suk (1999) divided patients with coccydynia into idiopathic and traumatic groups, according to their medical history. The traumatic type is defined by the symptoms associated with trauma that occurred more than three months previously and the idiopathic type is defined as bearing an unknown origin. The objective assessment of coccygeal mobility is based on radiological research to define normal and abnormal mobility of the coccyx. It can provide the regular range of mobility of the coccyx for surgical purposes (Kim and Suk, 1999). The functional anatomy of the coccyx and pelvis is discussed in Section 2. 2. Postacchini and Massobrio (1983) first proposed a radiologic classification of coccygeal shape, with four grades from standard lateral radiographs (Grade I: curved and slightly forward; Grade II: more markedly curved with the coccyx pointing straight forward; Grade III: sharply angled anteriorly; Grade IV: subluxation of the sacrococcygeal joint or intracoccygeal joints). However, this classification is based on descriptions and not exact measurements.

Another classification was proposed by Maigne and Tamalet (1996) for the determination of coccygeal mobility, drawn from their research involving dynamic x-rays of lateral sitting. Compared with regular lateral radiographs, a standard radiological protocol for the lateral sitting positions was developed and carried out in 1996. In control groups, motion of the coccyx in the sitting position was at a mean angle of 9.3°±5.7°. The classification for lesions over the coccyx was defined as hypermobility at a flexion angle of more than 25°, and luxation by a displacement of the coccyx of more than 25°. The different classifications are summarised in Table 2.1.

**Table 2.1.: Classification of coccydynia according to different critera (Postacchini and Massobrio, 1983, Maigne and Tamalet, 1996, Maigne et al., 2000a)**

| **Criteria for classification** | **Defination/ Classfication** | | | |
|---|---|---|---|---|
| Pain duration | Acute<br>1st week | | Chronic<br>>3 months | |
| History | Idiopathic<br>Unknow origin | | Traumatic<br>Symptoms associated with trauma> 2 months | |
| **Radiological measurement** | | | | |
| Coccyx shape<br>Postacchini and Massobrio (1983) | Grade I<br>curved and slightly forward | Grade II<br>more markedly curved with the coccyx pointing straight forward | Grade III<br>sharply angled anteriorly | Grade IV<br>subluxation of the sacrococcygeal joint or intracoccygeal joints |
| Coccyx mobility<br>Maigne and Tamalet (1996) | Normal<br>Flexion 0-25° | Hypermobility<br>Flexion> 25° | Sub-luxation<br>Displac.< 25° | Luxation<br>Displac. >25° |

Cyriax (1982) sub-classified four types of coccydynia according to findings on palpation. He suggested that palpation should start at mid-sacrum and be classified into the four types below:

- *Contusion of the tip of coccyx and the tissue immediately surrounding it. This is the most common type.*
- *Sprain of the posterior intercoccygeal ligaments.*
- *Sprain of the sacrococcygeal joint.*
- *Irritation of the coccygeal fibres of the gluteus maximus muscle. In this condition the pain is unilateral and may spread slightly to one buttock. Occasionally the patient complains that walking is uncomfortable.*

*(Ombregt et al., 1995)*

This Cyriax classification is closest to the clinical symptoms to date but the difficulty lies in quantifying the findings between different examiners. There is no report considering the reliability of this classification to date but it is used for functional diagnosis clinically.

***2.1.2. Possible causes of coccydynia***

Key (1937) proposed that coccydynia is due to local pressure over an unusually prominent coccyx or inflammation of the various ligaments attached to the coccyx. However, this concept only takes the actual condition into consideration and does not explore other possible factors which contribute to causing coccygeal dysfunction. An early paper which discussed the aetiology and treatment of coccydynia was by Thiele in 1963. He speculated that poor posture, or anorectal or other associated local infections caused coccydynia in 80 percent of cases, and that direct trauma only caused 20 per cent of cases with symptoms. From his clinical observations and practices, he concluded that spasms of pelvic floor muscles are responsible for the discomfort in coccydynia, and that anorectal infection is often a causative factor. Local pathologies around the coccyx were reported to afflict pain in or around the coccyx, including chordoma, giant cell tumors, intradural schwannoma, perineural cysts and intra-osseous lipoma (Wray et al., 1991).

The potential causes of coccydynia may be multifactorial, so differential diagnosis is important before effective management commences. While reviewing the relevant articles, the common potential causes were divided into three categories: external trauma, cumulative trauma and nearby pathology (Ryder and Alexander, 2000, Fogel et al., 2004, Johnson and Rochester, 2006). The most common cause was direct external trauma that had often occurred as the result of a fall into a sitting position or a direct blow (Maigne et al., 2000a, Ryder and Alexander, 2000 ,Laycock and Haslam, 2003). From the above publications, the symptoms and the potential causes of coccydynia were mainly based on empirical observation rather than a well-designed study approach. Coccydynia is defined as a symptom but may result in subsequent dysfunction or coexisting dysfunctions in the lumbopelvic region.

Congenital anatomical variation or post-traumatic deformities of the coccyx or sacrococcygeal and intercoccygeal joints may be potential factors in inducing coccydynia. In Figure 2.3, a typical female pelvic outlet is shown to be wider than a male's, and the coccyx is more prominent in women which is presumably more prone to injury (Wray et al., 1991). This anatomical difference could explain the more frequent occurrence of coccydynia (around five times) in women than in men (Thiele, 1963, Wray et al., 1991, Fogel et al., 2004).

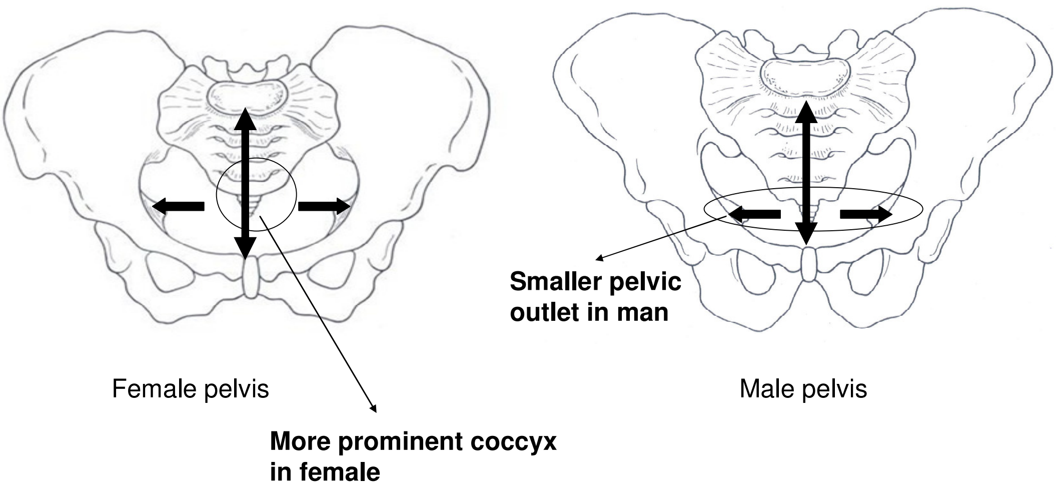



**Figure 2.3. Gender differences in the configuration of the pelvis.**

Due to a lack of objective measurement of the coccyx, Kim and Suk (1999) carried out a study in Korea to measure and compare the intercoccygeal angles amongst idiopathic coccydynia (13 patients), traumatic coccydynia (19 patients) and normal control groups (20 controls). This measure is the angle between the first coccygeal segment and the last coccygeal segment (Figure 2.4). They reported that the intercoccygeal angle of the idiopathic coccydynia group was greater than that of the traumatic and control groups, and could be considered a possible cause of idiopathic coccydynia. Their findings suggest that congenital anatomical traits may lead to the occurrence of coccydynia, and indicate that the measurement of intercoccygeal angle could be used in future studies.

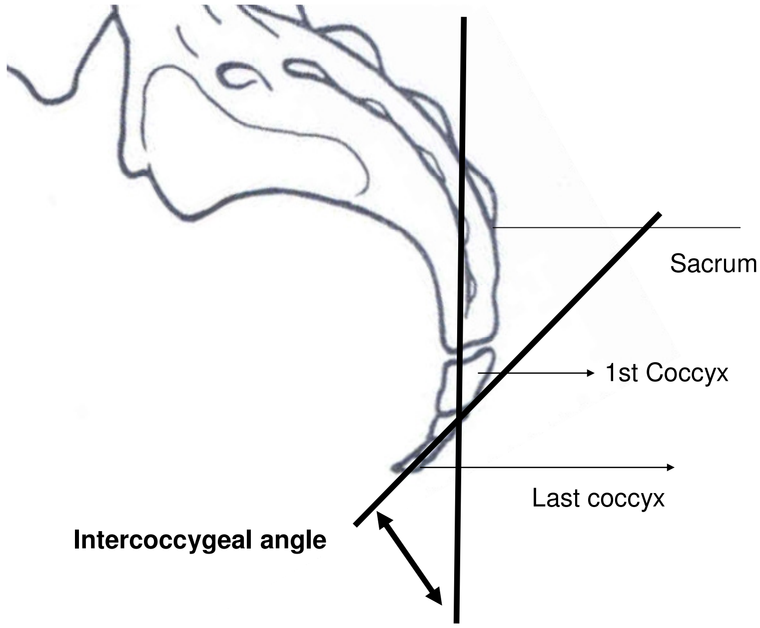
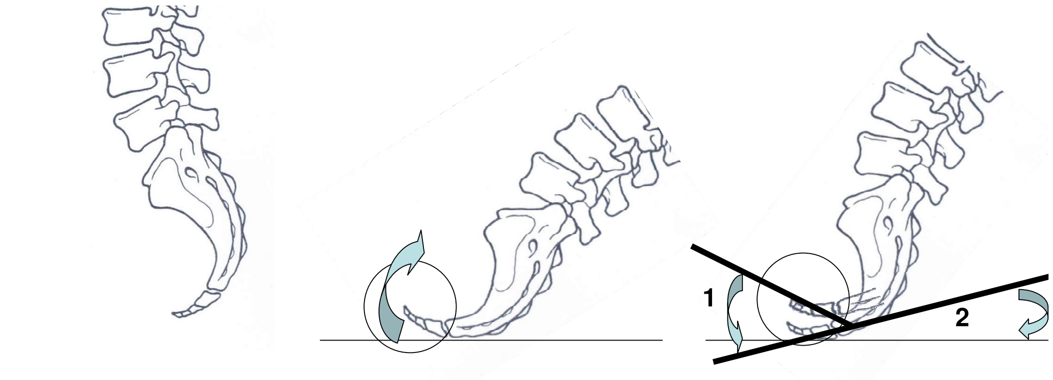



**Figure 2.4. Intercoccygeal angle is defined as the angle between the first coccygeal segment and the last coccygeal segment, and can be used as the objective measurement of forward angulation of the coccyx. Modified from 'The source of Medical Illustration'.**

Maigne and Tamalet (1996) developed a standard radiological protocol for the lateral sitting position, compared with usual lateral radiographs, to obtain a measurement of the functional mobility of the coccyx (See Figure 2.5.). There were 47 healthy controls and 91 patients involved in this study who had complained of chronic coccydynia for more than two months. The findings showed 26 patients with luxation, 18 patients exhibiting hypermobility, and 47 patients with a normal range of mobility (0-25°). It was reported that patients with coccydynia tended to have an unstable coccyx; perhaps it should be said that symptoms are associated with the development of progressive coccygeal instability (Maigne et al., 2000b, Patel et al., 2008). Their findings indicate that the instability of the coccyx is relevant to coccydynia and could become a routine protocol for the assessment of coccydynia. However, the correlations among the severity of symptoms, activities of daylily living (ADL) function and the level of instability of the coccyx are unknown.




A. Standing radiograph

B. Sitting radiograph: flexion of coccyx

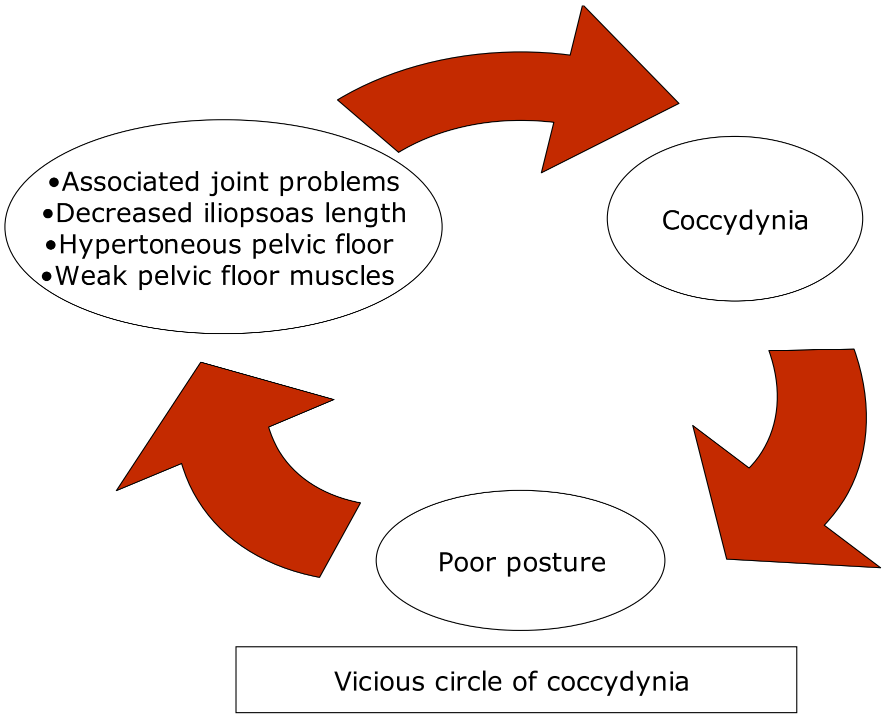
C. Angle 1: coccygeal mobility; Angle 2: angle of incidence

**Figure 2.5. Measurement of coccyx mobility. A. Standing radiograph. B. Sitting radiograph. The arrow indicates flexion of the coccyx. C. Superposition of the two radiographs by matching the sacrum. Angle 1 is defined as angle of mobility and angle 2 is defined as the angle of incidence. Modified from Maigne et al., 2000b and 'The source of Medical Illustration'.**

Poor posture results in many musculoskeletal problems, such as increased strain on lengthened tissues and joints around the pelvis. Coccydynia is related to the posture of sitting and during the postural changes between sitting and standing. Lumbar movements of standing and lying down do not provoke pain. Patients may feel pain during defecation and walking once the coccygeal fibres of the gluteus maximus fibres are involved (Ombregt et al., 1995). A neutral spine and a symmetrical pelvis during activities of daily living can protect the pelvic and lumbar joints, hip, trunk, and muscles (White and Panjabi, 1990, Laycock and Haslam, 2003, Richardson et al., 2004a). If these components (i.e. a passive system, an active system and a neural system) cannot co-operate appropriately, they may work ineffectively against the compressive load on joints during functional tasks, with increased intra-abdominal pressure (Richardson et al., 2004a, Mens et al., 2006b). Therefore, patients with coccydynia may demonstrate postural impairments which could repeatedly damage their pelvis and surrounding tissues.

In patients with lower back pain, paraspinal muscle spasms were observed in muscles that were also found to be severely wasted on ultrasound imaging (Hides et al., 1994). Therefore, muscle spasm can occur simultaneously with muscle atrophy, and thus does not necessarily mean that a muscle will hypertrophy just because it is in spasm. Similarly, perhaps patients with coccydynia may demonstrate spasms in pelvic floor muscles (i.e. anal elevator and coccygeus) and hypertonous of the pelvic floor. Also, these muscle spasms may induce the symptoms of coccydynia. Thiele

(1963) believed that spasms of pelvic floor muscles are responsible for the discomfort in coccydynia, and that anorectal infection is often a causative factor. Thiele's speculation about the influence of pelvic floor muscles and infections on coccydynia is reasonable. The above mentioned factors relating to the mechanism of coccydynia may be mutually influenced and become a vicious circle (Figure 2.6.). The correlations among these factors are not clear and based on the clinical observation, and therefore require investigation.




. **Figure 2.6.: Vicious circle of coccydynia**

Another common cause was cumulative trauma resulting from poor posture, for example, prolonged sitting in poorly designed chairs. Additionally, body mass index (BMI) was proposed to influence the sitting position (Maigne et al., 2000a). People with a high BMI showed a high coccygeal angle of incidence due to insufficient pelvic rotation, so the coccyx was more prominent in these people (Maigne et al., 2000a). Another cause was nearby pathology, such as referred pain from disc prolapses in the lumbar spine. It was also a sign of lumbar degenerative disease. Wray et al (1991) discussed the possibility of the co-existence of coccydynia and lower back pain. (Dittrich, 1951) thought of it as referred pain and (Richardson, 1954) believed that it could be from a lumbosacral disc prolapse. (Bremer, 1896) was of the opinion that these patients have some form of neurosis or even frank hysteria (psychological problems). However, the relationships between these possible dysfunctions and coccydynia are thus far unclear.

### *2.1.3. Existing interventions*

Intervention programmes are variable, and a universal one for coccydynia could not be found in the literature. The favoured method for the management of coccydynia is to try conservative treatment first, and then more aggressive approaches of nerve blockades and surgery if the patient fails to respond to initial, less intensive treatment. The focus of these studies relevant to coccydynia was to introduce aggressive interventions rather than conservative treatments. Therefore, the details of conservative intervention were not detailed in the publications (Thiele, 1963, Wray et al., 1991, Andres and Chaves, 2003, Ramsey et al., 2003, Fogel et al., 2004, Cebesoy et al., 2007, Patel et al., 2008).

As for the more moderate management of coccydynia, Thiele (1963) proposed massage of the pelvic floor muscles, and working to develop a proper sitting posture. The massage technique was proposed in 1937 and focusses on the management of levator anus and coccygeus. The first step is to assess pelvic muscle tone (Thiele 1937). The examiner inserts the index finger following the axis of the rectum. Then, the finger gradually pushes upward (posteriorly) to stretch the pelvic floor until contract is made with the coccyx and then the push is released. If the finger is returned to its initial position in the rectum immediately, it indicates that the patient's muscle tone is abnormally high. The second step is to massage levator anus and coccygeus. The finger is gradually pushed downward (anteriorly) to massage muscles in the long direction of the fibres on both sides.

As for postural advice, Thiele suggested that patients should sit erect on a firm chair and adjust their seated posture to ensure the transference of body weight from the coccygeal region to the ischial tuberosities, and the under surface of the thighs. This can help patients to relieve stress on the sacrococcygeal joints and surrounding structures. Additionally, massage of the levator ani and coccygeus muscles can be used to relieve symptoms. Thiele is the first person who recommended massage for the pelvic floor muscles (Thiele 1937), and stated the way to approach this in detail. He also suggested the optimal frequency of intervention: the massage session should be repeated daily and then gradually less often until the pain disappears. Thiele (1963) proposed that the frequency should be daily rather than intermittent; otherwise the massage may be a waste of time. He reported that 223 of 324 patients were treated by massage only; of these 142 patients (63.7%) were cured and an additional 60 (27%) were improved. However, this technique can be considered intrusive and it is not easy to broach such a suggestion in clinical practice, particularly in Asian society.

Wray et al (1991) conducted a five-year prospective trial involving 120 patients to investigate the aetiology and treatment of coccydynia. All patients were initially treated by physiotherapy involving ultrasound and short-wave diathermy. If these treatments failed to produce a response, patients received local injections around the side and tip of the coccyx. If coccydynia persisted, the coccyx was manipulated under general anaesthesia. If patients failed to respond to the above treatments after six weeks, surgical intervention (i.e. coccygectomy) was suggested to remove the coccyx. According to the findings of Wray et al (1991), physiotherapy only offered little help, but 60% of their patients responded to local injections. Manipulation and injection was even more successful and cured about 85%. Their study was designed specifically by physicians, so the details of physiotherapy were restricted to machines for ultrasound and short-wave diathermy only. No exercise or suggestions for posture were offered. Although Wray et al. (1991) mentioned massage for pelvic floor muscles in the discussion, they did not apply this treatment to their patients due to lack of expertise in this area.

(Maigne and Chatellier, 2001) carried out a pilot study to compare three different manual treatments (levator anus massage, coccygeal mobilisation and mild levator stretch), with a follow-up at 7 days, 30 days, 6 months and 2 years. A 25.7% overall success rate was reported, and a “satisfactory” figure was obtained for each treatment: 29.2% with massage, 16% with mobilisation, and 32% with stretching. These results varied with the cause of coccydynia and a good outcome was reported specifically in patients with a normally mobile coccyx. A good outcome was attained for patients with a more stable coccyx, shorter duration and traumatic etiology, and lower scores on pain assessment (Maigne et al., 2006).However, this study was not designed with any placebo control and therefore cannot substantiate the effectiveness of such manual treatments on chronic coccydynia. Also, mild effectiveness was reported.

The aggressive interventions of nerve blockades and surgeries are recommended if patients have failed to respond to the above more moderate treatments for more than six months. A technique of nerve blockade is to target the ganglion impar (ganglion Walther), which is located at the end of the sympathetic chain in front of the sacrum. This has been reported to relieve coccydynia and other pelvic pain syndromes. Prior techniques were to insert the needle through the anococcygeal ligaments; more recent alternative methods were to inject via the sacrococcygeal joint/intracoccygeal joints. Accurate needle placement is important in nerve blocks to prevent complications but the location of the ganglion impar exhibits anatomic variability. Therefore, how to discern the injection site determines the success of the blockade. Imaging methods are being considered for use in identifying the ganglion and guiding the needle, such as computed tomography (CT) (Datir and Connell, 2010). The potential complications of ganglion impar blockade are (1) perforation of the rectum or bladder and (2) sciatic nerve injuries or inadvertent injection. Although nerve blockade seems to be a relatively easy and effective way to relieve the symptoms of coccydynia, non-invasive treatments are recommended due to their significantly lower risk of complications.

Surgical intervention, i.e. coccygectomy, was suggested to remove the coccyx when these conservative interventions did not work (Andres and Chaves, 2003, Fogel et al., 2004 )A patient without physical findings, e.g. coccyx instability, or with significant abnormal psychological evaluation was not eligible for surgery. The success rate for coccygectomy with a control of selected patients who specifically demonstrated an unstable coccyx ranged from 60% to 91% (Postacchini and Massobrio, 1983, Bayne et al., 1984, Eng et al., 1988, Hellberg and Starange-Vognsen, 1990, Wray et al., 1991, Maigne et al., 2000b). The complications of coccygectomy include delayed wound healing and wound infection, and the occurrence rates range from 2%-22% (Postacchini and Massobrio, 1983, Eng et al., 1988, Wray et al., 1991, Maigne et al., 2000b). Fogel et al (2004) found that “in a very thin patient with a kyphotic sacrum, the remaining end of the sacrum may be prominent and be a source of continued pain that is not easily managed.” In principle, these studies aimed to show that coccygectomy worked effectively. The selection of patients was critical for a successful operation. All patients were requested to accept the conservative intervention prior to the surgical intervention. The details of conservative intervention were lacking in these studies.

### *2.1.4. Current means of investigating coccydynia and unknown aspects of this condition*

Coccydynia is a symptom rather than a dysfunction itself and the aetiology remains unclear. Diagnosis is mainly based on pain assessment and consideration of medical history. Objective assessment is based on the bony structure and mobility of the coccyx, informed by radiographic techniques. The co-incidence of coccydynia and lower back pain or other dysfunction in the lumbopelvic region is possible, but no evidence supports this theory to date. Additionally, the majority of studies relevant to coccydynia were reviews of aetiology, radiological presentations and rough guidelines for treatments. These papers mentioned physiotherapy as an option in conservative treatments but only to provide some assistance (Wray et al., 1991, Ryder and Alexander, 2000). Johnson and Rochester (2006) conducted a review on coccydynia and also found no strong evidence to prove the effectiveness of physiotherapy. Physical management can include ultrasound, postural correction, and musculoskeletal assessment for the whole body. Existing papers only interpreted the thoughts of physicians (such as orthopaedists and radiologists) but did not provide information regarding the views of physiotherapists.

## 2.2. Biomechanics of the lumbopelvic region

The stability of the lumbopelvic region is maintained by the integration of several complex and precise systems, including muscular systems, bony structures and the neural modulation system. In this section, these associated systems and different biomechanical models of the lumbopelvic region are reviewed and discussed.

### *2.2.1. The muscular system*

Bergmark (1989) proposed a classification system of muscles, the local system and global system, based on architectural properties. The local muscular system includes deep muscles, with the deep portions of some muscles originating or inserting on the lumbar vertebrae (i.e. the lumbar multifidus, the transversus abdominis, and the intersegmental muscles), and the orientation of produced forces are indicated by the arrows as Figure 2.7.a shows. These muscles are activated prior to the predictable changes, in order to control spinal mobility and stability. In contrast, the global muscle system incorporates the large, superficial muscles of the trunk. These muscles do not directly attach to the vertebrae and cross multiple segments (i.e. the obliquus internus abdominis, the obliquus externus abdominis, the rectus abdominis and the lateral fibres of the quadratus lumborum) and demonstrate later contraction whose force directions are shown in Figure 2.7.b, and act as torque generators for spinal motion and balance of load transfer (Richardson et al., 2004a).

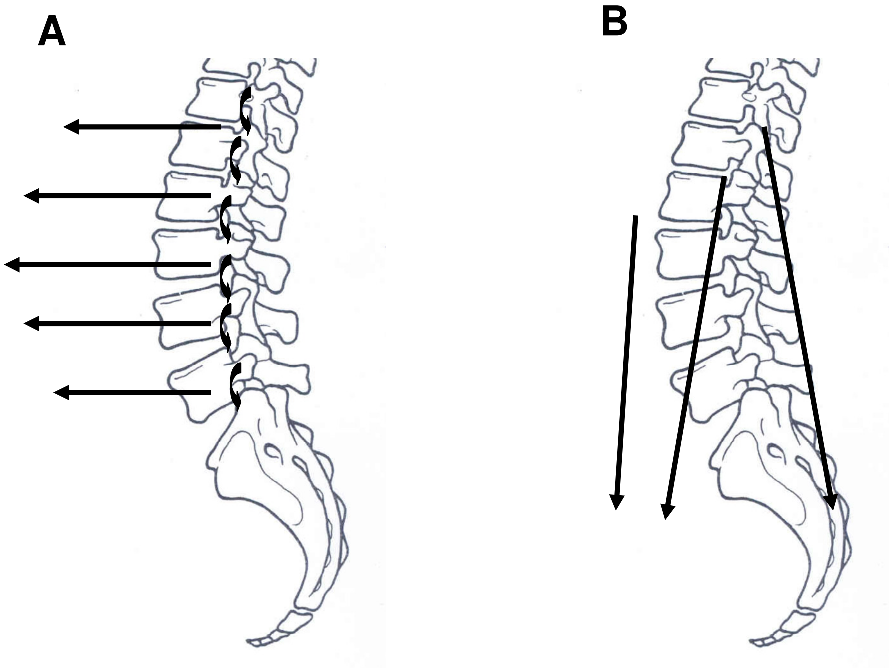



**Figure 2.7. Direction of muscles forces in the lumbopelvic region: A local, B global. Modified from 'The source of Medical Illustration'.**

Cholewicki et al, (1997) in their '*in vivo'* model, reported that the global muscles linking the pelvis to the rib cage generated significant amounts of stiffness to the spinal column, while the local muscles were vital in the stability of the spinal segments. If there was no activity in the local muscle system, the spine was unstable even if global muscles generated substantial forces (Cholewicki et al., 1997, Lee, 2004, Richardson et al., 2004a). In the lumbopelvic region, transversus abdominis (TrA), the deepest of the abdominal muscles, plays a critical role in protecting the spine when a perturbation occurs (Hodges and Richardson, 1999b). For example, the contraction of TrA was present prior to the anticipatory movement task (Hodges and Richardson, 1997, Hodges, 1999, Hodges et al., 2001b). This series of studies by Hodges et al provided evidence of the feedforward mechanism. They studied anticipatory movement adjustment during rapid bilateral upper limb movements at different speeds in healthy people and patients with low back pain. Electromyography (EMG) was used to detect muscle activation of abdominal, trunk extensor and deltoid muscles. Needle EMG was applied for the TrA muscle and surface EMG was used for other superficial muscles including IO, EO, back extensors and deltoid muscles. They found that the reaction time of TrA was not affected by the complexity of tasks in controls but was increased in patient with low back pain.

In other words, the TrA muscle provides preparatory spinal stability against reactive forces from limb movements and the displacement of the centre of mass (Hodges and Richardson, 1997). The response of TrA was not found to be affected by the direction of arm movements, hence it was concluded that this muscle contributes to the general stability of the spine and pelvis in a non-task-specific manner. In contrast, IO was reported to be more variable between movement directions. It can be interpreted from this that the function of TrA is to provide spinal stability, rather than the control of spinal orientation (Hodges and Richardson, 1999a, Hodges and Richardson, 1999b) . Hodges (1999) reviewed studies regarding the function of TrA and summarised that contraction of TrA can reduce abdominal circumference, increase intra-abdominal pressure (IAP), and contribute to respiratory function.

### *2.2.2. Functions of intra-abdominal pressure (IAP) and Transversus abdominis muscles (TrA)*

Since the 1920s, it has been argued that IAP contributes to trunk control. Cresswell and colleagues (1992; 1994) identified a close active relationship between IAP and TrA during the performance of rapid arm movement (Cresswell et al., 1992, Cresswell et al., 1994) . They found that the tension of IAP was increased following activation of TrA and preceded the onset of limb movement. This meant that IAP could contribute mechanically to the preparatory process occurring prior to limb movement. Recruitment of the diaphragm during rapid arm movement was reported to occur earlier than the onset of deltoid (Hodges and Richardson, 1997, Hodges et al., 1999), and pelvic floor muscles were found to co-activate with TrA. Richardson et al, (2004) summarised the initial hypothesis of the IAP mechanism in these words: " the abdominal cavity functions as a pressurised 'balloon' in front of the spine, with a force up on the diaphragm and down on the pelvic floor to extend the trunk" (Richardson et al., 2004a). See Figure 2.8.

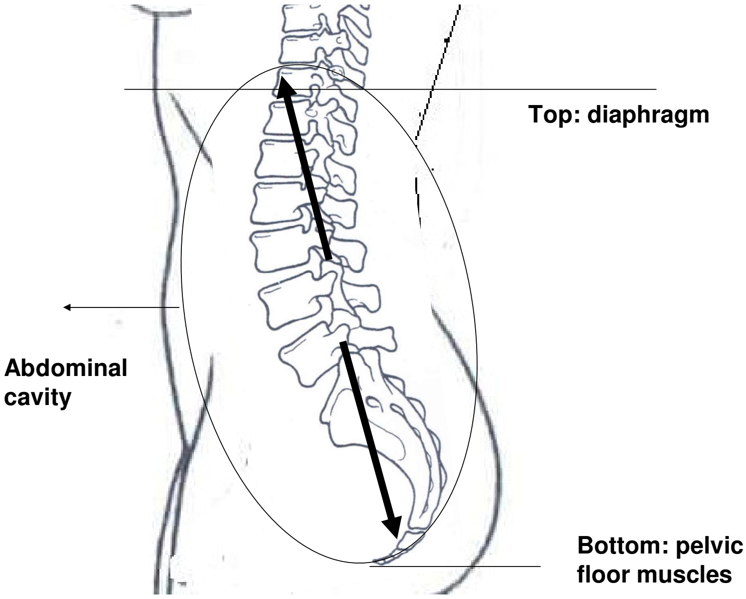



**Figure 2.8. The contribution of intra-abdominal pressure: the production of an extensor movement by a distracting force between the diaphragm and the pelvic floor. Modified from 'The source of Medical Illustration'.**

Based on the initial model, the extension movement from IAP was proposed to reduce the demand for back extensor activity and decrease the compressive load on the lumbar spine. This abdominal mechanism should be referred to as being biomechanically beneficial for the lumbar spine. The transversus abdominis, internal oblique, diaphragm and the pelvic floor muscles are believed to work together to control IAP, and thereby increase the stability of the lumbar spine (Richardson et al., 2004a, Stuge et al., 2004, Mens et al., 2006b). In other words, pelvic floor muscles may contribute to the stability of the lumbopelvic region. Pool-Goudzwaard et al, (2004) supported this notion and revealed that pelvic floor muscles contributed to stiffening the pelvic ring by force closure, and is explained below. These findings supported the previous hypothesis that TrA, the diaphragm and the pelvic floor muscles are co-activated to form an enclosed abdominal cavity for the control of spinal stability. Pel et al. (2008) used a validated static 3-D musculoskeletal model containing 100 muscle elements, 8 ligaments and 8 joints in the trunk, pelvis and upper legs to analyse sacroiliac joint (SIJ) stability in the upright posture. They found that vertical SIJ force reduction results in increases of SIJ compression. Although this study did not investigate the influence of IAP, they suggested that training these muscles (TrA and PFMs) could increase stability of the sacroiliac joints, which concurs with the hypothesis of Pool-Goudzwaard et al (2004).

### *2.2.3. Structure and function of the skeletal system*

The lumbopelvic region also includes important skeletal components: the sacroiliac joint (SIJ) and the coccyx. Vleeming et al. (1997) stated that the stability of the SIJ was achieved by a combination of form and force closure. In this model, the sheer force of the SIJs may be averted by friction produced by anatomic features (form closure) and dynamically influenced by muscle force, ligament tension and fascial structure (force closure), as illustrated in Figure 2.9). Once the balance is destroyed, some disorders (see section 2.2. for mechanisms) may exist in the lumbopelvic region (Vleeming et al., 1997, McGrath, 2004).

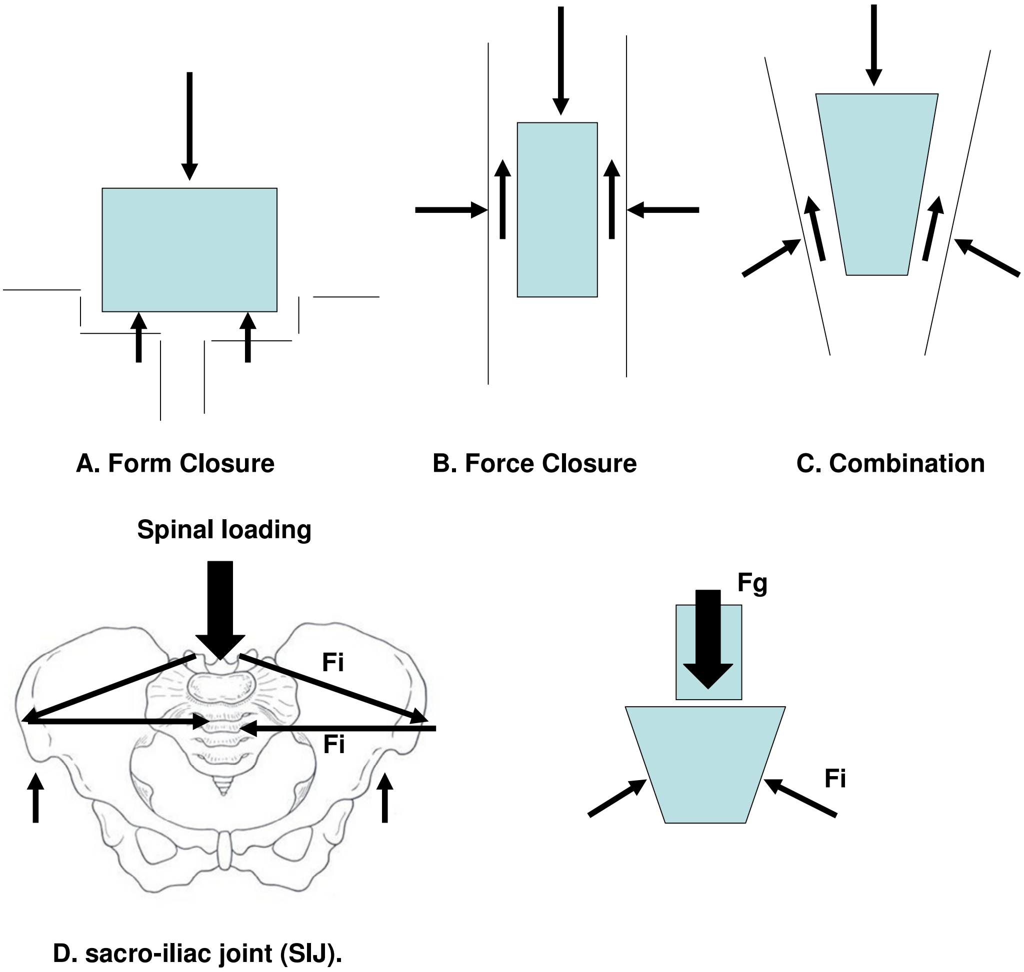



**Figure 2.9. The object is held in place by (A) form closure, (B) force closure, and (C) combination of form and force closure, less friction—and thus less compression being needed than in (B). (D) shows the mechanism of an arch. Force FI may be raised by ligaments, muscles, or a pelvic belt just cranial to the greater trochanter and cadual to the sacro-iliac joint (SIJ). This force prevents lateral movement of the hip bones to secure the form of an arch.**

The main movements of the SIJs are nutation, defined as forward tilting of the sacrum relative to the ilium (see Figure 2.10), and counternutation, which is reverse backward tilting. During nutation, the multifidus and sacrotuberous ligament can counterbalance the slackening of the long sacroiliac (SI) ligament. At the same time, biceps femoris and/or gluteus maximus and the lumbar lordosis can work to help control nutation (Vleeming et al., 1997). The optimal stable position of the SIJ is full sacral nutation, during both forward and backward bending of the trunk; this is in contrast to the position of sacral counternutation or pelvic anterior rotation (Lee, 2004). Richardson et al, (2004) quoted the findings of Snijder et al. (1995), claiming that while pelvic floor muscles counternutate the sacrum, voluntary contraction of TrA can reduce the laxity of the SIJ by putting compression force on the joint (Richardson et al., 2004a, Snijders et al., 1995).

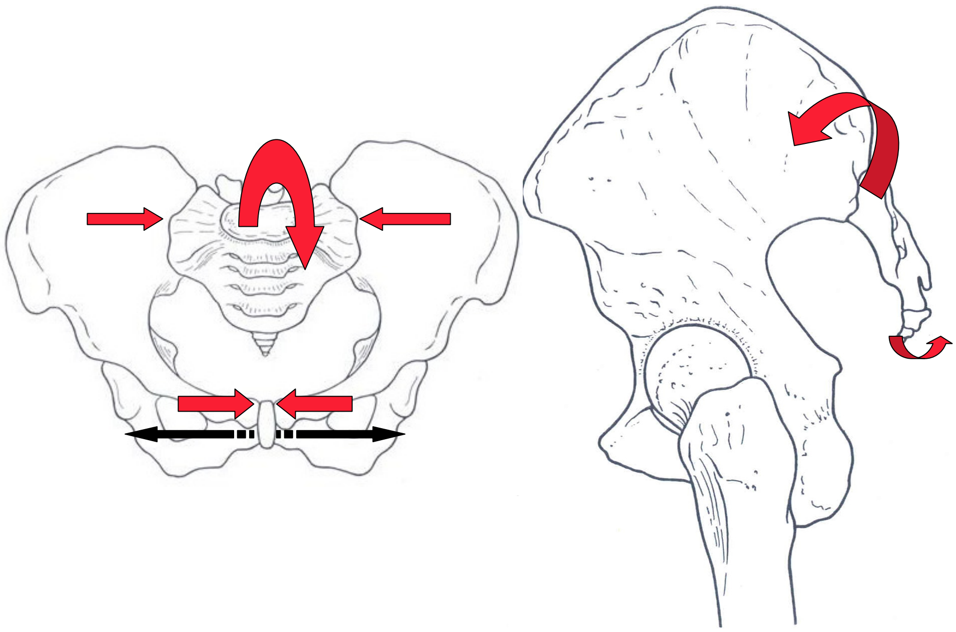


**Figure 2.10. Nutation in the sacro-iliac joint (SIJ). The iliac bones are pulled to each other due to ligament tension (among others) and compress the SIJs (upper black arrows). It can be expected that the upper (anterior) part of the pubic symphysis is particularly compressed. Modified from 'The source of Medical Illustration'.**

The coccyx is a vital link between the bony pelvis and the soft tissue of the pelvic floor. This small bone is directly attached to the sacrotuberous ligaments and to the dural sac. The coccyx also acts as the posterior bony anchor of the pelvic floor muscles. The mobility of the coccyx, flexion and extension, is performed by levatores ani (i.e. pelvic floor muscles) and sphincter ani externus muscles (see Figure 2.11). Extension is defined as a backward direction resulting from relaxation of these muscles and increased IAP (see Figure 2.8). Conversely, contractions of these muscles (forward direction) result in coccygeal flexion (Vleeming et al., 1997, Grassi et al., 2007). O'Sullivan and Beales, (2007) summarised in a recent study that the *"depression of the pelvic floor is associated with generation of high levels of intra-abdominal pressure and global activation of the pelvic floor, abdominal wall and chest wall muscles"*. However, this strategy showed less facility in stabilising the SIJs (O'Sullivan and Beales, 2007). During movement, it may be assumed that the control of IAP was associated with activation of the pelvic floor muscles but further research is needed to investigate and provide evidence for this.

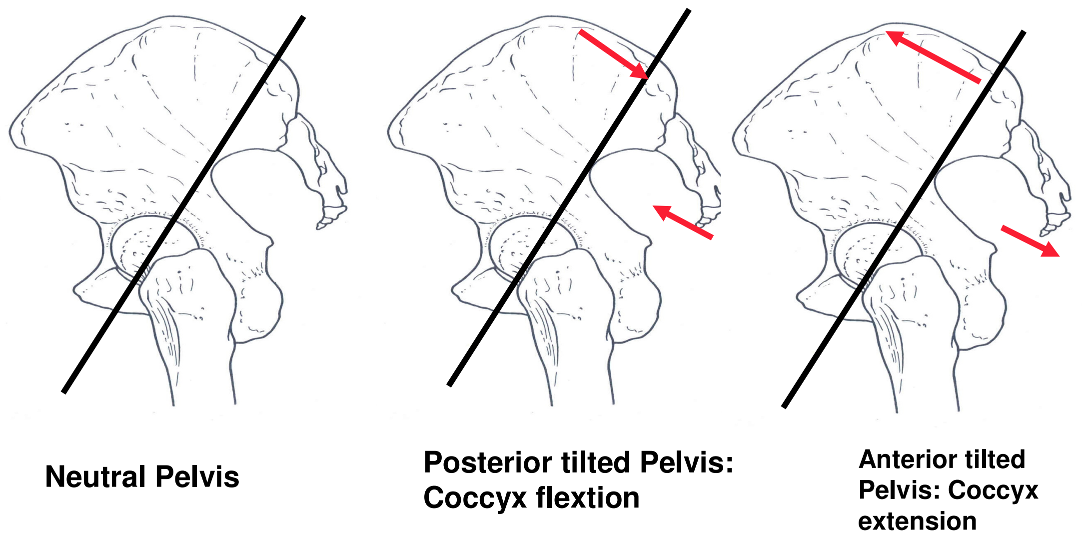



**Figure 2.11. The correlations between pelvic positions and coccygeal motions .Modified from 'The source of Medical Illustration'.**

Gluteus maximus, biceps femoris, and the sacral part of erector spinae attach to the sacrotuberous ligament, and couple to achieve sacral stability. Herein, biceps femoris showed that tension of the sacrotuberous ligament is increased by contracting the long head of this muscle. However, this tension mechanism depends on body position and more force is transferred to the sacrotuberous ligament in a flexed position than in an erect stance. In other words, larger compression force coupled by these muscles is needed to maintain sacral stability in a flexed position (Vleeming et al., 1997).

### *2.2.4. Load-deformation behaviour in spinal stability*

According to Panjabi (1992b), the load-deformation behaviour of the spinal segment is non-linear, and the high flexibility of spinal motion is demonstrated in the vicinity of the neutral position, known as the neutral zone *(see* Fig 2.12.A*).* Panjabi (2003) used the analogy of a "ball in a bowl" to visualise the load-displacement, (see Figure 2.12.B) this was then used to explain his hypothesis of lower back pain. The load-displacement curve was defined as the extension part in the bowl where the ball moved around the axis of displacement. The neutral zone was reflected in the base of the bowl, where the ball can move easily. In the hypothesis, the painful spine has a greater neutral zone (NZ). A stabilised spine demands a decreased NZ which is pain-free. A greater effort will be demanded if the ball moves toward the steeper sides of the bowl. The situation is similar to spinal motion in the outer region beyond the neutral zone (Panjabi, 2003).

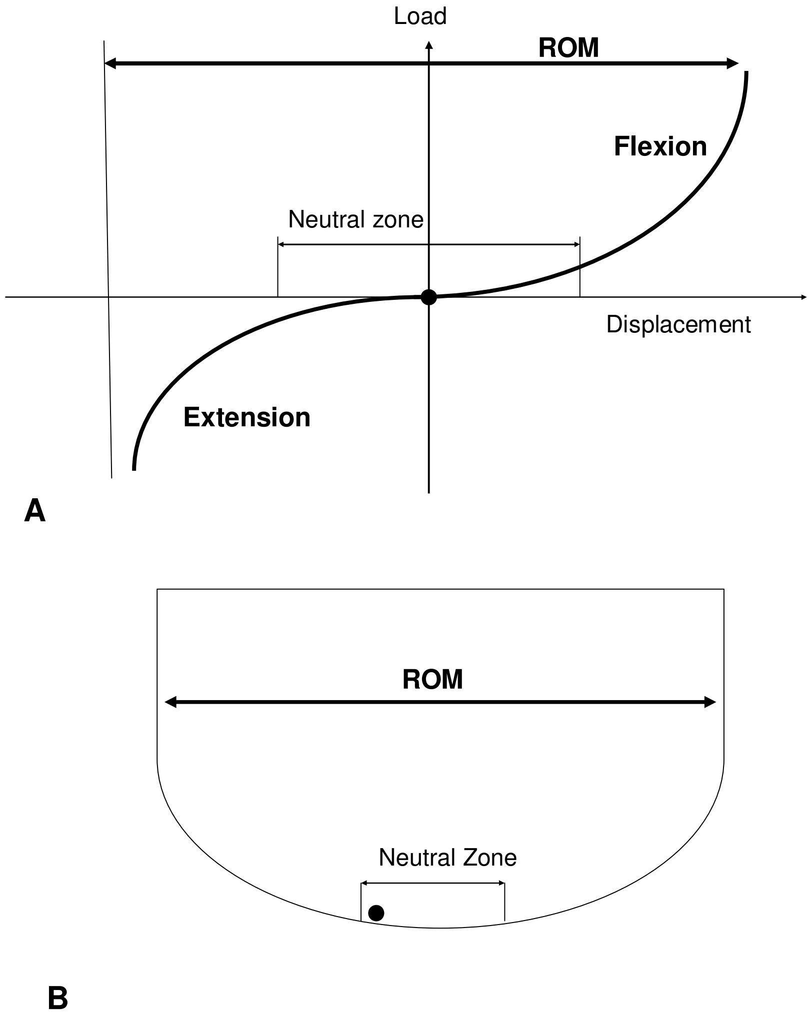



**Fig. 2.12 Load–displacement curve. (A) Spine segment subjected to flexion and extension loads exhibits a nonlinear load displacement curve, indicating a changing relationship between the applied load and the displacements produced. Addition of neutral zone (NZ) parameters, representing laxity of the spinal segment around the neutral position, to the range of motion (ROM) parameter better describes the nonlinearity of the spinal characteristics. (B) A ball in a bowl is a graphic analogy of the load–displacement curve.**

In the studies by (Panjabi et al., 1989) and (Abumi et al., 1990) they both found that the neutral zone and physiological range were increased when the spine was injured.

Furthermore, Oxland and Panjabi (1992) reported that the neutral zone was observed to increase more than the physiological range, in a study subjecting porcine cervical spines to high-speed trauma. A normal person has a normal neutral zone and range of motion. When an injury happens, abnormal motion may occur with an increase in the neutral zone and range of motion. The reaction of the spinal stabilisation system is to actively decrease the neutral zone through muscular actions, or perhaps adaptive stiffening of the spinal column which occurs over time i.e. formation of osteophytes (Panjabi, 2003). These findings led to a new definition of clinical instability, as the stabilising system cannot maintain the intervertebral neutral zone (Richardson et al., 2004, p.26.). Nowadays this concept is used widely in physiotherapy to treat chronic lumbopelvic pain disorders (O'Sullivan, 2005, O'Sullivan, 2006,).

However, the theory (ball on bowl) was only based on passive control by muscles and skeletal systems, and does not provide the whole picture of spinal stabilisation by also considering motor control. To fill the gap of input control, Reeves and Cholewicki (2010) further expanded the viewpoints of the spinal system using the task of stick balancing to explain some forms of control to maintain spinal stability (Figure 2.13). The two scenarios of the stick balance system are (1) to position the stick on the left hand with zero velocity, and (2) to place in the same starting position with the hand moving to the right. In the first situation, the hand will be moved to the left to bring the centre of mass of the stick. In the second case, the direction of hand movement is unclear, as different velocities may result in different results. They point out that the controller (central nervous system) may use both position and velocity-feedback to stabilise the stick, so the position control similar to the passive control theory is not enough to describe the stick balancing system. This concept is based on the dynamic interaction of three systems to maintain spinal stability, allow load bearing and conduct controlled movement with prevention of injury and pain. In this current configuration, assumed perturbations were applied to the spine to determine spinal stability. Muscles were found to stiffen the spine to maintain the equilibrium (Bergmark, 1989, Gardner-Morse et al., 1995, Cholewicki and McGill, 1996, Granata and Marras, 2000). If the theory of Bergmark (1989) was to be applied to the stick-balancing example, the system would be unstable because the Bergmark system fails to capture the dynamics of the task and may lead to incorrect prediction of spinal behaviour. It is clear that individual systems can only explain partial behaviours of spinal mechanisms under specific conditions and cannot explain the performance in a more complex situation, which would be more relevant to reality.

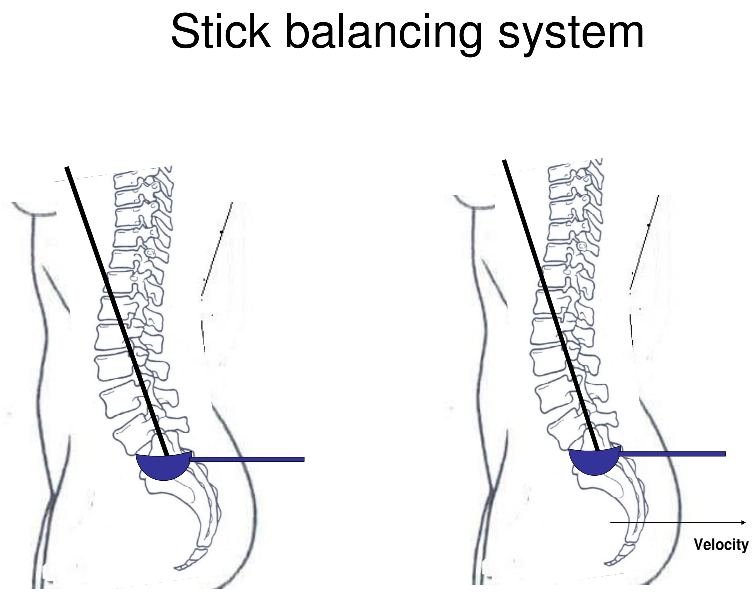



**Figure 2.13. Stick balancing system. (A) Stick is positioned on the left hand (B) Stick is placed in the same position but moving hand to the left. Modified from 'The source of Medical Illustration'.**

The current biomechanical model for spinal stabilisation is based on a muscle system to increase trunk muscle stiffness and maintain static spinal stability (Bergmark, 1989) but it fails to explain the dynamic status of the spine. It should also be associated with the central nervous system which is described in Section 2.3. A question arises regarding the controller in the "stick balancing system". Which factors may affect the responses of the controller to capture the stick back? The shape of the spine should also be considered due to the fact that it may affect the performance of spinal function. The shape of the spinal curvature may be affected by the surrounding soft tissues and further influence the physiological range of motion. These alterations may change the recruitment of muscles related to stabilisation and may further be reflected in the morphology of muscles.

### 2.3. Motor Control system

The neural system is viewed as the control centre for modulating the information from sensory input and then to recruit appropriate muscles to conduct the movements. Changes in motor control function have been reported in low back pain (LBP) (Hodges and Richardson, 1999) and it is proposed in the present study that they may also be found in coccydynia.

### *2.3.1. The control of movement*

Since the 1960s, the central nervous system (CNS) has been known to prepare for predictable challenges in posture by recruiting muscles of the lower limb and trunk prior to the initiation of prime limb movement (Hodges et al., 1999). This information can be obtained by investigating muscle recruitment patterns during a task. When a change is presented in body configuration due to an anticipatory movement, the preceding activation of trunk muscles occurs prior to the initiation of limb movement in order to maintain the optimal stability of the trunk. This is achieved by opposing the generation of the reactive force and the displacement of the centre of mass. The CNS pre-programs this strategy, for example, muscle recruitment patterns in the trunk, in order to maintain trunk stability. This is called “feedforward”, because it occurs in advance of the onset of activity of the muscles responsible for limb movement (Hodges and Richardson, 1996, Hodges et al., 1999, Hodges and Richardson, 1999a, Hodges and Richardson, 1999b).

Motor control relates to the muscle activation pattern that involves timing of specific muscle action and inaction during loading. The theory of a pain-adaptive model is more suitable for the interpretation of clinical findings, and will be used in this present study. In the lumbopelvic region, pelvic stability requires coordinated muscle action of the lumbopelvic local system without restrained postures or injuries (Lee, 2004). Perhaps coccydynia causes some alteration in specific sequencing of muscle activation leading to inefficient movement during functional tasks. The present study aims to explore this suggestion.

### *2.3.2. Normal recruitment in the trunk muscles during voluntary movement*

Several studies focused on how the CNS controls the recruitment pattern during a specific task. For example, when a shoulder was flexed, the centre of mass was displaced anteriorly due to the forward displaced arm, and this resulted in reactive forces acting backward and downwards, all imposing on the body. Early activation of rectus abdominis (RA), erector spinae (ES) and TrA, were found (Hodges and Richardson, 1997). The activation of TrA was consistently reported as the first response during different tasks such as “rapid unilateral arm and leg movements”. This suggests that TrA consistently contributes to the preparation of the spine for the perturbation, resulting from the reactive forces on the spine under the control of the CNS. The recruitment of the diaphragm was also found to occur prior to the onset of shoulder movement, and supported the hypothesis of mechanical efficiency of the feedforward activation of the diaphragm (Hodges et al., 1999).

During a rapid upper limb movement, the feedforward mechanism increased intra-abdominal pressure (IAP) and muscle activation of the deep abdominal muscles (i.e. TrA) was shown to work together to control the trunk. The timing and magnitude of TrA activity did not vary between movement directions. This finding may be explained by the TrA not being involved in contributing to the direction of the specific preparatory trunk movement but that it may contribute to controlling the lumbar stability by increasing tension in the thoracolumbar fascia or by increasing IAP (Hodges et al., 1999). These findings offered the evidence that the CNS deals with the anticipatory perturbation to spinal stability by preceding preparatory motion of the spine to “dampen” the force rather than simply making the trunk rigid.

In people with no history of LBP, the contraction of ES, TrA, and IO, preceded the prime mover of the limb during the anticipatory movement of the limb (Hodges and Richardson, 1996, Hodges and Richardson, 1999a, Hodges and Richardson, 1999b). Hodges and Richardson, (1999) performed a study to investigate the recruitment patterns of trunk muscles in response to the upper limb movements at different speeds, with and without LBP. The definitions of three different speeds were fast, intermediate and slow. They found that people without LBP demonstrated early activation of TrA and IO in the majority of trials, at both fast and intermediate speeds. The reaction forces were positively associated with the velocity of limb movement and muscle recruitment at fast and intermediate speed. There was no difference in muscle activities of the abdominal muscles between groups for slow movement, but a difference of muscle activities of ES was shown in the majority of trials at the slow speed of limb movement (Hodges and Richardson, 1999a). The muscle recruitment patterns for the responses to protect the spine are consistent with the “feedforward” mechanism to initiate ES, which then activated abdominal muscles depending on the magnitude of reactive forces. It can be assumed that the passive spinal supporting structure is sufficient to maintain stability when the perturbing force is small.

### *2.3.3. Abnormal recruitment in the trunk muscles during voluntary movement*

Because of the inherent instability of the spine, altered recruitment of the trunk muscles, in response to a spinal disturbance and during the performance of voluntary tasks, may indicate inadequate protection of the spine from injuries. Hodges and Richardson (1996, 1999) found no proceeding or absent abdominal activity at both fast and intermediate speeds in people with LBP (Hodges and Richardson, 1996, Hodges and Richardson, 1999a). Many studies reported over activity of superficial muscle systems in patients with LBP (Hodges and Richardson, 1996, Hodges and Richardson, 1999a, Hodges, 2001). Many studies revealed different findings between normal subjects and patients. A decrease in co-contraction of the ES with the abdominal muscle during a sit-up manoeuvre was reported in LBP compared with normal subjects (Soderberg and Barr, 1983). (O'Sullivan et al., 1998) reported a reduced ratio of IO activity in comparison with that of RA during the performance of a voluntary abdominal muscle contraction. ES relaxation was absent at the end of range of trunk flexion in standing (Kaigle et al., 1998), and a loss of the biphasic pattern of ES recruitment when catching an unexpected load anteriorly in the hands (Kin et al, 1988).

The TrA was reported to have delayed activation with movement of the leg and an increased threshold for TrA activation was found in people with back pain. Hodges and Richardson (1999) further indicated that TrA was no longer activated independently of the superficial trunk muscles. Also, Hodges (2001) reported that the reaction time of TrA was not simply delayed but varied with the complexity of the task. In contrast, the control group showed a constant reaction time of TrA activation, despite the movement reaction time varying.

Studies reviewed in this section have demonstrated altered recruitment of the deepest muscles, i.e. TrA and multifidus, in lumbopelvic dysfunction and the feedforward mechanism was delayed or lacking in LBP. These alterations in neuromuscular function are proposed to occur in coccydynia, which was explored in the present PhD study.

### *2.3.4. Pain model: pain adaption and pain-spasm- pain model*

There are two main theories proposed for the interpretation on how pain affects motor control: "*Pain-spasm-pain model"* and *"Pain-adaptive model".* Travell et al, (1942) propagated a model called the pain-spasm-pain model. This is when pain occurs due to hyperactive muscle activity, referred to as spasm, which in turn causes pain. The other theory proposed by Lund et al, (1991) considered the clinical findings of muscle activity in pain syndromes, and predicted the patterns of muscle activation to be reduced in agonist and increased in antagonist muscles. As shown in Figure 2.14, the possible mechanisms of pain affecting motor control are multiple, therefore, both models can interpret part of the mechanisms supported by existing studies but neither model cant capture the whole picture. A mutual finding of the two theories is that pain results in the alteration of motor control. Hodges and Moseley (2003) suggested that one should use a pain-adaptive model to interpret the mechanism of LBP, because the CNS uses movements to optimise spinal stability while a perturbation occurs, and antagonist muscles co-contract to keep the spine upright. In the present study, a pain-adaptive model is used to investigate coccydynia.

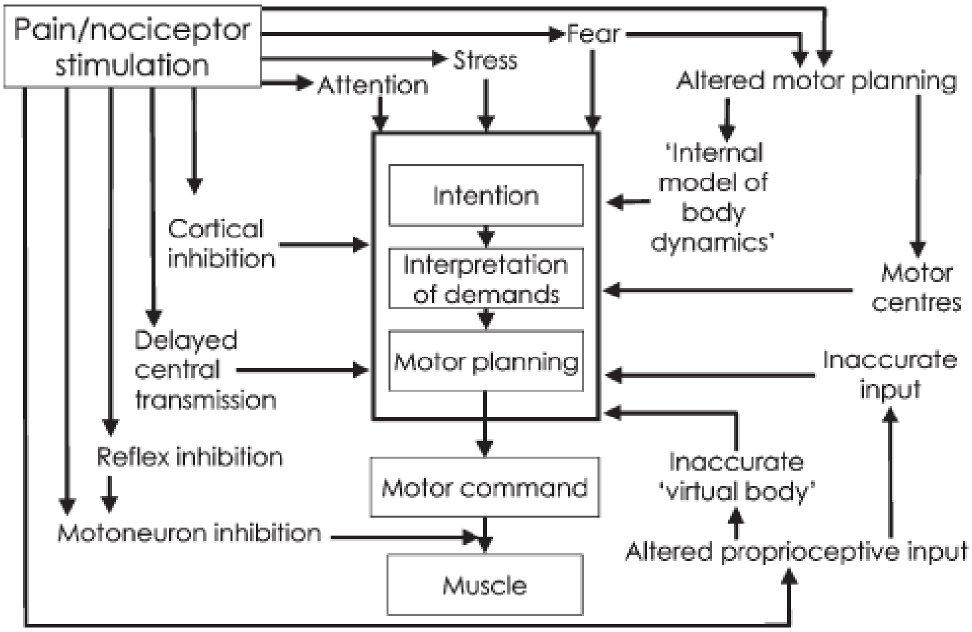



**Figure 2.14. Possible mechanisms for pain to affect motor control. Multiple mechanisms have been proposed. It is unlikely that the simple inhibitory pathways (left) can mediate the complex changes in motor control of the trunk muscles. The most likely candidates are changes in motor planning via a direct influence of pain on the motor centres, fear-avoidance, or due to changes in the sensory system (adapted from Moseley & Hodges 2003, with permission).**

## 2.4. The alignment theory in the lumbopelvic region

The alignment theory in the lower extremity is based on clinical observation and experience of assessing individual body types. The observations can be basically divided into pelvic position, femoral position, knee position, ankle position and foot position. This information commonly forms the topic of continued professional development courses for physiotherapists and shared experiences between clinicians but is rarely reported in studies, due to difficulty in quantifying the findings and too much bias being involved.

Postural asymmetry is not essential for orthopaedic dysfunction but is found in many chronic patients. Optimal posture in standing is illustrated in Figure 2.15 and is viewed as the reference for comparison with actual posture. In the sagittal plane, a vertical line should pass through the external auditory meatus, the bodies of the cervical vertebrae, the glenohumeral joint, slightly anterior to the bodies of thoracic and lumbar vertebrae, slightly posterior the hip joint and slightly anterior to the talocrural joint. The spinal curve should be maintained in the neutral position of lumbar lordosis and thoracic kyphosis.

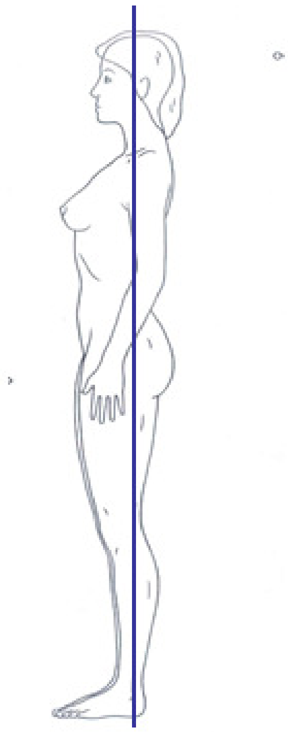


**Figure 2.15. Optimal posture in standing. Modified from 'The source of Medical Illustration'.**

As shown in Figure 2.16., there are three different pelvic positions termed the neutral, forward and backward pelvis. In comparison with the forward and backward pelvis, the hip flexors and the hamstrings which co-work to maintain the pelvic positions are assumed to be tight in the hip flexor and stretched in the hamstrings in a forward pelvis, and vice versa.

The femoral position is observed to classify according to internal rotation and external rotation of the femoral neck in reference to the acetabulum, which causes the pelvis to rotate upward and backward or downward and forward. Internal rotation of the femoral head leads to valgus of the femoral shaft, and external rotation of the femoral head leads to varus of femoral shaft (See Figure 2.17)(Ganz, 2008).

The pronated foot and supinated foot may be observed in the positioning of the feet and are relevant to the ankle positions. The feature of a pronated foot is a flat arch, which is commonly accompanied with a valgus subtalar joint, internally rotated lower extremity and a shortened lower extremity. As for the supinated foot, a high arch is found, with a varus subtalar joint, an externally rotated lower extremity and a lengthened extremity(Sulean, 2010, Dalton, 2008).

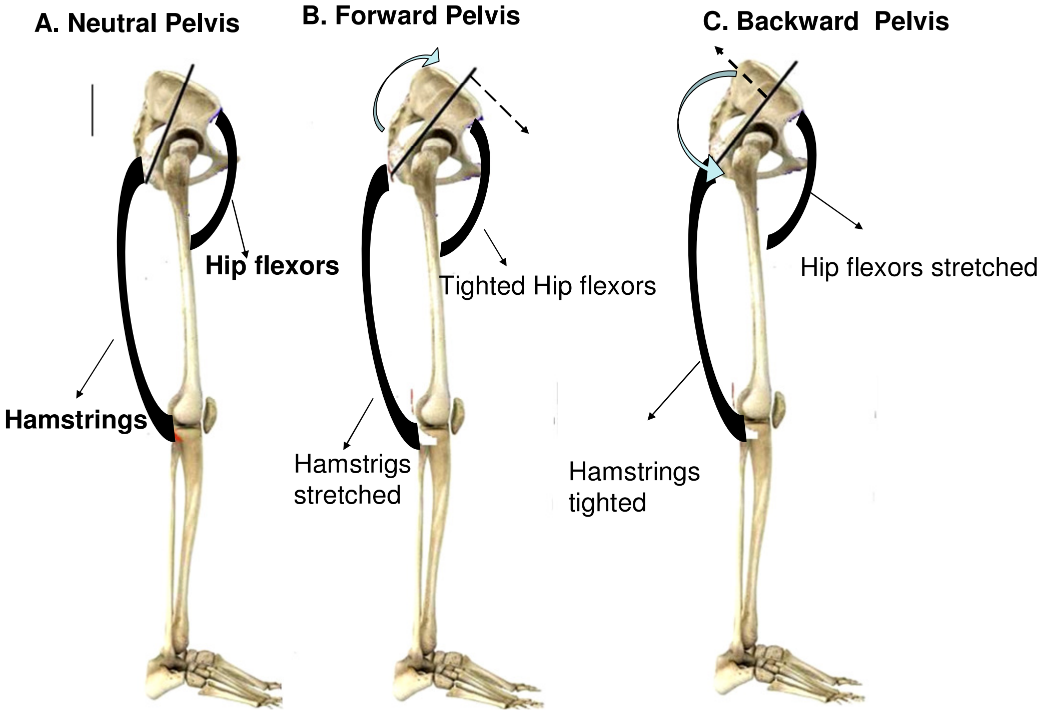



**Figure 2.16. The three different types of pelvic positions.**

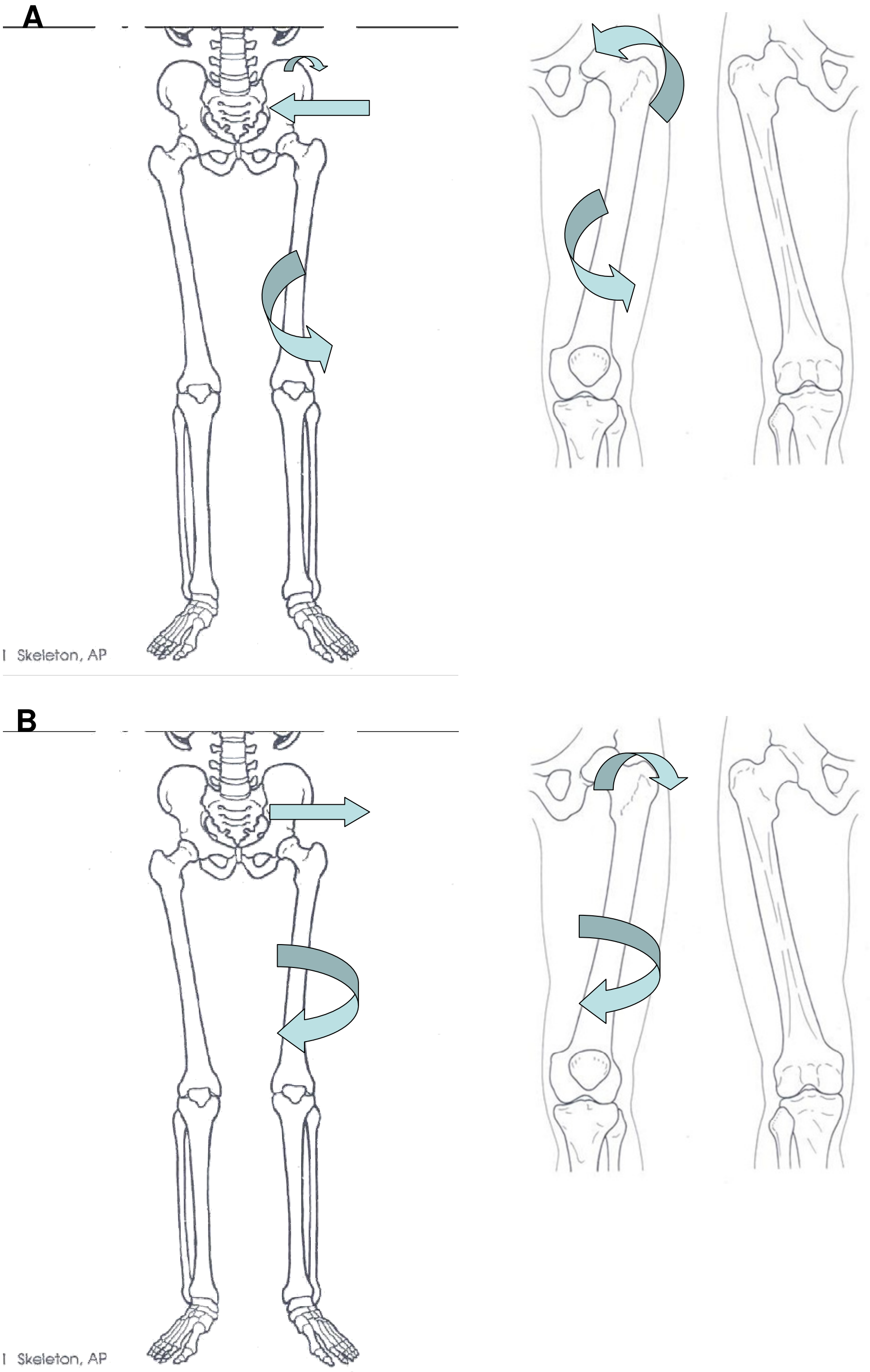
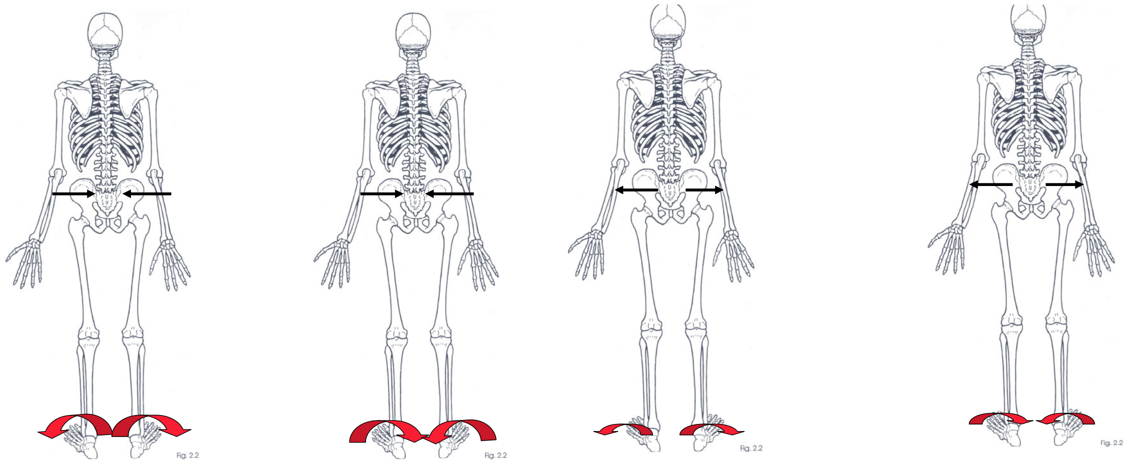



**Figure 2.17. (A) Internal rotation of the femoral head leads to an upward and backward facing pelvis, closing the ilia and a valgus femoral shaft. (B) External rotation of the femoral head leads to a downward and forward facing pelvis, separating the ilia and a varus femoral shaft. Modified from 'The source of Medical Illustration'.**

Although the lower extremity joint positions could be mutually affected by each other, no absolute correlations between pelvic and foot positions were reported in a well-designed study. As shown in figure 2.18., it is possible to show the internally rotated femoral shaft with a supinated/or pronated foot.



A. Valgus femoral shaft with supinated foot

B. Valgus femoral shaft with pronated foot

C. Varus femoral shaft with supinated foot

D. Varus femoral shaft with pronated foot

**Figure 2.18. The different combinations for foot positions. Modified from 'The source of Medical Illustration'.**

The asymmetrical positions of these four classifications are possible to present individually. The joints could affect each other, in particular during the spinal loading activity. According to the findings based on the alignment theory, the principle of intervention is to reposition these joints. There are several clinical studies which used this concept to manage dysfunction, or to develop the tools for assisting the clinicians to intervene, e.g. (Khamis and Yizhar, 2007, Endo et al., 2010).

Based on the biomechanics of the lumbopelvic region, pain symptoms are supposed to be improved by reducing the abnormal laxity of the sacroiliac joint (SIJ) and the lumbar spine by adjusting the mal-alignment of the SIJ, whilst increasing the stability of the lumbar spine. According to Mens et al, (2006), a pelvic belt positioned just caudal to the anterior superior iliac spines (ASIS) demonstrated better stability of the SIJ than at the level of the pubic symphysis (Mens et al., 2006a). The findings of this study may indicate the actual impairments of the neuromuscular system and hence support the application of a pelvic belt. Therefore, a pelvic belt was selected for using in case studies in the present PhD, in order to examine its effect on coccydynia.

### 2.5. Conclusion

This chapter has introduced several biomechanical models including static and dynamic models. Coccydynia could be viewed as a type of LBP but few studies have investigated this dysfunction. Coccydynia should show similar changes in neuromuscular function to LBP. The techniques for detecting the differences in neuromuscular functions are introduced in the next chapter.

## 2.6. Research questions and hypotheses in the current thesis

### *2.6.1. Research questions*

a. Do any differences exist between controls and patients with coccydynia in the morphological changes that occur on ultrasound images of the lumbopelvic muscles when an active straight leg raise is performed from a resting position?

b. Does the IO muscle become activated before a functional task in healthy controls?

c. Does latency of the IO muscle EMG signal during a task differ between controls and patients with coccydynia?

d. Does the in change in the lumbopelvic angle during the one leg standing task differ between controls and patients with coccydynia?

e. Are there any improvements in symptoms in patients with coccydynia after a six week intervention of a pelvic belt?

### *2.6.2. Research hypotheses*

a. Patients with coccydynia will demonstrate thinner TrA muscle size at rest than in healthy age-matched controls.

b. Patients with coccydynia will demonstrate less thickness changes in TrA muscles and greater thickness changes in IO and EO during a functional task than in controls.

c. Patients with coccydynia will demonstrate less change in lumbopelvic angles than controls during a functional task to maintain their balance.

d. Patients with coccydynia will have a longer latency of IO muscle firing in comparison with controls.

# Chapter 3: Overview and selection of techniques for examining neuromuscular performance

Potential aspects of dysfunction and techniques that could be used to study coccydynia are vast. This chapter reviews some aspects of the techniques that are relevant to physiotherapy and those selected for use in the present research are discussed in relation to other established techniques. The advantages and shortcomings of each technique are discussed. The main concerns when studying differences between normal subjects and people with dysfunction are based on consideration of biomechanics, joint kinematics (bony structures), function of soft tissues (such as muscle strength) and motor control.

An important muscle function of interest is strength, which can be assessed by manual muscle testing (MMT) and dynamometry under specific conditions, i.e. isometric and isokinetic(Gruther et al., 2009). Dynamometers are used as a gold standard for muscle strength measurement but some instruments are designed for specific areas of the body, such as the lower limbs or hands, so cannot be generalised for applying to all regions (Hagen et al., 1993). Coccydynia can be viewed as a type of low back pain (LBP), so function of the trunk muscles need to be examined.

Valid and reliable trunk muscle strength measurements have been made using dynamometers such as the Biodex and Cybex systems (Madsen, 1996, Gruther et al., 2009). Gruther et al (2009) examined the accuracy and reliability of trunk muscle strength in patients with chronic LBP. They reported a high learning effect in line with previous studies (Hutten and Hermens, 1997), so it would be reasonable to use the second test as the baseline value. However, it is not clinically feasible for baseline data to be collected on two different days. Learning effects therefore influence reliability and restrict the use of measurements for clinical assessment. The value of trunk muscle strength as an outcome measure in studies of LBP is inconclusive, as variable findings have been found regarding whether or not differences can be demonstrated between healthy controls and patients with LBP. For example, (Keller et al., 2001) found no differences but Gruther et al. (2009) reported differences. Possible reasons for the different findings could be that the studies used different tasks and it is clear that discrepancies occur between studies. Manual muscle testing (MMT) is a subjective assessment tool and is commonly used for documenting impairments of muscle strength (Barbanol, 2000). Although it is clinically useful, it is not objective and thus not adequate for research purposes, as it relies on the perception and experience of the investigator. The grading system of MMT is based on muscle performance according to the degree of manual resistance applied by examiner. The muscle group is evaluated as being subjectively “weak” or “strong” on a 5-point scale, with 5 being the strongest (Barbanol, 2000).

Several factors can affect the reliability of strength measurements and need to be considered, as summarised in a review by (Cuthbert and Goodheart, 2007):

- Proper positioning so the test muscle is the prime mover
- Adequate stabilisation of regional anatomy
- Observation of the manner in which the patient or subject assumes and maintains the test position
- Observation of the manner in which the patient or subject performs the test
- Consistent timing, pressure and positioning
- Avoidance of preconceived impressions regarding the test outcome
- Non-painful contacts and non-painful execution of the test
- Contraindications due to age, debilitative disease, acute pain and local pathology of inflammation

Assessment of back muscle strength is not widely used, possibly as it relies on maximal effort, which can be limited by pain, making measurements unreliable. Also, it is not possible to isolate specific muscles of the abdomen or back to test their strength.  For the above reasons, muscle strength was not tested in the present study.

Muscle size and architecture, which can be measured by imaging techniques, may serve as indirect measures of muscle strength. Several imaging techniques are available for measuring muscle morphology and are discussed in Section 3.1. Measurement of joint kinematics is mainly classified as being linear or 3-dimensional. Possible techniques vary from the simplest and most convenient manual goniometry to a more complex optical tracking system, such as the Vicon motion analysis system (see Section 3.2). Measurement of spinal kinematics is always a challenge, due to the unique shape and being covered by soft tissues. Also, spinal motions integrate several joints working together, and are difficult to analyse separately.

As explained in Chapter 2 (Section 2.3), the feedforward mechanism in relation to muscle contractions was found in normal subjects but was delayed or absent in patients with LBP. The delayed onset of muscle during functional tasks indicates a deficiency in central nervous system (CNS) modulation, indicating dysfunction. Electromyography (EMG) is a technique used for assessing muscle activation and motor control, and is discussed in Section 3.3.

To investigate dysfunction associated with coccydynia, altered neuromuscular characteristics are anticipated to be present in muscle morphology and muscle activation strategies in the lumbopelvic region, since these abnormalities occur in back pain (Hodges and Richardson, 1996, Hodges and Richardson, 1999a). The present study used various techniques to: (1) measure the static and dynamic thickness of muscles in the lumbopelvic region; (2) measure the angular changes in lumbar and pelvic positions; (3) measure muscle activation timing of onset in the lumbopelvic region during tasks. Findings from studies using these different techniques could offer scientific and clinical information about the neuromuscular performance in patients with coccydynia.

### 3.1. Techniques for measuring muscle morphology

Muscle characteristics and functions are expected to be altered in patients and objective assessments are necessary to support the concept. There are many methods used to examine muscle morphology, whether in static or dynamic tasks, which can be used for interpretation of the pathological mechanism. This section briefly introduces the techniques for assessing muscle morphology and summarises the features of each one in Table 3.1. The rationale for the techniques selected for the present study is then presented.

#### *3.1.1. Magnetic Resonance Imaging (MRI) and Computed Tomography (CT)*

The gold standard technique to measure muscle size is magnetic resonance imaging (MRI). This is primarily a non-invasive medical imaging technique to visualise the detail of internal structures without the risks of exposure associated with ionizing radiation (Squire and Novelline, 1997). This technique can provide the detailed structure of soft tissues, such as muscles in a static situation. However, it is difficult to access MRI for research purposes due to the large clinical demand and the considerable cost. A computed tomography (CT) scanner is also an imaging technique commonly used clinically. This technique uses X-rays to acquire images of internal structures. However, obtaining an image has risks of exposing the person to ionizing radiation (Herman, 2009). Both MRI and CT scanners generate multiple two-dimensional cross-sections of tissues and three-dimensional reconstructions.

#### 3.1.2. Ultrasound imaging

Ultrasound imaging is a more portable, relatively inexpensive non-invasive technique for imaging muscle (Whittaker et al., 2007). The local muscle system of the trunk, the paraspinal lumbar multifidus and the transversus abdominis (TrA), is located deep in the tissues and plays an important role in stabilising the trunk (Hodges, 1999), as discussed in Chapter 2. Ultrasound imaging has been introduced in rehabilitation in recent years and offers a direct way to observe and assess the deep muscles, in particular the abdominal muscles and paraspinal multifidus. The terminology of rehabilitation ultrasound imaging (RUSI), was proposed and achieved agreement in an international symposium in 2006 (Teyhen, 2006). At the symposium, the role of RUSI was defined and several possible applications were discussed.

At the symposium, topics discussed included:

- *Role of RUSI in rehabilitation*
- *Professional, political, ethical, and legal issues*
- *Clinical applications*
- *RUSI of the pelvic floor muscles*
- *RUSI of the lateral abdominal muscles*
- *RUSI of the posterior paraspinal muscles*
- *RUSI of other muscles*
- *Technology and techniques* *(Teyhen, 2006)*

Generally, the technique of RUSI demonstrates the potential to assist clinicians to evaluate and treat patients with deficient function of motor control based on real-time visual feedback. Ultrasound has been verified to provide a non-invasive method to measure the morphology of muscles to document changes in muscle thickness. RUSI also can be used to evaluate the function of pelvic floor muscles (PFM) via observing the bladder shape in transverse and sagittal views (Whittaker et al., 2007b, Whittaker, 2007). Due to no bony markers being available for reference, RUSI cannot provide a way to measure muscle morphology of PFMs. However, real-time ultrasound imaging could provide a way to observe the behaviour of the PFMs during contractions. RUSI also can be used for assessing muscles during the acute stage. Hides et al (1994) investigated the size of lumbar multifidus using ultrasound imaging 26 patients with acute low back pain (LBP), aged 17-46 years, and 51 normal subjects, aged 19-32 years). The cross-section area (CSA) of multifidus between L2-5 was measured in all patients and CSA of multifidus at L4 was measured in all normal subjects (Hides et al., 1994). This study had sufficient numbers of subjects in each group to demonstrate significant differences between them. The findings reported marked asymmetry of multifidus cross-sectional area (CSA) in patients at the spinal level of the pain and on the same side as symptoms. Smaller and rounder muscles were found on the symptomatic side, which may have indicated muscle wasting and spasm. This study provided evidence that RUSI could document changes in muscle morphology objectively in people with acute LBP.

The validity of RUSI measurement on abdominal wall muscles at rest and during dynamic trials has been demonstrated using MRI and needle electromyography (EMG), as discussed below (see Section 4.10 for an overview of validity).

*3.1.2.i Validation of ultrasound imaging versus magnetic resonance imaging (MRI)*

MRI is undoubtedly the gold standard for the assessment of muscle morphology, so it can be used to assess the validity of measuring the size of muscle (i.e. morphometry) and changes with ultrasound imaging. Hides et al, (2006) carried out a study to evaluate thickness changes in the lateral abdominal muscles during the change from rest to contraction with the active drawing-in manoeuvre (ADIM) using MRI and ultrasound imaging. High correlation coefficients for muscle thickness measurements in both states were reported (>0.78) and high similarity to MRI findings in the mean scores was reported in this study (Hides et al., 2006). Therefore, ultrasound imaging can be proposed to be an adequate assessment tool for assessing muscle morphometry in the abdominal muscles. The findings were consistent with the findings of Richardson et al. (2004b) using the same task.

Hides et al, (1995) conducted another study to compare the evaluation of CSA of lumbar multifidus with MRI and ultrasound imaging. They found no significant difference in morphological measurements between the two modalities (Hides et al., 1995). Similar findings were reported for cervical multifidus at C4-C6 levels by Lee et al. (2007), who investigated muscle thickness, area and shape ratio in 10 asymptomatic Taiwanese adults. They found no significance between MRI and ultrasound imaging. These studies indicate that RUSI can be used to evaluate the muscle characteristics but the investigation of different muscles and in different situations, needs to be studied further.

*3.1.2.ii Validation of ultrasound imaging versus EMG*

Changes in muscle thickness from the resting state to a contracted state are considered to reflect changes in muscle activity level, although the linearity of the relationship is controversial (Teyhen et al., 2007, Teyhen et al., 2008). Existing studies correlated muscle morphology changes and amplitude of EMG activity in TrA and lumbar multifidus. Hodges et al, (2003) found a curvilinear relationship between muscle thickness changes and muscle activity for TrA and IO, with maximal muscle thickness being reached at approximately 30% of maximum voluntary isometric contraction (MVIC) (Hodges et al., 2003). McMeeken et al, (2004) demonstrated a more linear relationship in TrA, with muscle thickness increases occurring up to 80% of MVIC (McMeeken et al., 2004). John and Beith, (2007) recruited 24 subjects to correlate two different tasks of isometric trunk rotation and drawing in the lower abdomen at different contraction levels and electrical muscle activity of the external oblique (EO) muscles. The majority of subjects demonstrated a positive significant relationship between muscle thickness changes and EMG activity of EO during isometric trunk rotation, although a significantly different performance was found between subjects (John and Beith, 2007). It was reported that there was a linear relationship between the thickness change on the lumbar multifidus and EMG activity across a narrow span of activation levels (19-34%) (Kiesel et al., 2007).

From the above studies, the relationship between muscle thickness change and amplitude of EMG was a positive correlation, but there was no conclusion as to whether a linear or curvilinear relationship relation was found. Because small sample sizes were used in the studies of (Hodges et al., 2003) and (McMeeken et al., 2004), n=3 and n=13 respectively, the relationship between muscle thickness and EMG remains inconclusive. For future work, a large sample size would be needed, in order to determine the relationships. The details regarding how to perform MVIC were closely linked to the normalisation of different contraction levels and should be described accurately (Hodges et al., 2003, McMeeken et al., 2004).

#### *3.1.2.iii Reliability of ultrasound imaging of muscle*

It is important to establish the reliability of clinical assessment tools by evaluating the degree of variance over repeated measurements (see Section 4.9). Use of RUSI to study muscles has included the abdominal muscles (Coldron et al., 2007, Rankin et al., 2006, Whittaker, 2007, Costa et al., 2009b, Teyhen et al., 2007, Teyhen et al., 2005, Costa et al., 2009a, Jhu et al., 2010), lumbar multifidus (Van et al., 2006a, Hides et al., 1992, Hides et al., 1994, Coldron et al., 2003, Stokes et al., 2005, Van et al., 2006b, Whittaker, 2007, Stokes et al., 2007), posterior neck muscles (Rankin et al., 2005, Stokes et al., 2007) and pelvic floor muscles (Whittaker et al., 2007b, Whittaker, 2007). A mutual characteristic of these deep muscles is that, it is not possible to make direct force measurements of individual muscles. In addition, size measurements by ultrasound imaging are not influenced by pain or motivation and can be an objective tool of indirect measurement of strength. Although, excellent intra-class correlation coefficient (ICC) values were reported in these studies, the repeatability of measurements on different manoeuvres at different contraction levels, in different patients groups, still needs to be identified further.

There are many methodological issues in the application of RUSI. The accuracy of assessment is influenced by many factors such as the investigator's skill and experience, patient's positioning, the measurement sites, the definition of muscle boundaries, probe placement and the applied orientation and downward pressure into the soft tissues (Whittaker et al., 2007a, Whittaker et al., 2009). To increase the reliability of ultrasound imaging, the procedural factors mentioned above by Whittaker et al. (2007a) must be controlled well, to result in good repeatability. Consistent findings were found within the existing studies, concerning the measurement of thickness changes on same muscles, during different positions held by subjects. Bunce et al, (2002) compared the measurements of thickness changes in TrA muscles, in different positions of supine; lying, standing and walking. No significant difference among the changes of measurements in the three positions was reported (Bunce et al., 2002). Coldron et al, (2003) found that the muscle size of lumbar multifidus was not influenced by body position (i.e. prone or side lying).

The influence of different contraction levels using different transducers or modes have been examined (McMeeken et al., 2004, Ainscough-Potts et al., 2006). Ainscough-Potts et al, (2006) measured the thickness of TrA and IO in; supine lying, relaxed sitting on a chair with both feet on the ground, relaxed sitting on a gym ball with both feet on the ground, and sitting on a gym ball lifting left the foot off the floor. No significant differences between measurements of TrA at different contraction levels, using the different transducers or modes were reported (McMeeken et al., 2004).Lee et al. (2009) examined the actual and percentage of muscle thickness change of the cervical multifidus muscles at C4-C6, at different levels of isometric head extension. Acceptable between-day intra-rater coefficients of variation (CV) were between 4.6 to 11.3%. However, these two studies only represented these specific muscles, other muscles may be affected. Their findings supported ultrasound imaging as a reliable tool for measuring changes of muscle thickness on muscles over lateral abdominal wall and lumbar multifidus.

Change in length of TrA is another measurement parameter for abdominal function, which indicates lateral sliding of the muscle-fascia junction during contraction (Hides et al., 2007, Hides et al., 2009, Jhu et al., 2010). A previous study reported moderate to poor between day intra-observer reliability of TA length change during the active drawing-in manoeuvre (ADIM) (ICC-0.44), and the reported standard error of measurement (SEM) value was 1.81 mm (Hides et al., 2007). Jhu et al. (2010) provided a novel way to improve the accuracy of measurement of length change of TrA during ADIM, and investigated the correlation between changes in length and thickness. They used an echo-absorptive nylon thread placed in person along the line which indicates the muscle-fascia junction from the scan to generate an acoustic shadow on the scan to act as a reference line monitoring medial-lateral motion of the muscle-fascia junction. Their results showed improved reliability, with ICC values >0.75 and SEM values ranging between 1-1.3 mm.

Recently, Pressler et al, (2006) conducted a study to examine the error associated with the cross-sectional area (CSA) measurements of S1 multifidus obtained by a physiotherapist with limited experience. Although the subject sample cannot represent all physiotherapists, the finding was that a physiotherapist without prior expertise in ultrasonography was able to obtain reasonable reliability in results.

*3.1.2.iv The application of RUSI for assessing movement control*

Local muscles, such as lumbar multifidus, do not recover spontaneously after pain remits (Hides et al., 1996). A possible mechanism is reflex inhibition that causes weakness and sustained muscle atrophy. Altered neuromuscular performance has been demonstrated using EMG (Hungerford et al., 2003, Hodges, 2001, Hodges and Richardson, 1999a, Ferreira et al., 2004) and movement strategy during a task can be directly visualised using ultrasound imaging. TrA was observed to be activated, prior to limb movement in normal subjects (Hodges and Richardson, 1996, Hodges and Richardson, 1999b).

In an MRI study, the selective atrophy of lumbar multifidus was reported in subjects with LBP, and a decrease of girth and fatty infiltrate development were found (Hides et al., 1996). The change of muscle thickness on the painful side was less than on the non-painful side during contraction. Whether the changes of muscle thickness can be indicative of relative muscle activity levels is still to be concluded. A good correlation was reported among thickness changes of TrA and IO with a submaximal contraction levels (< 30% MVC) in Hodges's study in 2003; however, the number of subjects was limited and needed a large sample size to clarify the relationship (Hodges et al., 2003). McMeeken et al (2004) reported a good correlation between thickness changes and concentric contraction of TrA at all levels of activity.

Critchley and Coutts, (2002) reported smaller increases in thickness of TrA in chronic LBP patients while performing abdominal drawing-in manoeuvres. In asymptotic subjects with a history of LBP, smaller thickness changes of TrA were reported during loading with a low extremity task (Ferreira et al., 2004). Kiesel et al, (2007b) reported similar thickness changes in pain-free subjects. A mutual finding of studies is that smaller changes occur in muscle thickness during dynamic tasks in patients or asymptotic subjects with a history of pain than in healthy controls.

*3.1.2 v Ultrasonography by physiotherapists*

Ultrasound is used by physicians as a diagnostic imaging modality and also as "interventional ultrasound" or "invasive ultrasound" that serves, assists and guides procedures during examination or surgeries (Machi and Staren, 2005). Ultrasound is not only used by physicians but also can be used by physiotherapists (Stokes et al., 1997, Whittaker et al., 2007a). Ultrasonography by rehabilitation professionals is not used diagnostically and is not a stand-alone assessment or treatment tool, but is incorporated alongside existing clinical skills. The interest from rehabilitation professionals in ultrasound imaging is primarily for viewing both static and dynamic muscle performances to define neuromuscular control of normal and specific alteration underlying dysfunction. These findings are foundational to training programmes, for assessment and treatment of neuromuscular control. As used by therapists, it is termed rehabilitative ultrasound imaging or RUSI (Teyhen, 2006). In general, RUSI provides a relatively low-cost and non-invasive way to examine the muscles, but the sensitivity for detecting muscle changes as an outcome measurement in an intervention study has still to be determined.

In comparison with MRI and CT, RUSI is a low-cost and safe technique which is applicable for clinical use. After considering the features of RUSI, it was judged to be an appropriate technique to use in the present study.

**Table 3.1. Imaging techniques for measurement of muscle morphology**

| **Magnetic resonance imaging (MRI)** | |
|---|---|
| Advantages | Disadvantages |
| • Characterise and discriminate among tissues in many different planes, not only limited in a 2-dimensional plane<br>• Non-invasive<br>• No exposure to ionising radiation, so low risk | • Expensive<br>• May limited by patients' body sizes<br>• Patients with claustrophobia (fearing of staying in the small chamber) may not be eligible to examine<br>• Patients with pacemakers and certain ferromagnetic appliances cannot be studied<br>• Static measurements only |
| **Computed tomography (CT)** | |
| Advantages | Disadvantages |
| • Characterise and discriminate among tissues in many different planes, not only limited in a 2-dimensional plane<br>• Non-invasive | • Expensive<br>• Static measurements only<br>• Moderate to high radiation |
| **Ultrasound Imaging** | |
| Advantages | Disadvantages |
| • Low-cost and low risk<br>• Non-invasive and high acceptability by patients<br>• Directly detect the deepest muscles<br>• Real-time investigation of muscle activity<br>• Acceptable validation with MRI in the multifidus, abdominal muscles and pelvic floor muscles<br>• Visual feedback of muscle contraction strategies for patients and clinicians<br>• High reliability of muscle thickness measurements in static and dynamic status<br>• an easy to learn technique with appropriate training | • Low sensitivity for detecting muscle performance in clinical situations is not clear<br>• The resolution of scans could affect the accuracy of measurements<br>• The limitation for the observation of pelvic floor muscles exists<br>• Different movement strategies are reported, but cannot be divided into different groups for further investigation due to the limited sample sizes<br>• The validation against EMG is still unclear. |

## 3.2. Techniques for spinal motion measurement

Functional performance is presented through the integration of muscle structures, bony structures and the central nervous system. In patients with dysfunction in the lumbopelvic region, the equilibrium of the spine is supposed to be achieved by compensatory strategies which may lead to altered neuromuscular performance. As the theory stated in section 2.2.4 in Chapter 2, spinal performance in the presence of dysfunction could be either unstable or rigid to achieve the optimal equilibrium. Human kinematics aim to assess the movement of bony structures rather than the general performance of integration by bone, soft tissues and motor control. The techniques used for motion assessments include invasive and non-invasive approaches (Lundberg, 1996). The principle of invasive techniques is to use bone pins, which may cause discomfort and thus impair motion performance. Only non-invasive techniques are therefore reviewed here, as they were the only type used in the present study, due to ethical considerations and participant acceptability. The precision and accuracy of measuring joint kinematics varies with different techniques and also for different parts of the body. Patients with coccydynia may demonstrate altered control of muscle balance in the spine. Therefore, spinal motion measurement was considered in the present study. In general, techniques to obtain spinal angle can be divided into the anatomical angle and change in angle during function. The latter (functional angle) is of more interest to the clinician due to it being more reflective of reality.

### *3.2.1. Radiographic method: Plain X-ray and Fluoroscopic imaging*

The imaging technique of plain x-rays is to provide a 2-dimensional presentation of all structures, and is commonly used clinically for detecting bony structures (see Figure 3.1). The main shortcoming of this technique is the hazard of exposure to radiation. Intercoccygeal angle, as mentioned in Section 2.1.2, can be measured from plain x-rays. However, this was not used in the present study, as it was considered that it may be unacceptable to some participants to undergo more x-rays in addition to the screening x-ray (see Section 4.4.3), which involved different views. In particular, those who had their symptoms for a number of years would have had many x-rays.

Fluoroscopy is an imaging technique which provides a real-time moving image of the internal structures (Squire and Novelline, 1997). This imaging technique consists of an X-ray source and fluoroscope, but patients could be exposed to relatively high absorbed dose of radiation due to longer length of procedure than a typical plain x-ray.


Frontal view Lateral view

**Figure 3.1. Example of plain X-ray in the examination of spine**

### *3.2.2. Goniometry and Electro-goniometry*

Consideration of acquiring six degrees of freedom in the spine is important. Goniometry of the lumbar spine can provide information on flexion, extension, rotation and lateral bending (Magee, 2005). However, the results of measurements rely on the individual experience of the examiner. Measurement errors may be high, causing poor reliability. Goniometry can only offer the liner dimension and cannot be used to obtain information of a cavity such as the pelvic outlet. The standard protocol may improve the reliability of goniometry (Table 3.2).

**Table 3. 2. The testing protocol of goniometry for the lumbar spine**

| Motion | Testing Position | Stabilisation | Center | Proximal Arm | Distal Arm |
|---|---|---|---|---|---|
| **Flexion** | Standing in the neutral position | Stabilise pelvis to prevent anterior tilting | Measure distance between spinous processes of C7 & S1 with tape measure | Start in upright zero starting position | End with measurement at end of ROM |
| **Extension** | Standing in the neutral position | Stabilise pelvis to prevent anterior tilting | Measure distance between spinous processes of C7 & S1 with tape measure | Start in upright zero starting position | End with measurement at end of ROM with patient putting hand on buttocks & bending backwards |
| **Lateral flexion** | Standing in the neutral position | Stabilise pelvis to prevent lateral tilting | Over posterior aspect of S1 spinous process | Perpendicular to ground | Posterior aspect of C7 spinous process |
| **Rotation** | Sitting with spine in the neutral position | Stabilise pelvis to prevent rotation. Avoid flexion, extension, & lateral flexion of spine | Over center of cranial aspect of head | Parallel to an imaginary line between the two prominent tubercles on the iliac crests | With imaginary line between the two acromial process |

An electro-goniometer is used to study the lumbar spine, such as the CA6000 spinal motion analysis system (see Figure 3.2). The main purpose of the spinal motion analysis system was to develop a 3- dimensional, non-invasive method to monitor the orientation of each vertebra. The main issue with this technique is fixation of the skin-pad due to skin motion, which may affect the results. The accuracy of the modified CA6000 compared with X-ray was studied in lumbar axial rotation and a high positive correlation (r= 0.972) with the X-ray measurements was reported (Troke et al., 2001). Troke et al. (2007) further examined the inter-rater and intra-rater reliability of the CA 6000 in sagittal, coronal, and horizontal plane positions, and high ICC values (≧ 0.8) were reported.

**Figure 3.2. OSI CA 6000 Spine Motion Analyzer linkage (Troke et al., 2007), with permission**

### 3.2.3. Optical tracking reflection systems

Optical tracking reflection systems are skin-based methods commonly used to observe real-time motor performance. The VICON system is a motion analysis system used to collect human motion data. The system includes hardware and software components. There are 4 to 12 infrared cameras for collecting the analogue data of the marker trajectories. The software includes VICON Workstation that collects and partly processes the motion and analogue data. The programmes of BodyBuilder and Polygon are used to construct and process the acquired data.

The reflective markers which are detected by the infrared cameras are placed on the skin surface of a person, based on the type of motion to be analysed and the number of body segments for the particular study. Before collecting data, the cameras are calibrated, including two recordings of static calibration and dynamic calibration; this ensures that each camera can capture the objects precisely in the specific space. For the brief duration of the calibration, the calibration wand and any reflective items must be removed. The first recording is a static calibration. The static calibration object (see Figure 3.3.) with 4 reflective markers (250 mm) is placed a specific location. The markers over the object are checked from each corresponding camera to verify whether any unwanted reflection exists or any markers are missing. If these problems appear, the corresponding cameras are adjusted or re-located to make sure of good visibility of the 4 markers, after which the calibration is completed.

**Figure 3.3. The static calibration object with 4 retroreflective marker balls**

The second recording is the dynamic calibration using the calibration wands with 3 reflective balls (250mm) (see Fig 3.4.). During dynamic calibration, the investigator shifts this wand randomly through all possible orientations throughout the entire volume of three-dimensional motion. The wand is placed in the centre at the beginning and the end of the whole process. This procedure is done several times until a suitable accuracy is achieved. The dynamic calibration is to make sure that each camera can capture the moving reflective markers.

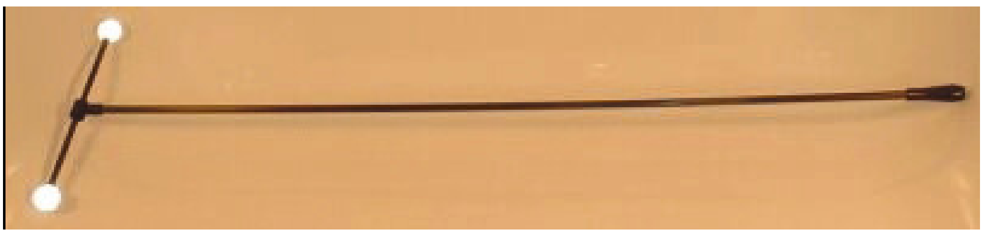


**Figure 3.4. The calibration wand with 25mm retroreflective maker balls.**

Information on the accuracy of motion analysis systems in general is limited. In 2002, there was a Clinical Gait Analysis Forum in Japan to compare characteristics and measurement accuracy of motion analysis systems from different companies used in clinical placements. Each company set up unlimited numbers of cameras in a 7m by 7m space that would be sufficient for the participant's motions. Three categories of comparison involved: (1) Basic specification comparison for rehabilitation or industry (2) sports (3) entertainment. From the forum on basic specification comparison for rehabilitation or industry, they summarised that the minimal detected angle and distance was obtained by the VICON system of 0.5 degrees and 0.2 cm respectively. Study design in motion capture systems is varied, so the protocol for lumbar spine examination is discussed below.

Optical tracking systems, such as VICON, can provide information for both dynamic and static measurements. The marker placements adopted are from the method used by Whittle & Levine (1997), to measure the lumbar curvature using two baseplates to cover directly over L1 and S2 as shown in Figure 3.5 (Whittle and Levine, 1997). However, the method only demonstrated the angle changes between L1-S2, and was not able to differentiate the values between the upper and the lower lumbar angles. The functional lumbar spine position is defined as the angle in the sagittal plane between the skin surface over the T12 process and the sacrum at S2 (see Figure 3.6.) (Levine et al., 2007).

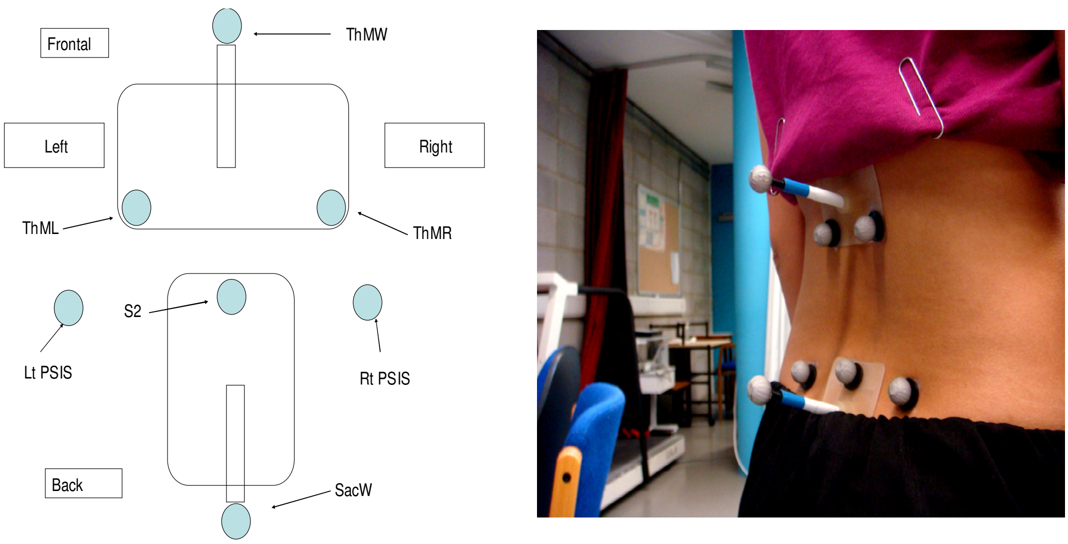



**Figure 3.5. The positions of two baseplates over the spine**

According to a study by Mörl et al (2005), investigating intersegmental lumbar motion, it was found that the lower lumbar spine offered a wider range of motion than the upper lumbar spine (Morl et al., 2005). Mörl et al. also conducted a study to compare the corresponding vertebral positions and orientation between skin markers in an open MRI system. High correlation of motion patterns was found between the external markers and the corresponding landmarks over the vertebrae, but high measurement errors occurred (Morl and Blickhan, 2006). As a result, an additional marker is placed over L3 to gain the angle changes between the lower lumbar spine and upper lumbar spine during the three functional tasks (see *Figure 3.6.*).

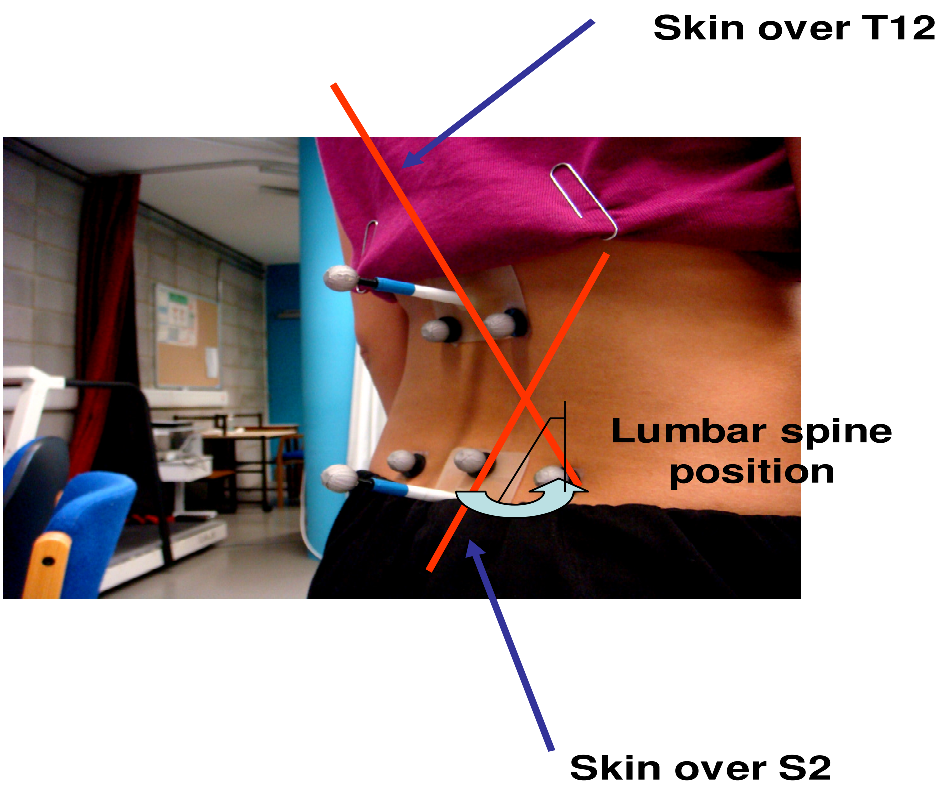



**Figure 3.6. The Lumbar Spine Position**

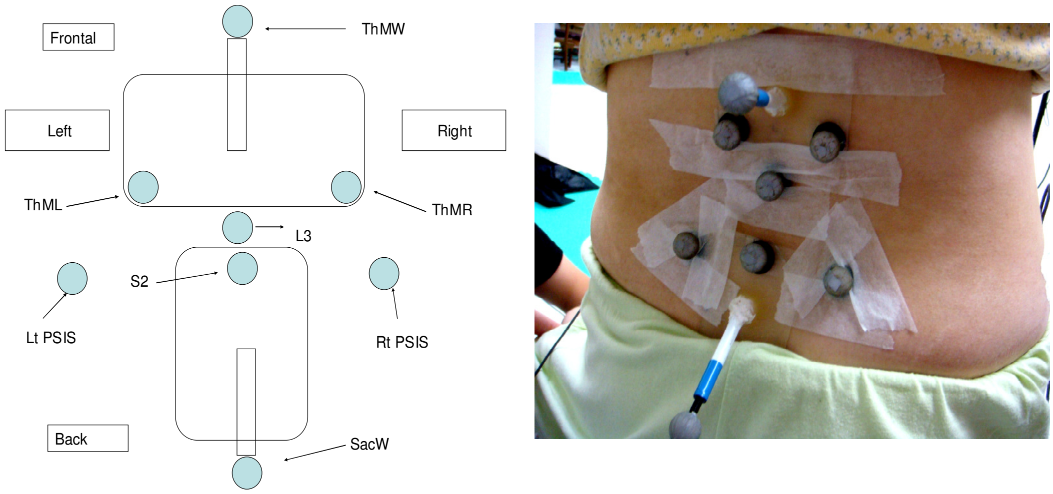



**Figure 3.7. The skin markers over the lumbar spine in the formal study**

Hungerford et al. (2004) used skin markers to determine the 3–dimensional angular and translation motion of the innominate bone, relative to the sacrum in a group with sacroiliac join pain and a control group. They compared skin markers over the posterior superior iliac spines (PSIS) and S2. Although motion was overestimated due to substantial skin movement, differences of motion pattern between the two groups were demonstrated (Hungerford et al., 2004). Due to lack of evidence, it is not obvious whether the patients with coccydynia show the same changes of this area, as referred to above. Therefore, a modified method can be used to measure the relative motion patterns between the sacrum and the innominate bones. The wands and skin markers over the spine were shown in Figure 3.7.

### *3.2.4 RÖntegen stereophotogrammetric analysis (RSA)*

The RSA technique was used for static analysis of spinal motion by (Oxland and Panjabi, 1992). They measured intervertebral motions at the levels of T11-T12 and T12-L1 in the thoracolumbar region a cadaveric experiment. They reported that the range of motion of extension (2.4 +/- 1.3 degrees) and axial rotation (1.8 +/- 0.7 degrees) were significantly different to the same motions in vivo at T12-L1 (extension 3.9 +/- 1.4 degrees; axial rotation 1.2 +/- 0.7 degrees). The different geometry in the facet joints explains these observed differences in the mechanical behaviour of T11-T12 and T12-L1, but cannot fully represent the performance in the vivo situation. The main asset of RSA is its high accuracy, which varies from 0.1 to 0.5 mm for translation and 0.2 to 1.0° for rotation in knee studies (Ryd, 1986, Lundberg et al., 1992).The main shortcoming of the RSA technique is the difficulties encountered when applying it to dynamic conditions. Additionally, this technique is a slow and time-consuming method due to the difficulties in identifying markers.

The advantages and disadvantages of the measurement techniques discussed above for measuring spinal motion are summarised in Tables 3.3.1 and 3.3.2. Considering the features of these techniques, VICON motion analysis was judged to be the most suitable technique to use, as it is one of the most precise techniques and was also available in the laboratories both in Southampton and Taiwan.

**Table 3.3.1 Techniques for spinal motion measurement**

| **Plain X-ray** | |
|---|---|
| **Advantages** | **Disadvantages** |
| • A routine examination for patients with backache<br>• Cheaper than MRI<br>• Offers the general impression of the skeletal system<br>• Allows measurement of the anatomical angle | • Not eligible for dynamic tasks<br>• Only the two-dimensions<br>• Exposure to ionising radiation |
| **Fluoroscopic imaging** | |
| • Monitors the dynamic task<br>• Cheaper than MRI<br>• Offers the general impression of the skeletal system<br>• Allows measurement of the anatomical angle | • Injection or ingestion of contrast material before the examination<br>• Relatively time-consuming<br>• Exposure to ionising radiation |
| **Goniometry** | |
| • Easy applied in the clinical environment | • Static measurement only<br>• Low reliability<br>• Only linear dimension |
| **Electro-goniometry (such as CA 6000 Spine Motion Analyzer)** | |
| • Assesses three-dimensional motion<br>• Monitors the dynamic task<br>• Non-invasive<br>• Allows measurement of changes in angle during function | • Laboratory-based study<br>• displacements between device and skin are difficult to avoid<br>• differences may exist between surface displacement and real joint kinematics<br>• The methodology for skin fixation is still a challenge. |

**Table 3.3.2 Techniques for spinal motion measurement**

| **Optical tracking reflection systems :e.g. VICON** | |
|---|---|
| **Advantages** | **Disadvantage** |
| • Assesses three-dimensional motion<br>• Monitors the dynamic task<br>• Non-invasive<br>• Allows measurement of changes in angle during function | • Expensive<br>• Laboratory-based study<br>• Differences may exist between surface displacement and real joint kinematics |
| **RÖntegen stereophotogrammetric analysis (RSA)** | |
| • High accuracy | • Slow and time- time-consuming<br>• difficulties in identifying markers<br>• dynamical assessment under very specific circumstance |

Certainly, each technique has its own applicability and technical limitations. In general, the technique accuracy of 3-D methods is excellent, although the optical tracking reflection system was not easy to carry out due to the accuracy defined by the field of view of the cameras used. The common technical limitations for these kinematics techniques are the possibility of measurements being affected by the execution of movement. Additionally, the spine is extremely difficult to assess adequately from external techniques. Lundberg (1996) summarised the factors affecting the accuracy of spinal measurements. The first factor is the anatomical features of the spine consisting of 26 small segments, except the sacrum. The second concern is that only spinous processes are comparatively close to the skin and the vertebrae are covered by large muscles, so the vertebrae are inaccessible to direct observation. The range of normal variation in the shape and orientation of the vertebral column, the third factor, is large. It increases the difficulty in identifying whether the condition is outside the normal range or not. In other words, the fascia over the spinous processes is rigidity fixed to bone, so the motion could be detected by assessing the skin markers which closely follow bone movements (Lundberg, 1996; Morl and Blickham, 2006). However, the issue for skin-based motion analysis is the difficulty in the accuracy of motion measurements, which represent the movement sought.  Skin-based methods have to be validated for all types of kinematic cases during studies, but very few studies also carry out assessment of repeatability.

### 3.3. Techniques for detecting muscle activation: EMG

Electromyography (EMG) is a technique that allows objective assessment of muscle activity. Basically, this technique has been approached in two ways via surface and inserted electrodes to detect the signals in different muscles. In *"Muscles Alive"*, Basmajian and De Luca (1985) described two groups which offered guidelines for the definitions and standards of EMG . One is the IFSECN at its Second International Congress (Guld et al, 1970), and the other one is the Second Congress of the International Society of Electrophysiological Kinesiology (ISEK) in 1972 and revised in 1980. More recently, the terminology and set of definitions in the SENIAM projects are most commonly used (Hermens et al., 1999).

#### *3.3.1. The rationale for using EMG*

A motor unit consists of a nerve cell body, the long axon connecting to the motor nerve and its terminal branches and all muscle fibres supported by these branches. In normal skeletal muscle, a motor unit is a functional unit in which an impulse descending the motor neuron causes all the muscle fibres in one motor unit to contract simultaneously (Basmajian and De Luca, 1985, Cram et al., 1998). Generally, muscles controlling fine movements and adjustments have the smallest number of muscle fibres per motor unit. Large motor units are found in large muscles such as in the limbs. The smaller motor units are innervated by the smaller alpha motorneurons and are excited earlier during a contraction requiring a progressively increasing force (Basmajian and De Luca, 1985, Cram et al., 1998). Larger motor units are innervated by larger alpha motorneurons and become activated at progressively higher force levels. This is known as the size principle of motor unit recruitment.

The principle of EMG application is harmless but the electrodes must be close to the muscle under investigation to detect the current generated by ionic movement in the muscle tissues. The electrode which makes direct electrical contact with the tissues is referred to as the detection surface. The two main types of electrodes for detecting muscle activity are surface electrodes and inserted (fine wire or needle) electrodes which are described in the next section.

#### *3.3.2. EMG electrodes: inserted and surface electrodes*

The types of EMG electrodes are summarised in Table 3.4. Surface electrodes are divided into disposable and reusable ones according to the usage of electrodes. Reusable electrodes can be used repeatedly and on different individuals, and are applied directly on the skin and held in place by adhesive tape. It is ideal for quiet and gentle movements, but not recommended for recording dynamic motions. A disposable electrode is used only once, and is very commonly applied in many studies. The most popular disposable electrode is the hydrogel electrode consisting of a silver chloride disc covered with a dry and sticky layer of gel (Cram et al., 1998).

The chief advantages of surface EMG is comfort, safety and convenience. The continued pressure over the electrode to ensure good contact is important. Electrical contact is greatly improved by the use of a saline gel or paste that was applied in the majority of studies (Cram et al., 1998, Hermens et al., 1999). However, the EMG signals may vary with temperature fluctuations, sweat accumulation, choice of electrodes (gel or paste types), relative movement of the metal and skin, and the amount of current flowing into the electrode. The main shortcoming of surface electrodes is that can only detect signals from superficial muscles and cannot detect signals selectively from small muscles. Therefore, the detection of "cross-talk" signals from other adjacent muscles becomes an inevitable problem.

The inserted electrode is invasive and can be classified as needle and wire electrodes. The advantages of needle electrodes are (1) precise to detect individual motor unit action potentials conveniently, especially during relatively low-force contractions (2) conveniently repositioned within the muscle to explore new territories or improvement in the quality of the signal. Wire electrodes are extremely fine and cause less discomfort compared with needle electrodes. The main purpose of wire EMG is to record a signal that is proportional to the contraction level of muscle. However, wire electrodes cannot be applied to distinguish multiple motor units and the electrode may migrate after it has been inserted. The main disadvantage of inserted electrodes is that they are too specific to investigate general tasks. The information from EMG signals is vast, so the recording technique relies on what information is needed during specific studies (Basmajian and De Luca, 1985). The advantages and disadvantages for EMG recording techniques are summarised in the Table 3.4.

**Table 3.4 Electromyographic techniques for detecting muscle activation**

| **Surface EMG** | |
|---|---|
| **Advantages** | **Disadvantages** |
| • Non-invasive<br>• High acceptability by participants<br>• Detects the general muscle activations during a task<br>• Easier clinical application to detect the muscles | • Cross-talk of muscle activation<br>• The accuracy may be affected by other electronic signals<br>• Re-useable electrode are not easy to fix over the back muscles<br>• For patients with more fat tissues, the signals are difficult to detect<br>• Poor between-days reliability |
| **Needle & Wire EMG** | |
| • More specific than surface EMG<br>• Provides the information of motor unit action potential (MUAP) and motor control properties<br>• Directly detects kinesiological and neurophysiological data of the deep muscles | • Invasive<br>• Lower acceptability by participants<br>• Discomfort may limit the performance of the tasks<br>• Can be too specific in certain situations<br>• Risk of infection |

### 3.4. General discussion of the techniques to be used in the current research

Based on the biomechanical perspective, spinal stability is maintained by the bony structures, muscles and motor control mechanisms (see Chapter 2, Section 2.2). The major local muscles comprise the lumbar multifidus and transversus abdominis to stabilise the intervertebral joints, and the pelvic floor muscles (Richardson et al., 2004a). These muscles work simultaneously in a coordinated fashion to achieve and maintain the stability of the sacroiliac joints (Vleeming et al., 1997). Coccygeal mobility may be influenced by modulating the intervertebral mobility and the neural control of stability may be altered (i.e. muscle response delayed during functional tasks). The capacity to fine-tune the segmental motion may be impaired. According the existing studies of normal function, the local muscle system is critical, but these muscles i.e. transversus abdominis and multifidus are deep and difficult to investigate directly (Bergmark, 1989). Therefore, ultrasound imaging can be used to measure both static and dynamic muscle performances and will be adopted in this study.

The issues relating to the three assessment techniques selected showed varied changes in patients with dysfunction of the lumbar spine. As the research questions and hypotheses Chapter 2 stated, patients with coccydynia will demonstrate neuromuscular changes in comparison with healthy participants. The dynamic changes in patients are what clinicians want to know about, as compensatory strategies may be used to carry out different tasks. Static postures may depict the anatomic features, such as spinal positions and muscle morphology, but cannot provide information about functional performance. The VICON motion capture system could be used to measure motion changes in the lumbar region during a dynamic task to examine performance. The technique of surface EMG can provide information about generalised muscle activation. The synchronisation and combination of these two techniques could provide answers to some of the problems of coccydynia. To investigate these alterations in patients with coccydynia, the three techniques of ultrasound imaging, VICON motion analysis surface EMG will be applied based on the considerations of the availability, costs and the features of each technique discussed above.

## Chapter 4: methodology for the study of musculoskeletal dysfunction associated with coccydynia

### 4.1 Introduction

In this chapter, the techniques used and the development of experimental protocols are presented. The protocols consist of using three techniques and were developed in a pilot study in Southampton between November and July 2008. The reliability of the techniques was examined in preparation for the main study in Taiwan between August and December 2009. Before the experimental protocols were formally commenced, the author tested their feasibility in Taiwan (April 2008, the China Medical University (CMU) and Hospital (CMUH)). The time-line of the development of the experimental protocols and studies is listed in Table 4.1.

**Table 4.1. The time-line of the PhD studies**

| Time-line | Achieved tasks |
|---|---|
| Oct-Dec 07 | • Techniques training<br>• Experimental protocol developing<br>• Ethical approval application for the pilot study in Southampton |
| Jan-June 08 | • Obtain ethical approval<br>• Commence the pilot study<br>• Ethical approval application for the pilot study in Taiwan and obtain approval<br>• Test the feasibility of study protocols in Taiwan<br>• Add a different ultrasound study in a different healthy group |
| July 2008-June 09 | • Data analysis of the pilot working |
| July –Dec 09 | • Commence the main study in Taiwan |
| Jan- June 09 | • Data analysis of the main study |

### 4.2. Training in experimental techniques

The investigator was trained to use the three experimental techniques in Southampton. She attended a training course “Rehabilitative Ultrasound Imaging of Skeletal Muscle: Clinical Evaluation and Biofeedback Practical Introductory Course for Physiotherapists” in St. James’ Hospital, School of Physiotherapy, Trinity College Dublin, Dublin, Ireland- 9th Nov. 2007. This is a training course for the application of ultrasound imaging taught by Professor Maria Stokes and Mrs Katy Cook. During the course, different configurations and shapes of muscles in different people were observed for images of normal muscles. Professor Maria Stokes and colleague, Ms Jackie Whittaker, provided further training for the investigator to use the ultrasound machine in the laboratory at the University of Southampton. Three volunteers in

Southampton attended the practice sessions under the supervisions of Professor Maria Stokes and Ms Jackie Whittaker. Due to the different ultrasound machines in Taiwan and in Southampton, the investigator went back to Taiwan in Easter 2008 to practice the skills under the supervisions of Dr. Chou Lei-Wei.

The training sessions of VICON and sEMG were taught by Mr. Martin Warner, the laboratory Experimental Officer in Southampton. Two days were used to train the investigator to manipulate the VICON and sEMG separately, and then to apply them together. During the training in the early stage, the foot-switch was used to record gait due to the inability to synchronise items of equipment at the same time. In the formal data collection from April 2008, the machine was set up to synchronise two pieces of equipment, so the foot-switch was removed from the study design. As for training of data analysis, Mr. Martin Warner installed the programme of Image J for analysing the ultrasound images and taught the investigator how to use this programme to measure muscle thickness. Before taking formal measurements, the analysis protocol for ultrasound imaging was established and the measurement database on Excel was set up. The VICON workstation was used to do data analysis step by step. Afterwards, a Matlab programme was used to further analyse muscle onset determination on the EMG traces. Due to the investigator being new in this area, both intra- and inter-rater reliability were examined and established before formal data analysis was undertaken (see Section 4.6.2.).

### 4.3. Methodology for studies carried out in Southampton and Taiwan

There were two studies; a pilot study of young healthy participants carried out in Southampton and a main study of patients and older healthy controls in Taiwan. The experimental protocols for the ultrasound technique and VICON were exactly the same as those used in Southampton. However, the EMG procedure was amended to detect back muscle activity without including the muscles of the lower extremities, due to technical difficulties.

### 4.4. The participants

Taiwanese females (total n=55) aged 23-65 years of age and were divided into three groups of healthy participants and patients; a. healthy young group in Southampton: n= 18, aged 23-34 years (16 of these completed data collection for reliability of RUSI and 13 for reliability of the VICON and EMG tests); b. healthy older controls in Taiwan: n=17, aged 23-65 years; c. patients in Taiwan: n=20, aged 23-65 years (17 of whom took part in reliability studies, aged 23-62 years). The precise numbers involved in each study are detailed in the relevant experimental chapters. The inclusion and exclusion criteria are stated below and summarised in Table 4.2.

### *4.4.1. Recruitment*

For the pilot study in Southampton, the investigator contacted the President of the Taiwanese Students' Society at the University of Southampton to obtain permission to post the information in the student discussion forum (Appendix 13.2.6). Any student who was interested in the study contacted the researcher directly by e-mail or phone. However, the ages of the participants in Southampton were restricted to the range from 20 to 35 years because they were Masters students studying at the University between 2007 and 2008. There were 18 participants taking part in the study, but data were only collected successfully in 13 of the 18 participants recruited. Therefore, older controls were recruited in Taiwan to obtain a large enough sample size and a more age-matched control group for comparison with the patient group. The older healthy controls in Taiwan, aged between 35-65 years, were recruited mainly from posters (Appendix 13.2.7) displayed in the hospital and nearby community, and leaflets. Participants who were interested in the study contacted the investigator directly. In both groups, the investigator confirmed the participants matched the inclusion criteria, and then informed them of the experimental protocol in an information sheet (see Appendix 13.2.4). Each participant signed the consent form once they agreed to engage in the study (Appendix 13.2.4).

Patients who met the requirements were referred to the investigator from physicians in the Department of Orthopaedic Surgery and in the Department of Rehabilitation and Physical Medicine. The investigator explained the content of study and gave the participant the information sheet (Appendix 13.2.4). Once the patient agreed to take part in the study, they signed the consent form, so that written, informed consent was obtained (Appendix 13.2.4). There were 20 patients who were recruited, and 14 of these patients attending the reliability study. Six of the 20 patients attended the case studies. The details of study setups and applied experimental protocol will be addressed in the following section.

### *4.4.2. Healthy participants*

The inclusion and exclusion criteria for the younger healthy participants in Southampton and the older healthy controls in Taiwan were similar except for age. Participants were excluded from the studies if they had a history of neurological, neuromuscular, rheumatological, dermatological, or systemic diseases; previous spinal surgery, observed spinal deformity, previous spinal or pelvic fracture, previous or current back pain, pregnancy and psychological problems. Subjects who had a history of back problems but were not restricted or had symptoms that caused them to spend time off work, were recruited into the study. In addition, before attending the experiments, each participant was given an information sheet to remind them not to take alcohol within 24 hours before the study. Also they were to not carry out vigorous exercise 48 hours before the experiment to avoid influencing the results.

### *4.4.3. Patient group*

Female Taiwanese patients aged 20-65 years old who were diagnosed with coccydynia were eligible for the study. The inclusion and exclusion criteria are shown in Table 4.2. A small number of 6 patients were requested to take part in a case study of an intervention of a pelvic belt for 6 weeks. These 6 patients were examined for both ultrasound and motion analysis before and after intervention (Chapter 9).

**Table 4.2. Summary of inclusion and exclusion criteria for recruitment of participants**

| Criteria | Healthy Participants | Patients |
|---|---|---|
| **Inclusion** | ● Good physical and emotional health<br>● Good understandings on the study<br>● History of backache, but not restricted the functions | ● Pain in and around the coccyx without significant low back pain or radiating or referred pain<br>● Pain localised at the sacrococcygeal joint or the coccygeal mobile segments<br>● Pain symptoms worsened by sitting or sitting to standing<br>● Pain symptoms persisting for more than two months<br>● No ongoing antidepressant treatment<br>● Having a good understanding of what is required to take part in this study |
| **Exclusion** | ● Neurological disease<br>● Neuromuscular diseases<br>● Rheumatological diseases<br>● Dermatological diseases<br>● Systemic diseases<br>● Previous spinal surgery<br>● Spinal deformity<br>● Previous spinal or pelvic fracture<br>● Current back pain<br>● Pregnancy<br>● Psychological problems. | ● Neurological disease<br>● Neuromuscular diseases<br>● Rheumatological diseases<br>● Dermatological diseases<br>● Systemic disease<br>● Pregnancy |

*Diagnosis of Coccydynia*

The diagnosis of coccydynia was made relying on the patients' symptoms (Wray et al., 1991, Maigne and Chatellier, 2001, Laycock and Haslam, 2003):

(1) Pain in and around the coccyx; (2) Pain localised at the sacrococcygeal joint or the coccygeal mobile segments; (3) Pain symptoms worsened by sitting or sitting to standing; (4) Pain symptoms persisting for more than two months. Patients had an X-ray examination including frontal view and lateral views to rule out problems originating from other areas. Manual examination of the coccyx was made to identify trigger points around the coccyx to confirm the diagnosis.

#### ***4.4.4 Ethics Approval and Informed Consent***

The studies in Southampton on the young healthy participants were approved by the Ethics Committee in the School of Health Sciences (Appendix 13.1.1) and for the studies in Taichung, Taiwan, by the Institutional Review Board in China Medical University Hospital (CMUH; Appendix 13.1.3). All participants gave their written, informed consent to take part in the project (Appendix 13.2).

## 4.5. The Protocol of Ultrasound Imaging

At the University of Southampton, ultrasound images were taken using a Pie Data Aquila scanner (Pie Medical Equipment, Maastrich, The Netherlands) with two transducers. In Taiwan, an ultrasound scanner made by GE (LOGIQ5) was used. Details of the machines and transducers are shown in Table 4.3. Images of the targeted muscles were captured both at rest and in a contracted state, and then downloaded to a computer to be measured off-line using Image J software 1.40. Details of the procedures are stated in the following sections.

**Table 4.3. Summary of the ultrasound machines and protocols in the two locations**

| Ultrasound | Southampton | Taiwan |
|---|---|---|
| Machine | Pie Data Aquila scanner | GE LOGIQ5 |
| Probes | • 6.0 MHz linear for abdominal muscles<br>• 5.0MHz curvilinear for multifidus | • 7 L (3-7 MHz) linear 47x6mm<br>• 3.5C (2-5MHz) curvilinear 48x11mm |
| Standard protocol | • Bilateral lateral abdominal area<br>• Midline abdominal fascia<br>• Left lumbar and sacral multifidus | • Bilateral lateral abdominal area<br>• Midline abdominal fascia<br>• bilateral lumbar and sacral multifidus |
| Level contraction protocol | Bilateral lateral abdominal area under the three muscle status: Rest, 20% MVE, and MVE | Patients only<br>Bilateral lateral abdominal area under the three muscle states: Rest, 20% MVE, and MVE |

MVE = maximal voluntary effort

### *4.5.1. Standard protocol*

The bilateral abdominal muscles and multifidus of the sacral and lumbar areas, and inter-rectus distance were investigated following the protocol stated below. Muscle thickness was scanned at the end of expiration to standardise the influence of respiration (Ainscough-Potts et al., 2006).

*4.5.1i. Abdominal areas: Lateral abdominal wall and Midline abdominal fascia (inter-recti distance)*

During scanning of the abdominal areas, subjects were positioned in the supine hook-lying position with arms by their sides and the head in midline (see Figure 4.1). The investigator sat on the right side of the subject. A linear transducer was selected to capture the images of the lateral abdominal muscles taken bilaterally and mid line abdominal fascia. While the subject performed the active straight leg raise (ASLR) task, a reference for the height of the leg lift was set by placing a ruler horizontally on a vertical stand (see Figure 4.3). Some transparent tape was placed on the screen to act as a reference for the position of the musculotendinous junction of the lateral abdominal muscles, to standardise the captured pictures.

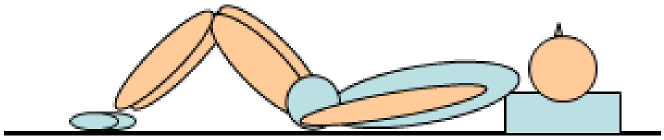


**Figure 4.1. Supine hook-lying.**

The protocol for scanning the lateral abdominal areas was based on the study by Rankin et al 2006 and examined the bilateral lateral abdominal muscles. The probe was placed halfway along the mid-axillary line between the ribcage and ASIS (Rankin et al., 2006) and then the probe was moved to position the targeted image on the screen as centrally as possible. When the optimal image was obtained, the image was captured and then saved as a whole image. The participant was requested to extend their left leg, then activate their transversus abdominis (TrA) muscle by a left ASLR for 3 seconds, lifting 5 cm off the plinth to touch the ruler while the right leg was maintained in flexion (see Figure 4.2.). The investigator requested the subject to slightly contract their gluteal muscles and draw in their abdomen whilst doing the task. For further standardisation of the protocol, the two transparent tapes were applied as references for each musculotendinous junction of the TrA muscles.

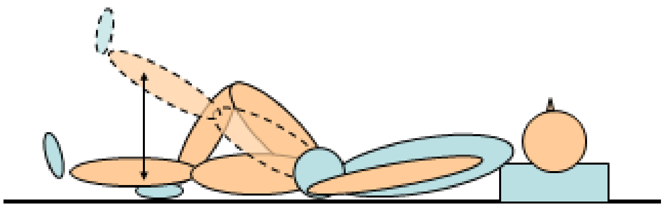


**Figure 4.2. Active straight leg raises (ASLR)**

In the protocol for observing the midline abdominal fascia, the width between bilateral rectus abdominis, the inter-recti distance (IRD), was measured following the protocol of Coldron et al (2007). The author placed the transducer transversely superior to the umbilicus to take the resting image of midline abdominal fascia (Coldron et al., 2007). The image of IRD was kept as central as possible for easy measurements. After obtaining the resting imaging, the investigator asked the subject to lift their head 5 cm off the plinth until their forehead touched a ruler held by a stand (Fig 4.3), in order to gain the image of muscles in contraction while the probe was at the same position.

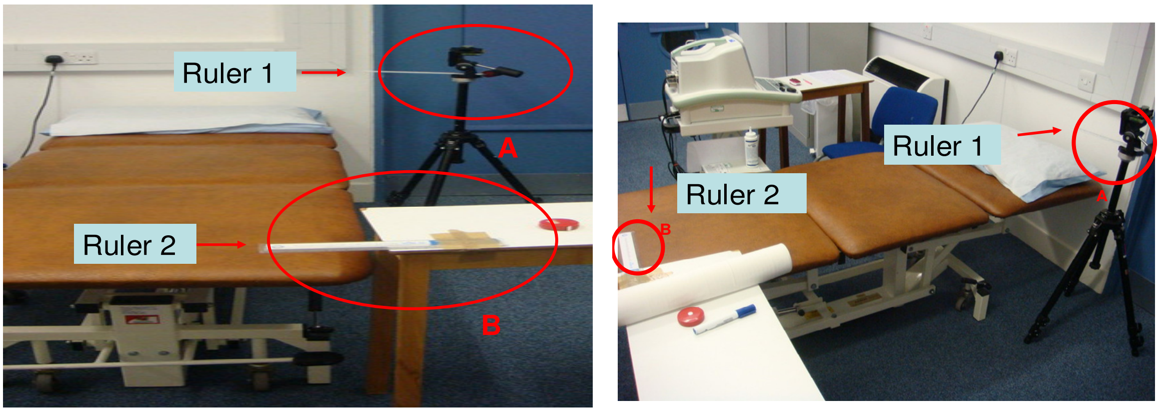



**Figure 4.3. The placement of two rulers as references during the ultrasound sessions. A. Reference height set for the task of head lifting (Ruler 1). B. Reference height set for the task of ASLR and leg lifting (Ruler 2).**

*4.5.1ii. Sacral and lumbar multifidus*

Subjects were placed in a prone position, with two pillows under the waist to keep the lumbar spine in the neutral position. A linear transducer was selected (5MHz), to obtain longitudinal scans of the multifidus in the L4-L5 and L5-S1 regions. The examiner localissed the individual spinal processes of L4, then immediately placed the transducer lateral to the bony landmarks on the left side. The angle of the probe was manipulated to achieve clear images of L4-5, and then subjects were asked to load their spines by lifting their right leg 3 cm off the plinth to obtain the image of muscles in contraction. The same procedure was used to obtain the images of L5-S1. Prior to collecting data, the investigator compared the activity level of the right multifidus by lifting their legs separately. The more significant muscle contraction was found during the contralateral leg lifting. Therefore, the author decided to use this method to activate the multifidus. During the pilot study, only the left side of the back area was scanned. In the main study, the two sides of back were scanned.

***4.5.2. Standardising level of contraction of the abdominal muscles (Chapter 6)***

Each participant lay in a supine hook-lying position with their arms by their sides and their head in the midline. The ultrasound scanner and the investigator were positioned on the right side of the participant. A linear transducer was used to capture images of the lateral abdominal muscles on the right and left sides, separately, following the standard protocol.

The drawing-in exercise is commonly used in clinical practice to retrain motor control of deep trunk muscle in low back pain (Hides et al., 2007, Teyhen et al., 2005, Teyhen et al., 2008). During functional tasks, the TrA muscle is anticipated to activate to protect the spine but the level of force should be not large. The validation of EMG and muscle thickness change is still unclear, but a linear relationship between EMG activity and muscle thickness was reported in TrA under a specific situation of sub-maximal muscle contractions (Hodges et al., 2003; McMeeken et al, 2004). In the present study reported in CH6, this task was taught at two contraction levels, maximal voluntary effort (MVE) and approximately 20% of maximal. The lower level is more similar to that used clinically but the maximal level was used as a reference for achieving the lower level, and for comparison in terms of reliability for the present study. Simultaneous contraction of the pelvic floor muscles was also performed in the manoeuvres.

To achieve a given level of contraction, the participant was asked to visualise a 10 storey building and to imagine an elevator going up to the tenth floor during a maximal contraction and to the second floor to achieve 20% MVE. Obviously it was not possible to ensure 20% MVE was achieved, as it was not measured objectively. The participant was allowed to practice a few contractions so that they were familiar with them before imaging commenced, although this was limited to 3 contractions so as not to induce fatigue.

The three contraction states: resting, 20% MVE and MVE were each measured twice in random order and scans were taken during the steady state of contraction. Three-minute rests were taken between trials to minimise fatigue. Alignment of the transducer was maintained as consistently as possible during the drawing-in manoeuvres, but some relative motion was unavoidable. Small deviations in transducer angle (below 10 degrees) do not cause significant changes in abdominal muscle thickness (Whittaker et al., 2009).

### 4.6 Protocol for pelvic motion analysis including surface EMG and VICON

Electromyography (EMG) and VICON motion analysis data were captured during the functional tasks synchronously. The chosen tasks in the two different laboratories in Southampton and Taiwan were the same, but the facilities were slightly different, in particular in the EMG. Before applying the surface EMG electrodes and the reflective Vicon markers, the investigator marked the bony landmarks over the bilateral anterior superior iliac spines (ASIS), the bilateral posterior superior iliac spines (PSIS), the bilateral lateral epicondyles, and each spinal process of lumbar vertebrae to increase the consistency of applied sites.

#### 4.6.1. Experimental protocol for surface EMG

The pattern of superficial muscle activity can be obtained by sEMG during functional tasks (Hodges et al., 1999, Hodges and Richardson, 1999b, Hodges et al., 2001b, Moseley et al., 2002). In the pilot study conducted, bilateral recordings were made from the internal oblique muscles (that directly attach to transversus abdominis); biceps femoris and gluteus maximus were measured using sEMG. Although gluteus maximums and biceps femoris play important roles in controlling part of the sacral nutation and coccyx mobility, recordings contained interference from compression over the electrodes during the sit to stand task and so recording of EMG from these muscles was not included in the study protocol. Therefore, the focus was on multifidus and the superficial muscles of the abdominal wall, which are known to show abnormal activation in patients with low back pain (Hodges and Richardson, 1999a, Hodges, 2001, Ferreira et al., 2004a, Tsao et al., 2008, Tsao and Hodges, 2008). Bilateral recordings were made from the sacral and lumbar areas of multifidus, and internal and external oblique muscles. The VICON and sEMG signals were recorded simultaneously.

#### 4.6.2. Surface Electromyography in Southampton and Taiwan

In Southampton, pairs of Ag/AgCl disposable surface electrodes, with a contact area of 20 mm and inter-electrode distance was 20 mm, were used to record the electromyographic (EMG) activities of bilateral obliquus internus abdominis (IO), gluteus maximus (GM) and biceps femoris (BF) in the mode of bipolar differential. The 6 electrode sites replicated from the published studies were (1) bilateral obliquus internus, 2 cm medial and inferior to the ASIS, (2) bilateral gluteus maximus, at the midpoint of a line between the inferior lateral angle of the sacrum and greater trochanter, (3) bilateral biceps femoris, mid distance between the gluteal fold and the lateral epicondyle (Hungerford et al., 2004, Smith et al., 2006).

Following the SENIAM procedure of skin preparation, by gentle abrasion with sandpaper and wiping with alcohol swabs, the impedance of the skin was measured with an impedance meter and recordings below 5kΩ were acceptable. Placement of electrodes were aligned parallel to the underlying muscle fibres. The EMG data were sampled at 1000 Hz and amplified by 1000 using a BIOPAC EMG system. The parameters of the EMG amplifier are that the input impedance was larger than 100 MegOhm, the common mode rejection ratio was larger than 100 dB.

The band-pass hardware filter was an eighth order Butterworth/Bessels low pass anti-alias filter in 500 Hz. The cut-off frequency was set to be 8 Hz for the high pass filter and 500 Hz for the low pass filter. According to SENIAM recommendations, a high pass (10-20Hz) filter is regarded as “anti-aliasing”, and is usually applied to further attenuate the raw data and noise. A low pass (500-1000Hz) filter can be applied to unwanted signals resulting from movement artefacts and instability of the electrode-skin interface. These unwanted signals are usually in the frequency range between 0 and 20 Hz, so the filter is often designed with a low-cut-off frequency range 10-20 Hz. After appropriate filtration, the raw data will become a smooth trace to assist the identification of the EMG onset.

In a TeleMyo 2400T® Transmitter data acquisition system, the A/D conversion card accepts a signal in the input range ±5 V and has 12 bit resolution. This system can run continuously for up to 4 hours under the use of a single fully-charged battery, and allow collection of data up to a distance of 100 meters. The transmitter carrying case with waist belt allows participants to carry it easily with less restriction and to perform the task quite naturally. Each transmitter can accommodate 8 channels. In Taiwan, re-useable electrodes were used, so more tapes were needed to fix the electrodes that were aligned parallel to the underlying muscle fibers following the procedure of the skin preparation (Table 4.4).

**Table 4.4. The electromyography systems used at the two data collection sites**

| EMG | Southampton | Taiwan |
|---|---|---|
| **Machine** | TeleMyo 2400T | Motion Lab System MA-300-10 |
| **Electrodes** | ● Disposable | ● reuseable |

*Measurement of EMG during maximum voluntary isometric effort (MVE)*

After applying the six electrodes, the relative maximum voluntary effort (MVE) of each muscle was obtained. Each participant was allowed to practice the motion, which activated the examined muscle twice, before collecting the data. The examiner applied the resistance for 5 seconds, whilst the subject did the motion, and orally encouraged the subject to contract as much as possible. The details of the examination procedure are listed below:

*(1) Right and Left Internal Obliquus*

The subject was positioned in supine hook-lying and the examiner requested the subject to rotate her trunk to the contrlateral side. The examiner stood on the contralateral side of the targeted muscle, and placed the hands over the knees and the shoulder of the tested side to give resistance for 5 seconds during the motion.

*(2) Right and Left Gluteal Maximus*

The subject was prone with the knee to be tested flexed to 90 ° and activated the gluteus maximus by extending the hip. The examiner fixed the flexed leg by her trunk and placed the hands over the popliteal area of the tested leg to apply the resistance for 5 seconds during the task.

*(3) Right and Left Biceps Femoris*

The subject was in a position of prone with the right knee extended. The task of muscle activation was to flex the knee to be tested. The examiner placed the hands separately over the popliteal area and the ankle of the tested leg and gave the subject resistance for 5 seconds during the motion.

In the study in Taiwan, the protocol was changed to (1) bilateral back muscles (2) Right and Left internal obliquus (IO) and external obliquus (EO). The examination procedure for MVC has been stated below. Recordings of EMG from the lower limbs were excluded for reasons explained above (Section 4.5).

*(1) Back muscles*

The subject was placed in a prone position, and the examiner requested the subject to raise the upper back with their hands crossed and placed over their lower back. The examiner placed her hands over the shoulder to give resistance for 5 seconds during the motion.

*(2) Right internal obliquus and Left external obliquus/ Left internal obliquus and Right external obliquus*

The subject was positioned in a supine, hook-lying position, and the examiner requested the subject to rotate her trunk to the contrlateral side. The examiner stood on the contra-lateral side of the targeted muscle, and placed the hands over the knees and the opposite shoulder of the tested side to give resistance for 5 seconds during the motion.

#### ***4.6.3. Experimental procedure for motion analysis***

The detecting VICON system used 22 lightweight reflective 25mm diameter markers (balls) to define the bony landmarks of the lumbar spine, the pelvis and the lower extremities (see Figure 4.4). Lumbar curvature was defined by the two baseplates with the rig directly over T12 and S2 and a reflective ball over the spinal process of L3. The pelvic outlet was defined by bilateral anterior superior ischial spines (ASIS), bilateral posterior superior ischial spines (PSIS) and the baseplates over S2. The reflective markers over the back were showed in Figure 3.7.

*VICON equipment in Southampton and in Taiwan*

The camera and two wand calibrations were carried out in the VICON workstation as mentioned in Chapter 3. The examiner was cautious not to tilt or to compress the rigs, in particular after conducting the wand calibrations. After applying of the tracking markers, the subject was asked to stand with slightly abducting arms, in order not to hinder the markers, and the 'static standing' data was collected under the trial type 'static'. The examiner changed the trial type from 'static' to 'general capture' when doing the three tasks. In Southampton, the VICON 460 was used with six cameras to capture the 22 reflective markers. In Taiwan, the VICON 612 was used with five cameras (as one was broken), which were sufficient to capture 22 reflective markers.

*Functional Tasks*

The first task was 'right leg standing', whilst flexing the left leg to the height of the waist (90°-90°). In consideration of safety, the participants were allowed to abduct their arms to maintain balance. The examiner instructed 'Ready', pressed the button to start the data collection, and then instructed 'Start' notifying the subject to flex her left leg up to the 90 degrees and to maintain it until the examiner said 'Stop' (Figure 4.4). The second task was followed using the same procedure in the other leg standing. In the third task, 'stand from sitting', the adjustable chair without the backrest was adjusted to allow the thighs and legs to be at a right angle. The participants were requested to rise from the chair whilst abducting the arms to avoid hindering the markers of the bilateral ASIS. Each task was carried out three times in each session. The EMG and VICON data was collected synchronously during the tasks. The data collection protocols are summarised in Table 4.5.

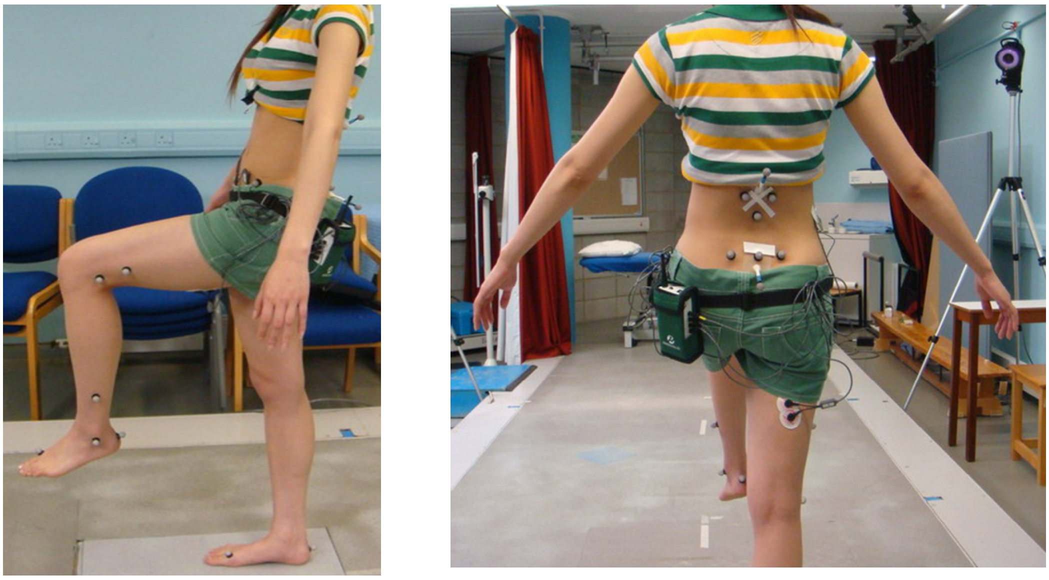


**Figure 4.4. Lateral and poster views of the functional task: One leg standing**

**Table 4.5. The summary of the data collection protocols**

| Experimental protocol | Pilot study | Main study |
|---|---|---|
| Ultrasound imaging: the target muscles | 1. Bilateral lateral abdominal walls<br>2. IRD<br>3. Left lumbar and sacral multifidus | 1. Bilateral lateral abdominal walls<br>2. IRD<br>3. **Bilateral** lumbar and sacral multifidus*. |
| VICON | Same protocol | Same protocol |
| Surface EMG: the target muscles | 1. Bilateral IO<br>2. Bilateral gluteal muscles<br>3. Bilateral biceps femoris | 1. Bilateral IO<br>**2. Bilateral EO***<br>**3. Bilateral back muscles*** |

** indicates the different parts from the pilot study*

### 4.7. Protocol for case studies reported in Chapter 9

Case studies of the intervention of a pelvic belt were carried out on six patients from the main study. Only patients who took part the examination within the first three months of the study were invited to take part in the case studies due to time limitation. The case studies needed to be followed-up to six weeks. Each subject wore a pelvic belt for eight hours a day for six weeks. They were requested to keep a diary for their use and record symptom changes and return for further tests of ultrasound imaging and questionnaires after six weeks (immediately after the end of the intervention period) to examine any effects from wearing the belt.

The pelvic belt was applied, after the baseline data had been collected. The applied pelvic belt is "core stability support" coding 3462 from OPPO Medical INC (see Figure 4.5).

**Figure 4.5. Core stability support- Hip and sacro brace (accessing from http://www.oppomedical.com/product/detail.asp?serno=243). Reproduced with permission, from OPPO Medical Corporation.**

The design of the belt is a main belt and two additional elastic straps. The function of the additional straps is to apply more compression to provide more stability for the pelvic outlet (see Figure 4.6). After fixing the main belt, the additional straps can be used to apply more compression forces according to the alignment of pelvis.

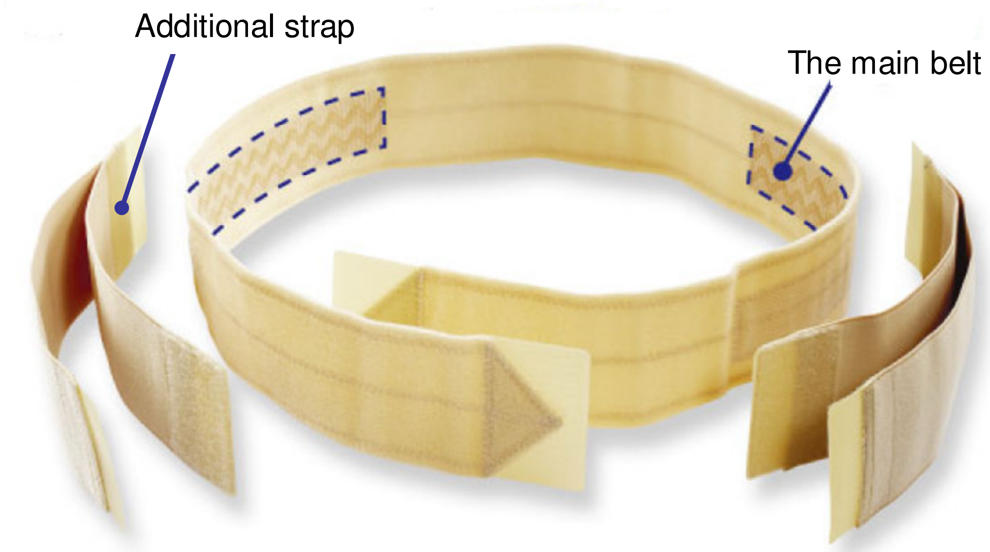



**Figure 4.6. The design of pelvic belt applied in the present study. Reproduced with permission, from OPPO Medical Corporation.**

There are four suggested ways to adjust the additional straps according to the findings on physical examination, including the ASLR test and the observation of pelvic alignment. Generally, a functional test of ASLR, which is a type of spinal loading task, is used for assessing the mobility of sacroiliac joints separately. In Figure 4.7, the alignment of the pelvis is backward facing, so the additional straps are applied following the direction from back (the height of PSISs) to front (the marker of ASISs).

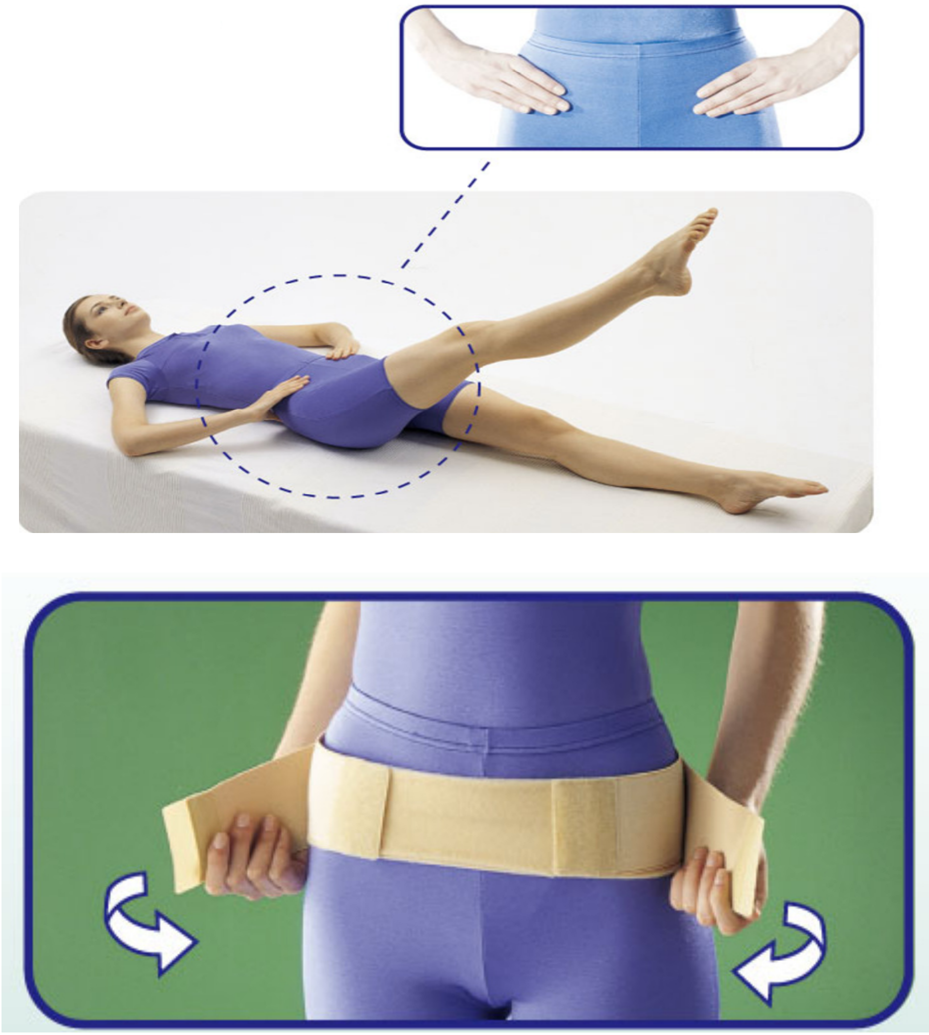


**Figure 4.7. The belt application for the backward facing pelvis. Reproduced with permission, from OPPO Medical Corporation.**

If the alignment of the pelvis is the forward facing type, the additional strap should be applied to fix over the ASISs and then pull toward to the markers of the PSISs (see Figure 4.8).

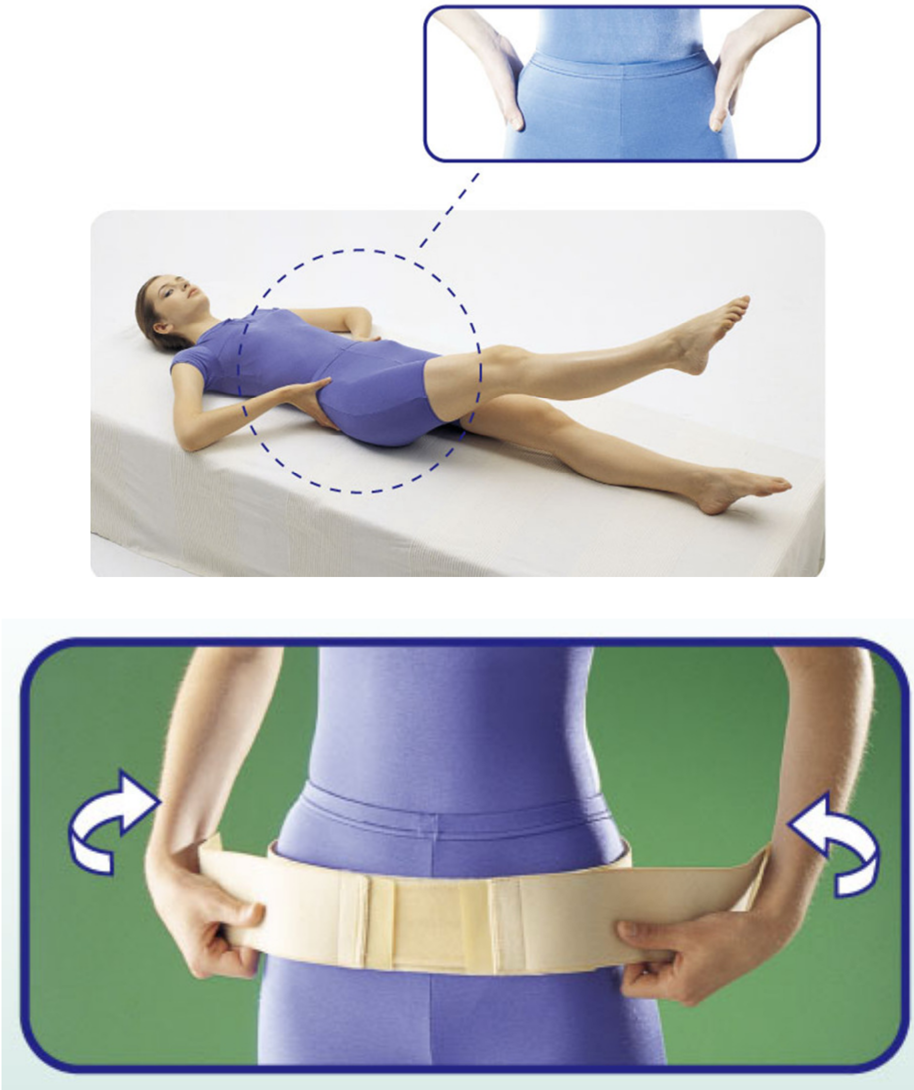


**Figure 4.8. The belt application for the forward facing pelvis. Reproduced with permission, from OPPO Medical Corporation.**

As for the asymmetrical type of pelvis, the pull forces of straps are varied depending on the adjusted directions. (See Figure 4.9 and Figure 4.10). Patients could wear it with different compression forces applied over the two sides by adjusting the direction of the straps and the applied compression forces.

**Figure 4.9. The belt application for the asymmetrical pelvic outlet for the example of right backward and left forward type. Reproduced with permission, from OPPO Medical Corporation.**

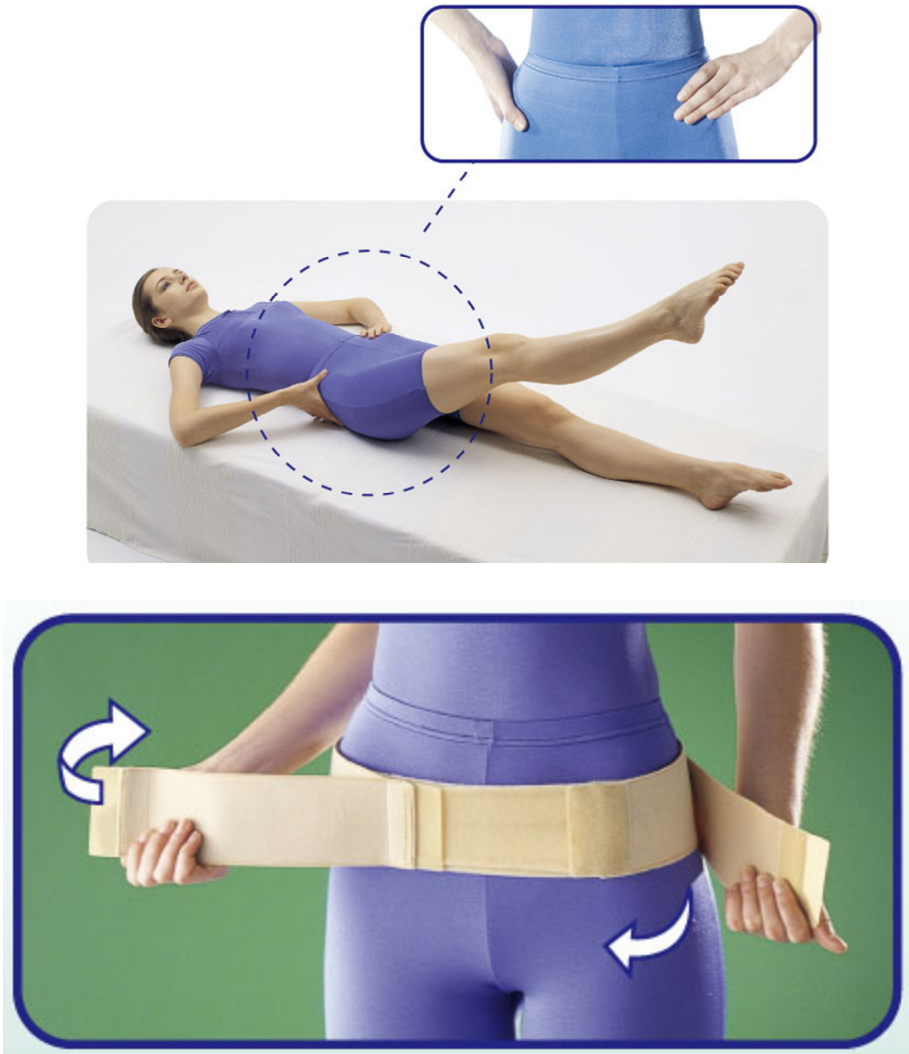
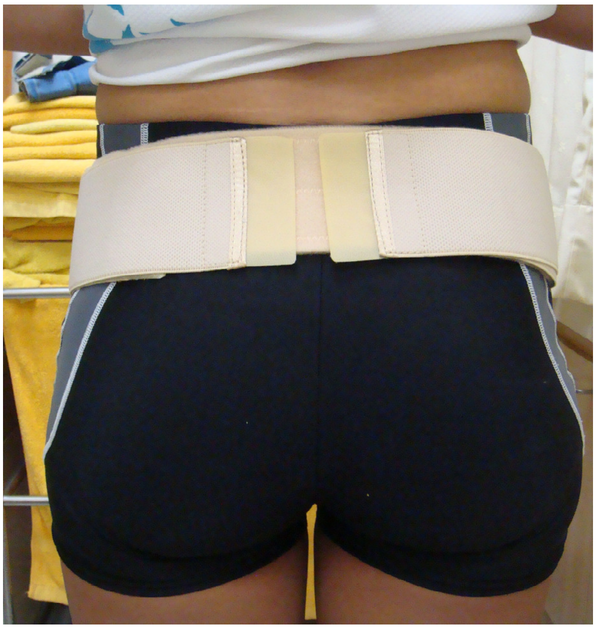


**Figure 4.10. The belt application for the asymmetrical pelvic outlet for the example of right forward and left backward type. Reproduced with permission, from OPPO Medical Corporation.**

The example of application in patients is presented in Figure 4.11 and Figure 4.12. In the example, the alignment of the pelvis was the forward facing type, so the pull of force was from front to back. The degree of pull forces depended on the tolerance of patients to adjust the belt until the most comfortable position was found.

Frontal view

Figure 4.11. The application of pelvic belt – frontal view



Back view

Figure 4.12. The application of pelvic belt – back view

Each patient in the case studies was requested to keep diary to record the length of time of wearing the belt each day and the change in symptoms. They recorded pain on a visual analogue scale, rated 0-10, where 0 was no pain and 10 the worst pain possible. They rated their pain in sitting and standing, and endurance in different positions/ functional tasks during six weeks. Patients were requested to wear for 8 hours in daytime, and come back weekly to follow-up and report any perceived changes.

## 4.8. Outcome measurements of the three techniques

### *4.8.1. Measurements from Ultrasound Imaging*

The measurement of muscle thickness of EO, IO and TrA were taken vertically through the muscle cross-sections, within the border between two muscles, in reference to the middle point of the horizontal scale on the scan (Figure 4.13.). The cursor was placed on the inside edge of the muscle border. Each muscle on each scan was measured twice within a session, taken over two days.

A

B

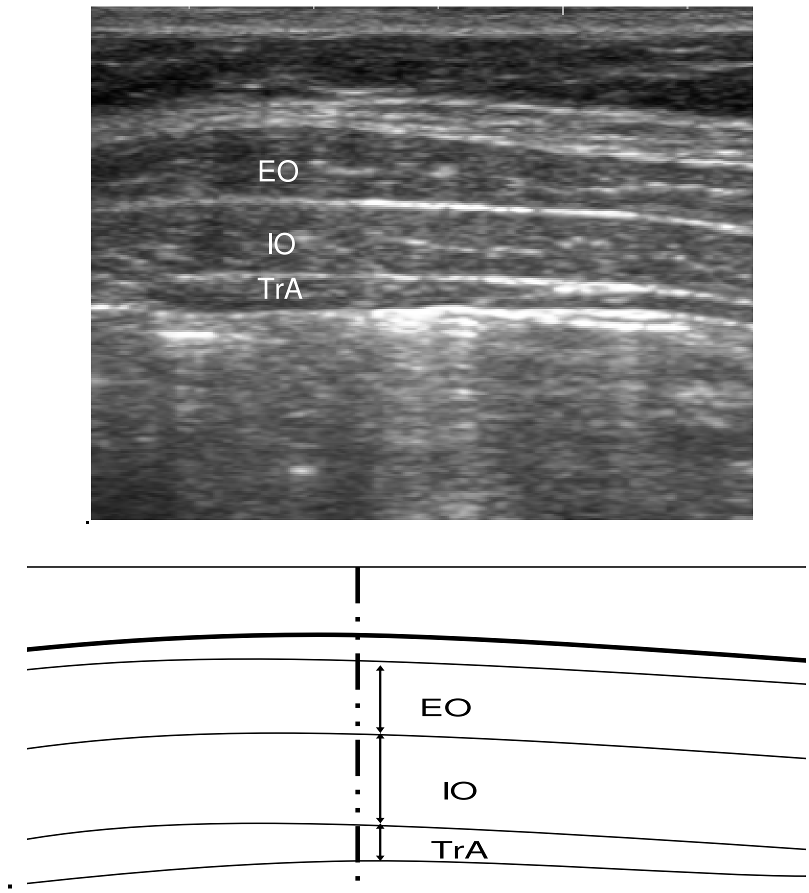



**Figure 4.13 Ultrasound scan of the lateral abdominal wall (A). The muscle thicknesses of three muscles were taken according to the same reference line (dashed line in B).**

The IRD is the gap between the two medial ends of rectus abdominis (RA) bellies, as figure 4.14 shows. The bilateral medial ends were identified by tracking along the superior border and inferior border of RA, to the cross point respectively. After identifying the medial ends of muscles, measurements were taken between two points and the distance was recorded.

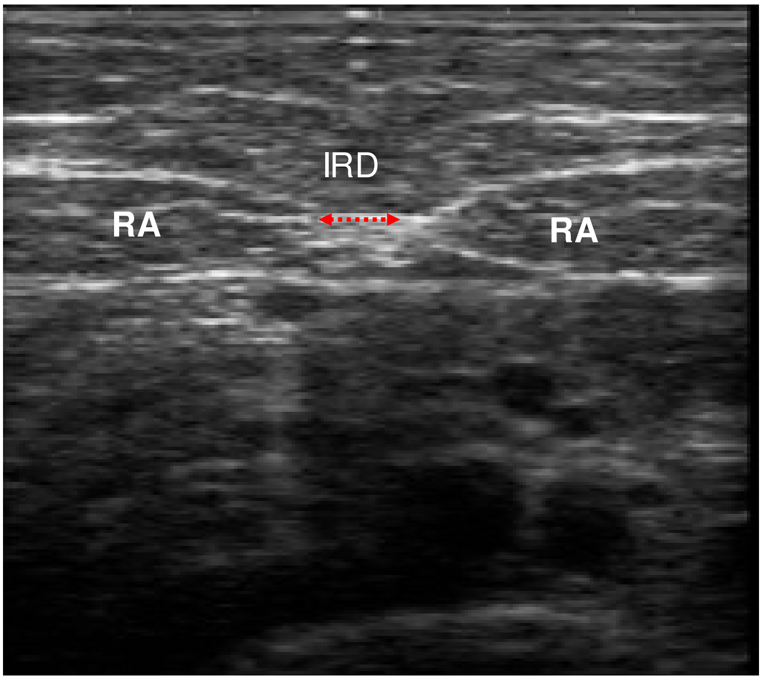
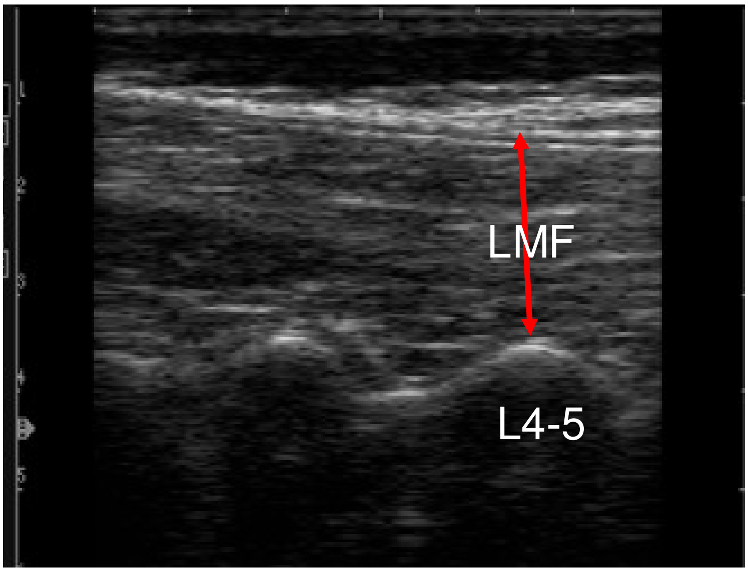



**Figure 4.14 Ultrasound scan of middle fascia. The red arrows indicated the inter-rectus distance (IRD).**

Measurements of thickness of lumbar and sacral multifidus muscles were taken in reference to bony landmarks. The reference points were L4/5 facet joint for lumbar multifidus and the sacral junction for the sacral multifidus (Figure 4.15. A and B). The distance between the reference point and the lower muscle boarder was measured as the thickness of multifidus.

A




B

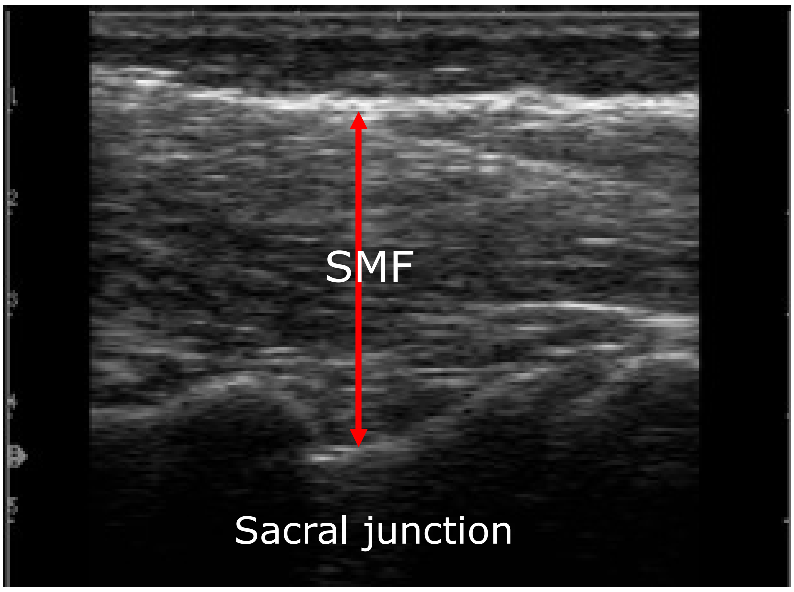



**Figure 4.15. Ultrasound scan of Lumbar multifidus (LMF) (A) and Sacral multifidus (SMF) (B). The red arrows indicated that the measurement of the muscle thickness was taken.**

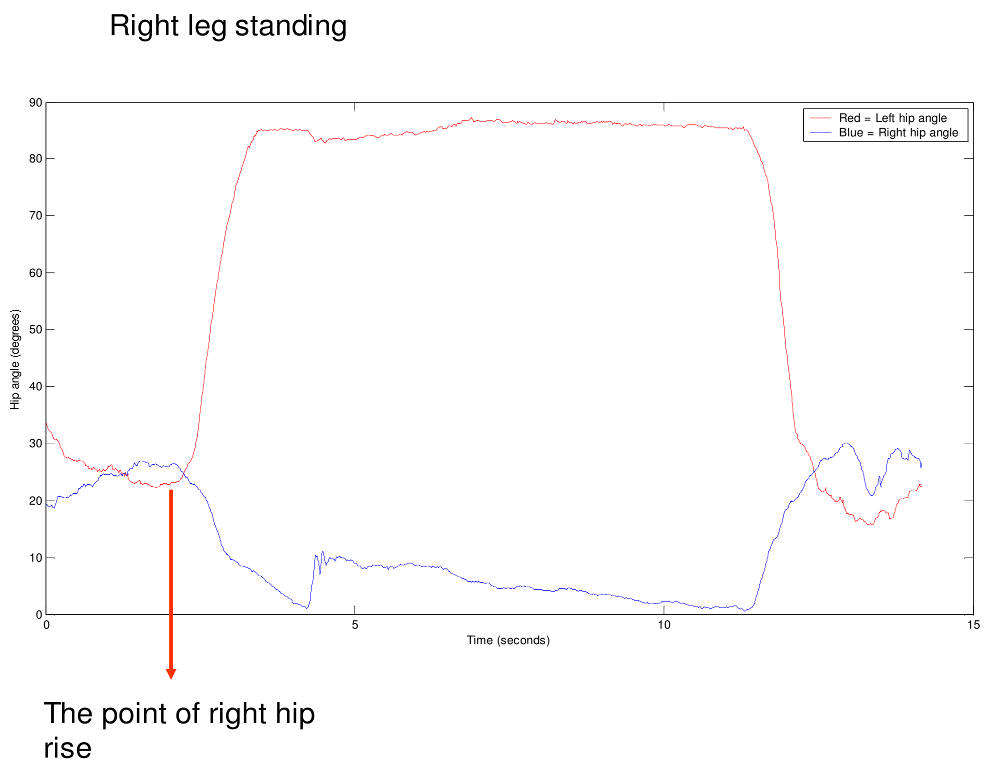
### *4.8.2. Measurement of EMG signals*

***Muscle onset:*** The onset of IO was determined using visual identification. This proved to be more reliable than computer-based methods due to being less affected by factors such as amplitude of background EMG or the rate of increasing activity. Iinterference from movement artefact can be observed and ignored if the situation existed (Hodges and Bui, 1996). Because the main examiner was new to reading EMG and may misjudge the data, the interrater and intrarater reliability of the determination of IO onset were conducted prior to going through the whole analysis.

The second examiner was a Sports Scientist and Experimental Officer experienced in EMG (MW). The 30 trials of one leg standing were randomly selected from 15 subjects. The two examiners calculated the onset time for each trace twice in one trial day, and the measurements were taken on 2 separate days, 3 days apart, to evaluate the reliability of between-traces and between-days.

The muscle onset was determined on the basis of the earliest rise of the EMG signals based on the first large deviation of signals from the baseline measurement. The procedure for analysing IO onset, during the trial of one leg standing, used the earliest rise of hip change as the reference point, to be compared with the earliest point of contra-lateral IO firing (see Figure 4.16.*)*.

***Amount of muscle activity:*** The task of one leg standing was divided into four phases: relaxed standing, hip flexion, holding flexed hip for 5 seconds and back to standing. The root mean square (RMS) of the EMG signal for each muscle was calculated during the holding phase. The muscle activity was normalised maximal as a percentage of activity during MVE, for comparison.



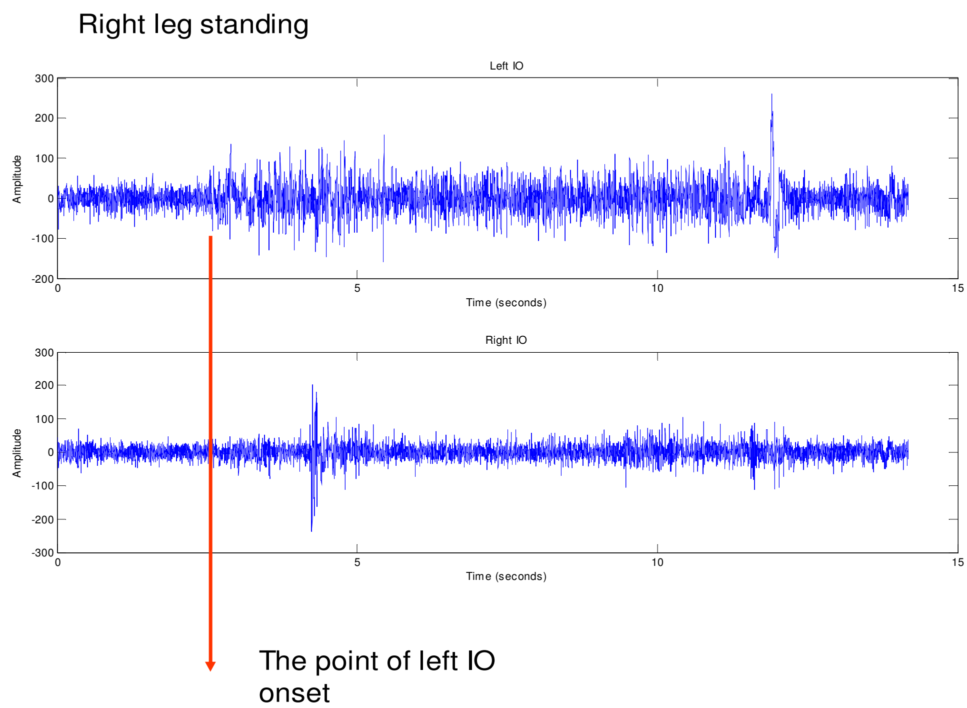




**Figure 4.16. The method for internal oblique (IO) onset determination. The red trace in the upper panel indicates the angles of hip motion and the blue trace indicates the angles of lumbar position.**

#### *4.8.3. Measurements of motion analysis from the VICON System*

The angle data was extracted from each trial using the VICON workstation. The motion range of the lumbar region was reflected in the difference in angle between static standing and the other tasks. The angle of static lumbar position was the average value during the trial of static standing. The task of one leg standing was divided into the same four phases as described above for EMG analysis (see Figure 4.17.). The holding phase was defined as the time between the first and the second turning points of hip flexion.

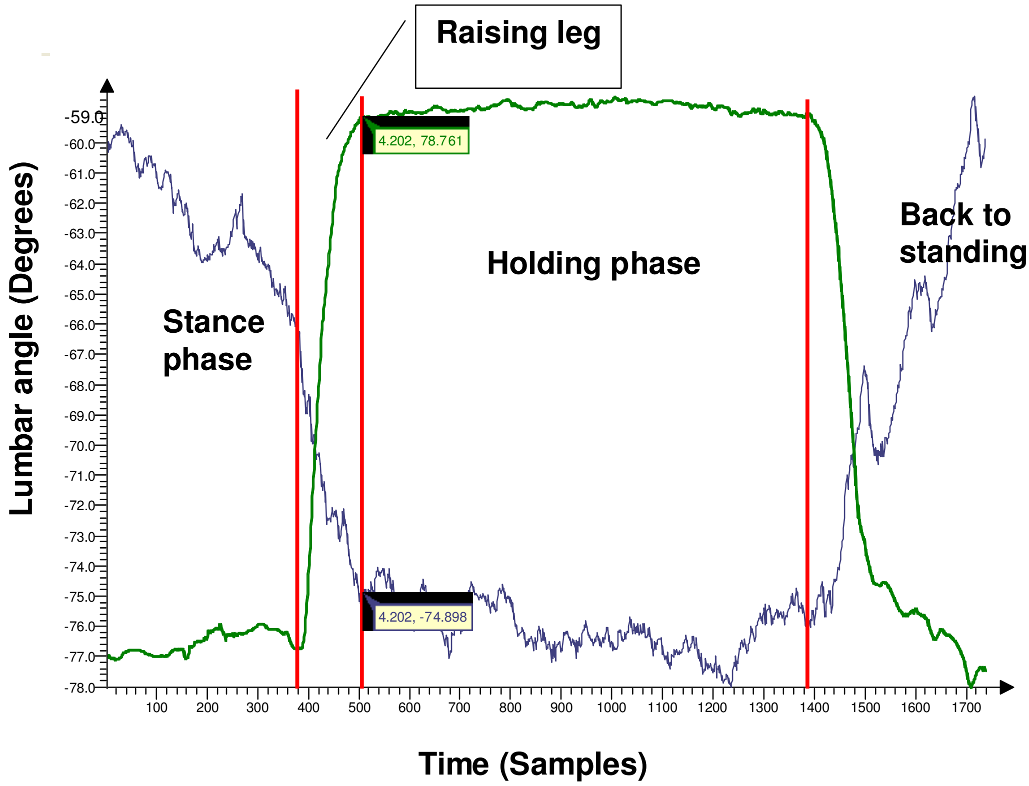



**Figure 4.17. Hip motions during one leg standing. The green trace indicates the angles of hip motion and the blue trace indicates the angles of lumbar position**

For the one leg standing task, the average angle was used from the trial of static standing, in order to make a comparison with the average angle from the holding phase. This was instead of using the standing phase, which had more variation of lumbar angle while performing the task. The lumbar motion range was defined as the difference between static standing and the holding phase of one leg standing (see Figure 4.18.).

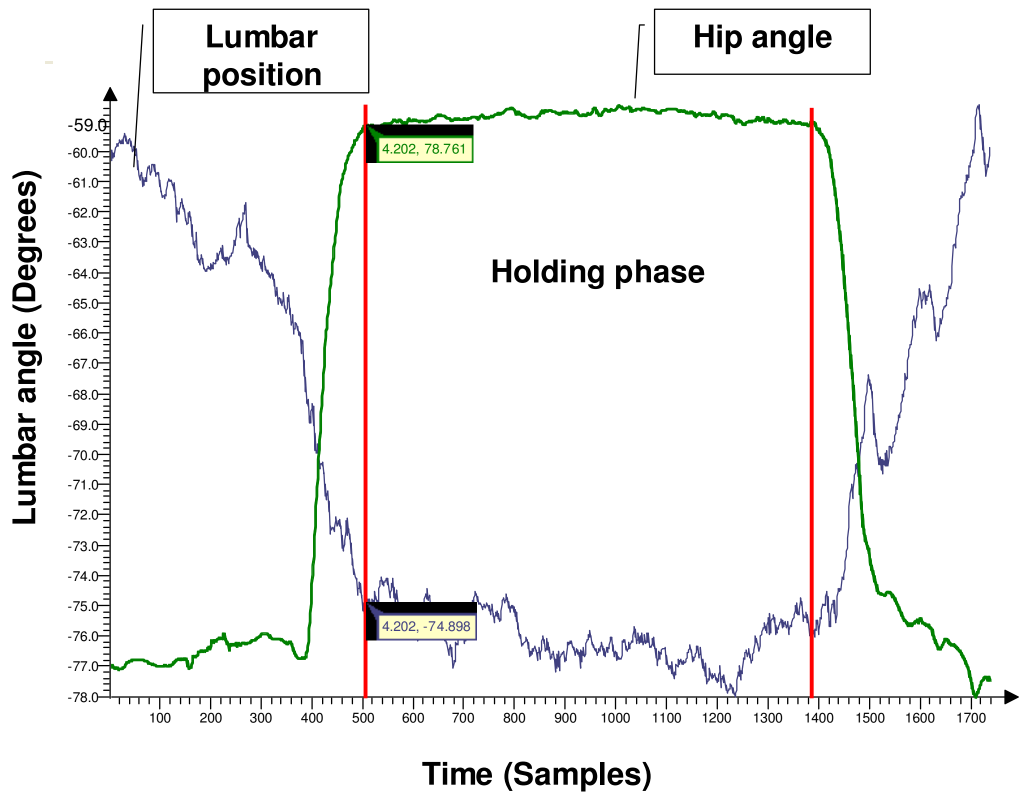



**Figure 4.18. Lumbar position and hip flexion during one leg standing trials. The blue trace indicates the lumbar position angles and the green trace indicate hip angles**

### *4.8.4. Other Anthropometric measurements*

The Flexi curve device was used to document the lumbar curvature between T12 and S2 in the static standing. The Flexi-curve is a rubber ruler which can be applied for record the curved shape of the objects. The examiner placed the flexi curve along the shape of lumbar curvature, and then drew the curve on the paper by tracing alongside the flexi-curve, labelling the ventral and dorsal orientations.

To obtain the ethnic picture of the pelvic girdle and body shape in Taiwanese women, the distances of ASISs and PSISs were measured in static standing. The waist-to-hip ratio (WHR) was calculated after obtaining the separate measurements of waist and hip circumferences. The way to measure the waist circumference was to place the tape measure evenly around the abdomen at the height of the bilateral iliac crests (the top of the bone), while the subject was standing. The subject was requested to breath out normally not “suck in” the stomach while taking the measurement. The hip circumference was measured at the height of the bilateral greater trochanters (GTs).

## 4.9. Reliability

Reliability and validity are prerequisites to all measurements in both clinical practice and research. Reliability means that a measurement is consistent and free from error, and validity assures that a test is measuring what it is intended to measure. The validity of the techniques applied in the present project has been established in the existing (see Chapter 3, Section 3.1.), so this was not the focus of this section. However, a brief overview of the concept of validity is given below (Section 4.10). As for reliability, a common reason for clinicians to perform measurements is to provide essential knowledge for decision-making. The prerequisite of clinical measurement is the acceptable reliability of examiners, measurement devices and the measurements themselves (Bruton et al., 2000). Therefore, the definition of reliability, the reasons for estimating it and how to measure it are described below.

### *4.9.1. Definition of reliability*

Many similar terms are used to present the construct of reliability, such as repeatability, reproducibility, stability, agreement or precision. Herein the term "reliability" refers to the consistency or reproducibility. Theoretically, any *observed score (X)* consists two components: a *true score (T)* and an *error measurement (E)*. The relationship is summarised by the equation

$$X = T \pm E$$

The true component is the score which is a hypothetically true measurement under ideal conditions. The difference between the true value (T) and observe value (X) is measurement error (E). The smaller measurement error indicates a smaller difference between the true value and observed value. To estimate the level of measurements attributable to error and true value is reliability (Portney and Watkins, 2009).

Measurement errors may be systematic or random. Systematic errors are predicable errors, occurring in one direction only, constant and biased. Once systematic error occurs, reliability would not be affected due to the feature being constant. However, the construct of validity would be affected due to the test value not being a true measurement. Random errors occur due to chance and unpredictable factors from trial to trial, so they are the basic consideration of reliability. As random error decreases, the observed score is closer to the true score, and the measurement is more reliable. The importance of reliability for measurement is to ensure the measurement error is small enough to detect actual changes in the measurement (Bruton et al., 2000, Portney and Watkins, 2009).

#### *4.9.2. Types of reliability estimated*

An understanding of reliability and how to estimate it could help clinicians to interpret the findings appropriately. The types of reliability estimation can be divided into three groups: test-retest reliability, rater reliability and instrumental reliability. Instrumental reliability is to estimate the reliability of the measurement device. Intra-rater reliability is to evaluate the reliability of the researcher/observer/ clinician who manipulates the measurement device. Finally, test-retest reliability is to estimate the reliability/ stability of the measured variables (Bruton et al., 2000, Portney and Watkins, 2009). The test-retest reliability and inter-rater reliability are important to establish reliability of experimental protocols which are presented in this chapter.

Test-retest reliability assessment is used to establish that an instrument can be applied to take measurements with consistency. In a test-retest study, the examiner carries out identical tests on two separate occasions, keeping the conditions as constant as possible, e.g. same equipment, same day of the week, same time of day etc. If the test is reliable, the measurements should be similar on different trials. Rater reliability is important for the validity of any research study involving an individual tester or several testers. Rater reliability can be divided into intra-rater reliability and inter-rater reliability. Intra-rater reliability indicates the stability of measures by one individual across two or more trials. Inter-rater reliability concerns variation between two or more raters who measure the same group of subjects. It is important to apply appropriate statistical analyses when assessing the different types of reliability and these are discussed in the next section.

#### *4.9.3. Statistical analyses used to assess reliability*

Traditionally, test-retest reliability has been analysed using Pearson's correlation coefficient. However, Pearson's correlation provides information regarding the consistency of the scores between repeated measures but does not account for systematic differences which may occur between repeated measures. The Intra-class Correlation Coefficient (ICC) has become the preferred index due to it reflecting both correlation and agreement. Standard error of measurement can provide the information of stability in measurements (Rankin and Stokes 1998; Bruton et al., 2000; Portney and Watkins, 2009). Other complimentary tests are Bland and Altman analysis (to test agreement and indicate bias), standard error of measurement (SEM; to test precision) and smallest detectable change (SDC; to give a clinically meaningful measure of error, outside which any change can be considered due to effect of pathology or intervention and not due to measurement error). These tests are outlined below.

*Intra-class Correlation Coefficient (ICC)*

Reliability can be expressed as a ratio of the true score variation to the total variance, termed a reliability coefficient. The ratio indicates that the reliability increases as the observed score approaches the true score. Therefore, minimal zero error is perfect reliability with a coefficient of 1, due to the observed score being the same as the true score.

The ICC analysis is a statistical method designed by (Bartko, 1966), commonly used for assessing the consistency and agreement between two or more measures, and also used as the index for reliability to indicate measurement error. The reliability coefficient indicates the percentage of the variability between subjects, and the remaining percentage of repeated trials in the same sessions or in different sessions on different days. The ICCs are calculated from results obtained from analysis of variance (ANOVA) for repeated measurements. There are six forms of ICC called (1,1) (2,1) (3,1) (1,k) (2,k) (3,k). Each form is appropriate for different study designs. The six types of ICC are classified using two numbers in parentheses. The first integer (number 1, 2, or 3) relates to 3 different study designs (models), and the second integer (1 or k) refers to the unit of analysis using either a single measurement (1) or the mean of several measurements (k). Mean scores will nearly always generate higher reliability coefficients than individual scores

For inter-rater reliability, ICC models 2 and 3 can be used, depending on whether the raters are representative of other similar raters (model 2) or where no generalisation is intended, model 3 is used. For intra-rater reliability, model 3 is recommended (Portney and Watkins, 2009).

*Model of the ICC: random effects and fixed effects*

In model 1, each subject is assessed by a different set of *k* raters randomly chosen from a large population of raters. Herein, the rater is considered as a random effect. However, the raters for one subject are not necessarily the same raters that take measurements on another subject. The only variance that can actually be assessed is the difference among subjects. This analysis could be appropriate for studying reliability before providing data from single case studies or multicentre trials. This analysis is calculated using one-way ANOVA:

$$\text{ICC}(1,1) = \frac{\text{Subject variability}}{\text{Subject variability + within-subject variability}}$$

Model 2 is the most commonly applied model of ICC for assessing inter-rater reliability. In this design, subject and rater are both random effects. This randomness may be only theoretical in practice. The chosen raters and the subjects are believed to represent the population of interest, e.g. physiotherapists. But the intent of this study is to demonstrate that the measurement reliability can be applied to others.

$$\text{ICC}(2,1) = \frac{\text{Subject variability}}{\text{Subject variability + rater variability +random error variability}}$$

In model 3, each subject is assessed by the same set of raters, but the raters represent the only raters of interest, e.g. within a given study. There is no intention to generalise findings beyond the rater(s) involved. Rater is considered as a fixed effect due to being chosen and not random. Subjects are still considered a random effect. Therefore, model 3 is a mixed model. Model 3 is also the appropriate statistic to measure intra-rater reliability, as the measurements of a single rater cannot be generalised to other raters.

$$\text{ICC}(3,1) = \frac{\text{Subject variability}}{\text{Subject variability +random error variability}}$$

*Forms of ICC: Singe and average ratings*

Each of the ICC models can be expressed in two forms, depending on whether the scores are single ratings or mean ratings. Using mean scores has the effect of increasing reliability estimates, as means are considered better estimates of true scores, theoretically reducing error variance. Versions (1,k) (2,k) and (3,k) are used only when the unit of analysis is the **mean** measurement obtained from more than one measurement or more than one rater. Thus **k** can refer to either the number of measurement repetitions or the number of raters.

In the present study, model ICC 3, k was used for intra-rater reliability due to the observer being a random factor. This chosen form of ICC can decrease the possibility of a systematic error. As for inter-rater reliability of muscle onset determination during one leg standing (Chapter 8, Section 8.4.3), the two-way random model was used (ICC 2, k). In current practice, “excellent repeatability” is defined as the ICC values in the range of 0.8-1 and ““good repeatability” in the range of 0.6-0.8, while the values below 0.6 indicate poor reliability (Bartko, 1966). The value of 0.7 is recommended as a minimum standard for reliability (Terwee et al., 2007).

***Standard error measurement*:** the SEM is used to estimate the reproducibility of measures on the same instrument, and was calculated to assess the precision of the measures obtained. The more reliable the measurement, the less variability there would be around the mean. The formula of SEM is defined in terms of the standard deviation (SD) of the observed scores and the reliability (R) from ICC (or other index of reliability) as:

$$\mathbf{SEM = S\sqrt{1 - r_{xx}}}$$

This equation indicates the relationship between ICC and SEM. When the ICC is 1.0, then there is no measurement error and the SEM is 0. In the other words, if the value of ICC is zero, then the SEM equals the SD of observed scales. The different information from the ICC and the SEM was like what Streiner and Norman (2008) summarised as "*the ICC (or any other index of reliability) reflects the scale's ability to differentiate among people; whereas the SEM is an absolute measure, and quantifies the precision of individual scores within the subjects (Weir, 2005)*" (Streiner and Norman, 2008, Weir, 2005).

***Bland and Altman test*:** this test was originally designed for method comparison studies (Bland and Altman,1999) but it can also be applied to test-retest reliability studies (Rankin and Stokes, 1998, Bland and Altman, 2007). This approach is used for pairs of measurements and begins with a plot of the difference between the two measurements against the mean of the pairs of measurements. The average difference in the measurements and the SD of the differences are calculated prior to the plot. The limits of agreement equal to the mean difference ± twice the SD. In the distribution plot, the mean average and the limits of agreement are defined as shown the example on Figure 4.19. There was one spot fell outside of the confidence interval, and indicated a trial reported larger variation. The majority of spots were close the central line which indicates small and acceptable variation between the measurements obtained at two different days. The plot showed a good agreement in TrA muscle thickness between days.

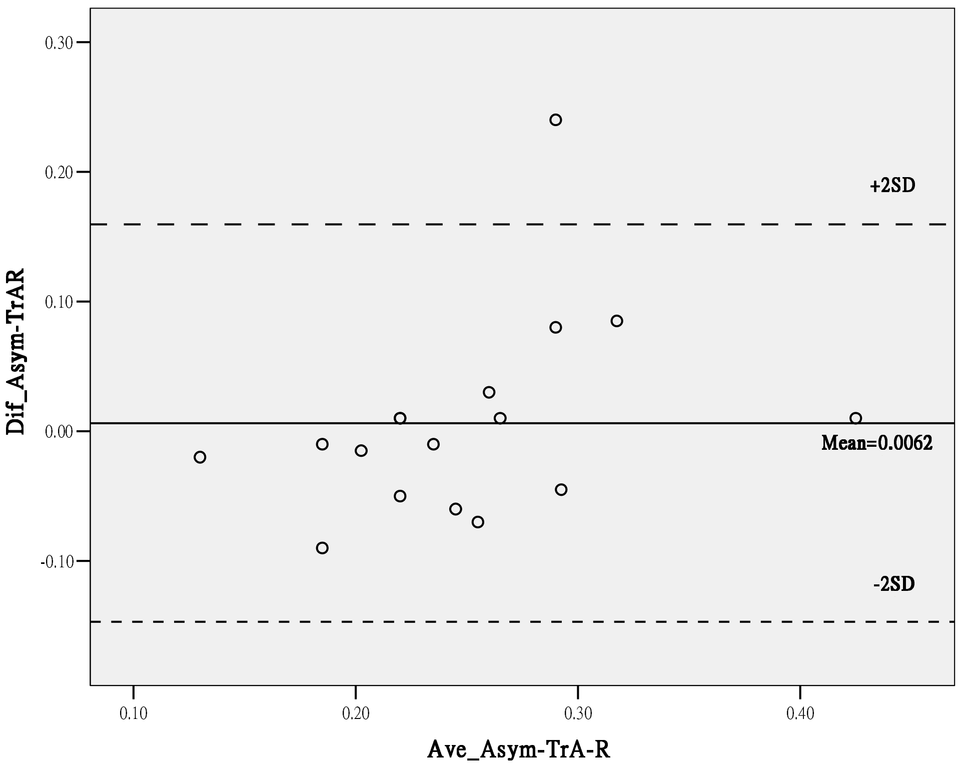



**Figure 4.19 Example Bland and Altman Plot showing the between-days reliability in TrA at rest**

***Smallest detectable change***: the SDC has been defined as *"the smallest difference in scores in the domain of interest which patients perceived as beneficial and would mandate, in the absence of troublesome side effects and excessive cost, a change in the patients' management"* (Jaeschke, Singer, Guyatt, 1989). The SDC indicates that this approach is to provide an indication of clinically meaningful variations in measurements. Terwee et al. (2007) stated that the formula of SDC is defined in terms of SEM

$$SDC=1.9\times\sqrt{2}\times SEM$$

**4.10 Validity**

Validity assures that a test is measuring what it is intended to measure and is defined to infer the degree of a meaningful interpretation from a measurement or test. Validation procedures of measurement are based on a process of hypothesis testing related to providing evidence to support validity, which is defined according to four types: face validity, content validity, construct validity and criterion-related validity Portney and Watkins (2009).

Face validity means that instrument appears to test what it is supposed to measure and is the weakest form of validity. For scientific purposes, face validity is not sufficient to document validity of a test due to lack of ability to judge or determine the degree of validity an instrument has. Content validity is about the adequacy of a sample to represent parts of the whole. The determination of content validity is essentially a subjective process defined by researchers and no statistical indices can be used for assessing the type of validity. As for construct validity, it is based on content validity where the content can be defined. It reflects the ability of an instrument to measure an abstract concept or construct. The process of construct validation demonstrates difficulties, as the constructs are not “real” and indirectly observable, so it only exists as an abstract concept.

The most practical and objective approach to validity testing is criterion-related validity, which is based on the ability of a test to predict results from an external criterion. This type of validity is tested by comparing a new type of measurement against a ‘gold standard’, to see if the target test being validated can be used as a substitute measure for an established reference standard. Criterion validity is often divided into two components of concurrent validity and predictive validity. Concurrent validity is to establish validity of two measurements taken at the same time to reflect the same incidence. It is most often used to assess a target test against a gold standard. An example of this is comparing measurements of muscle size made using ultrasound imaging compared with the gold standard of magnetic resonance imaging (see Section 3.1). The other component is predictive validity used to establish the outcome of a target test as a valid predictor of some future criterion score, outcome or risk.

## 4.11. Data analysis strategy

### *4.11.1. Descriptive findings*

The demographic features of age, body mass, height and body mass index (BMI) are presented in the descriptive statistics for the healthy participants and patients. The descriptive analysis was applied to the outcomes of the three techniques used:

(1) Muscle thickness measurements at rest and changes in thickness during the test manoeuvres in the muscles investigated
(2) Angle changes of lumbar position and pelvic tilting during functional tasks
(3) Latency between IO EMG signal firing and movement commencement

In healthy participants, the sides were defined as dominant and non-dominant sides; in patients, the sides were defined as symptomatic and asymptomatic sides. Some patients reported equal symptoms on both sides, and then the author observed the configuration of gluteal muscles to define whether more muscle atrophy presented on the symptomatic side.

The normality of data was assessed before further analysis. The Kolmogorov-Smirnov test (D value) and the Shapiro-Wilk test (W value) are the two common tests used to assess the normal distribution of data (Pallant, 2007). If the sample size is larger than 50, the Kolmogorov-Smirnov test is used; alternatively, if the sample size is under 50, Shapiro-Wilk test will be more reliable. If the D or W value is under 0.05, it indicates a rejection of the null hypothesis and means that the data is normally distributed. A paired sample t-test was used to further examine the difference between sides in the same group, and a two way analysis of variance (ANOVA) was used to examine the variation between sides to confirm the stability of the variation of scores, in particular in the thickness of the abdominal muscles.

#### *4.11.2. Reliability for between-scans and between days (ICC, Bland-Altam plot, SEM, SDC) in pilot work and the main study*

The data analysis of ultrasound imaging was conducted using the statistical methods listed below. The descriptive findings of the measurements taken were displayed. The intraclass correlation coefficients (ICCs), standard error of measurement (SEM), smallest detectable change (SDC) and Bland and Altman tests were adopted for reliability studies, as discussed above, and also were considered as the appropriate statistical methods for repeated measurement of muscle thicknesses (Hopkins, 2000, Rankin and Stokes, 1998, Spies-Dorgelo et al., 2006, de Vet et al., 2006).

#### *4.11.3. Comparison of difference between groups*

The independent sample t-test was used to compare the findings of descriptive analysis on the outcomes, to assess the differences between groups. As for further exploring the factors affecting the outcome from ultrasound imaging, the healthy participants were divided into younger and older age groups, and into three BMI groups. Patients were divided into two groups, those with and without scoliosis. The findings for the different techniques are described in the relevant following chapters.

### 4.12. Concluding Comments

In this chapter, the methodologies in the two studies in Southampton and Taiwan were detailed. The procedures for recruitment of healthy participants and patients were described. The reliability of the RUSI technique of the author and experimental protocols were established in the study in Southampton. Due to the limitation of only young participants being available in Southampton, age-match controls could not be achieved. Therefore, senior healthy women were further recruited in Taiwan, along with patients with coccydynia. The detailed methodologies in the two studies in Southampton and in Taiwan were described in this chapter. The outcome measurements and data analysis of the three techniques used were also described. The next chapter presents the findings of muscle thickness using the ultrasound imaging technique and the subsequent chapters present the findings from motion analysis and EMG in patients and healthy participants.

# Chapter 5: Ultrasound imaging of muscles of the lumbopelvic region: reliability of muscle thickness measurements and differences in muscle characteristics between coccydynia patients and healthy participants

## 5.1 Introduction

It is important to establish the reliability of clinical assessment tools by evaluating the degree of variance over repeated measurements. In this chapter, the findings of the rehabilitative ultrasound imaging (RUSI) skills that were examined as described in Chapter 4 are presented, as well as the comparisons in muscle characteristics associated with different ages and the presence of coccydynia. The reliability of RUSI could be affected by many possible factors, as discussed in Section 3.1.2. Standardising the ultrasound protocol is a way to further ensure reliability of the technique during specific tasks.

## 5.2 Aims, Research Questions and Hypotheses

### *5.2.1. Aims*

1. To examine the intra-rater reliability within a session and on different days for measuring thickness of the abdominal and multifidus muscles in healthy participants and patients with coccydynia.
2. To compare the muscle characteristics between female patients with coccydynia and healthy age-matched controls

### *5.2.2. Research question*

Are there any differences in the changes in muscle thickness on ultrasound ultrasound images of the lumbopelvic muscles at rest and during an active straight leg raise (ASLR) between patients with coccydynia and healthy age-matched controls?

### *5.2.3. Research hypotheses*

1. Patients with coccydynia will demonstrate thinner muscle size of transversus abdominis at rest than in healthy age-matched controls.
2. Patients with coccydynia will demonstrate less thickness change in the transversus abdominis (TrA) muscle than healthy age-matched controls than during a functional task.

## 5.3 Methods

### *5.3.1. Participants*

Studies in this chapter involved different groups of participants: a) pilot reliability study in Southampton on healthy young Taiwanese women; b) reliability and main comparative studies in Taiwan, on patients with coccydynia (generally older than the healthy participants in Southampton) and healthy age-matched controls.

The recruitment processes for the different groups are described in Chapter 4 (Section 4.4.1). The inclusion and exclusion criteria for the healthy participants and patients are were as described in Sections 4.4.2 & 4.4.3, respectively, as summarised in Table 4.2. The numbers and ages of the participants involved in the studies included in the present chapter were:

Reliability studies (see Table 5.9):

a. healthy young group in Southampton: n= 16, aged 23-34 years

b. patients in Taiwan: n=17, aged 35-65 years

Comparative studies (see Table 5.9)

a. patients in Taiwan: n=17, aged 35-65 years (same group as above)

b. healthy age-matched controls in Taiwan: n=17, aged 23-65 years

The studies were approved by the local ethics committees in Southampton and Taiwan (see Chapter 4, Section 4..4.4 and Appendix 13.1), and written, informed consent was obtained from all participants (Appendix 13.2).

#### *5.3.2. Experimental protocol*

The bilateral abdominal muscles and multifidus of sacral and lumbar areas, and inter-rectus distance were investigated. Muscle thickness was scanned at the end of expiration to standardise the influence of respiration (Ainscough-Potts et al., 2006). The protocol for scanning the lateral abdominal areas was based on the study made by Rankin et al 2006 to examine the bilateral lateral abdominal muscles. The probe was placed halfway along the mid-axillary line between the ribcage and anterioir superior iliac spine (ASIS; (Rankin et al., 2006) and then the probe was moved to position the targeted image on the screen as centrally as possible. The subjects were requested to extend their left leg, then activate their transversus abdominis (TrA) muscle by a left active straight leg raise (ASLR) for 3 seconds, lifting 5 cm off the plinth to touch a ruler while the right leg was maintained in flexion (see Figure 4.2.). The investigator requested the subjects to do the task whilst slightly contracting their gluteal muscles and drawing in their abdomen.

In the protocol for observing the midline abdominal fascia, the width between bilateral rectus abdominis, the inter-recti distance (IRD), was measured following the protocol of Coldron et al (2007). The author placed the transducer transversely superior to umbilicus to take a resting image of the midline abdominal fascia (Coldron et al., 2007). After obtaining a resting image, the investigator asked the subject to lift their head 5 cm off the plinth until their forehead touched a ruler held by a stand (Fig 4.3), in order to gain the image of muscles in contraction while the probe was at the same position. In the protocol for observing lumbar and sacral multifidus, subjects were placed in a prone position, with two pillows under the waist to keep the lumbar spine in the neutral position. The angle of the probe was manipulated to achieve clear images of L4-5, and then subjects were asked to load their spines by lifting their right leg 3 cm off the plinth to obtain the image of muscles in contraction. The same procedure was used to obtain the images of L5-S1.

The test-retest reliability of this technique was investigated by the author to measure muscle thickness of abdominal muscles and multifidus of the sacral and lumbar areas in healthy participants, using the protocols established in the developmental pilot work carried out in the UK (2008), as outlined in Chapter 4 (Section 4.5). The same protocol was carried out in Taiwan to establish the reliability of RUSI in patients with coccydynia in 2009. The difference between the two protocols is that multifidus was scanned bilaterally in the 2009 in Taiwan study and was only performed unilaterally (left side) in the earlier 2008 study in Southampton.

## 5.4. Results

The descriptive analysis of demographic data and the differences between groups are presented, followed by reliability of thickness measurements of muscles.

### *5.4.1. Characteristics of participants in the two reliability studies*

The demographic data of healthy participants and patients in the reliability studies of RUSI in the two data collection sites are listed in Table 5.1. The age range of the patient group was wider and older than the healthy participants, and the average BMI value was also larger in patients than in the healthy group.

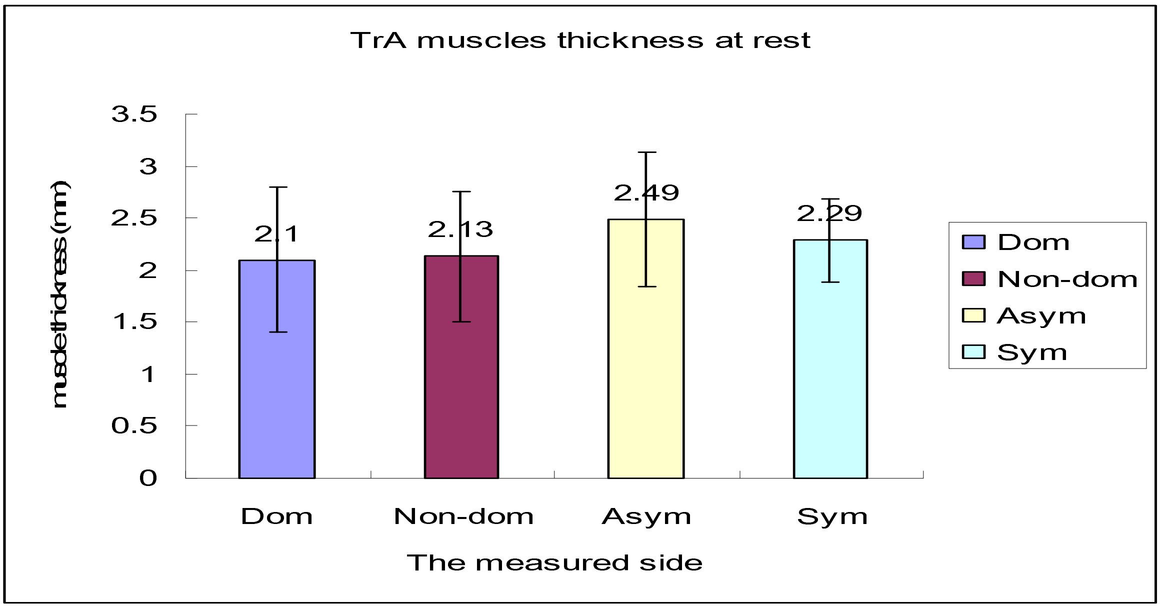
**Table 5.1. Demographic data of the participants for the two reliability studies**

| | **Healthy participants (n=16) UK** | | **Patients ( n=17) Taiwan** | |
|---|---|---|---|---|
| | **Mean (Range)** | **SD** | **Mean (Range)** | **SD** |
| **Age (years)** | 25.9 (23-34 ) | 3.26 | 42.1 ( 23-62) | 11.6 |
| **Height (m)** | 1.6 (1.45-1.7 ) | 7.55 | 1.58 (150-169) | 0.05 |
| **BW (kg)** | 52.8 ( 44.5-64.5) | 7.55 | 58.1 (45-75) | 8.6 |
| **BMI (kg/m$^2$)** | 20.4 ( 17.09-25.84) | 2.26 | 23.2 (17.9-31.8) | 3.5 |

### *5.4.2 Muscle thickness measurements for the two reliability studies in healthy young participants and patients*

The average thickness measurements of investigated muscles in the lumbopelvic region at rest and during contraction are illustrated in Figures 5.1-5.3. In healthy participants, the measured sides were divided into the dominant and non-dominant sides; in patients, the measured sides were classified as the symptomatic side and asymptomatic side. In the Table 5.2., the descriptive findings of muscle thickness of lumbar multifidus (LM) and sacral multifidus (SM) are presented. The normality of the data was assessed, and no significant result ($P>0.05$) was presented to indicate lack of normal distribution of scores. A paired sample t test was used to compare the abdominal muscles of the dominant and non-dominant sides in healthy participants and between the symptomatic and asymptomatic sides in patients, and no significant difference between sides was found in either group ($p>0.05$). The independent sample t test was used to compare the two groups. A significant difference in thickness change in IO was found between groups ($p<0.05$).

A.




B

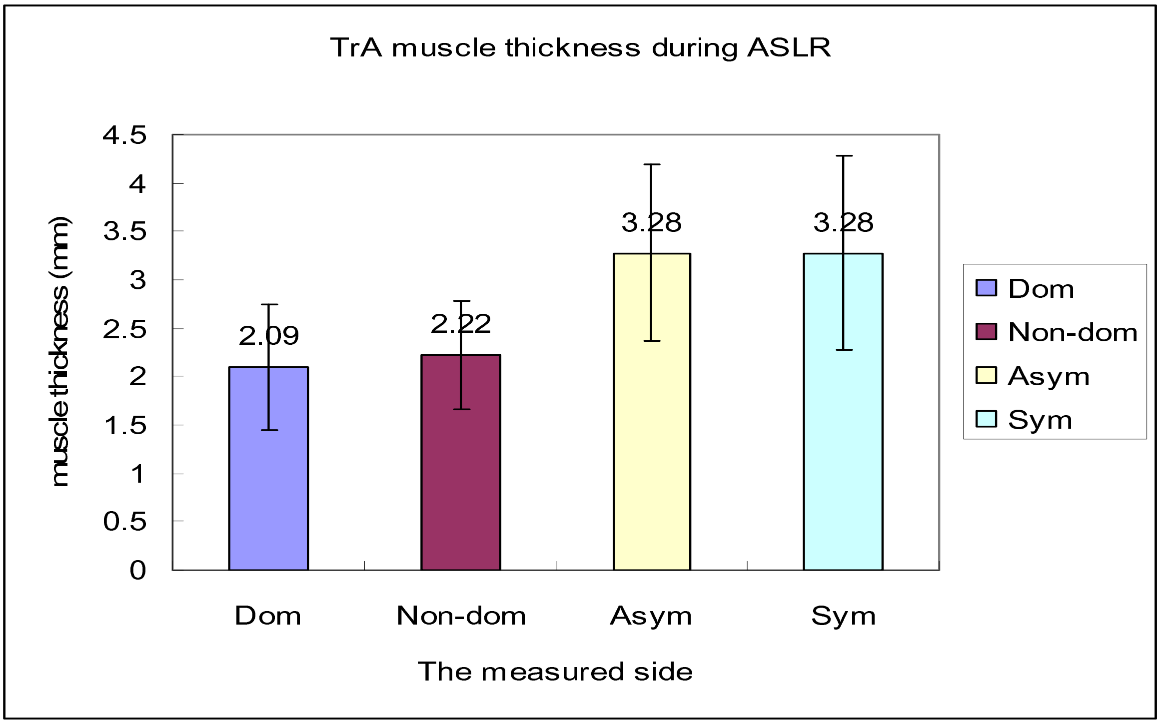
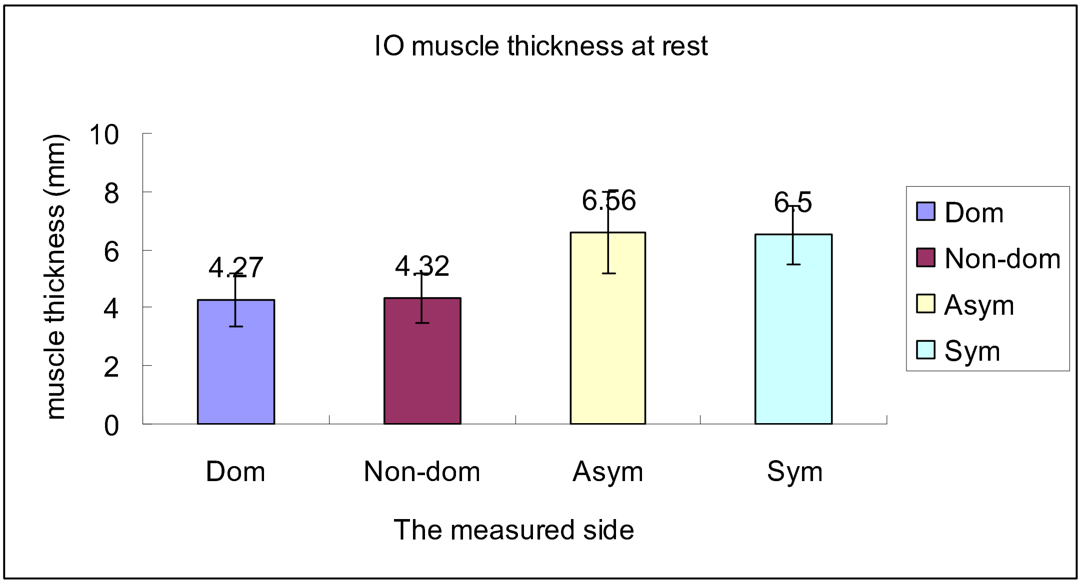



**Figure 5.1. The bar-plots indicate TrA muscle thickness in different muscle contraction states: A- at rest; B- during active straight leg raise (ASLR) in the patients with coccydynia (n=17) and young healthy group (n=16)**

A.




B.

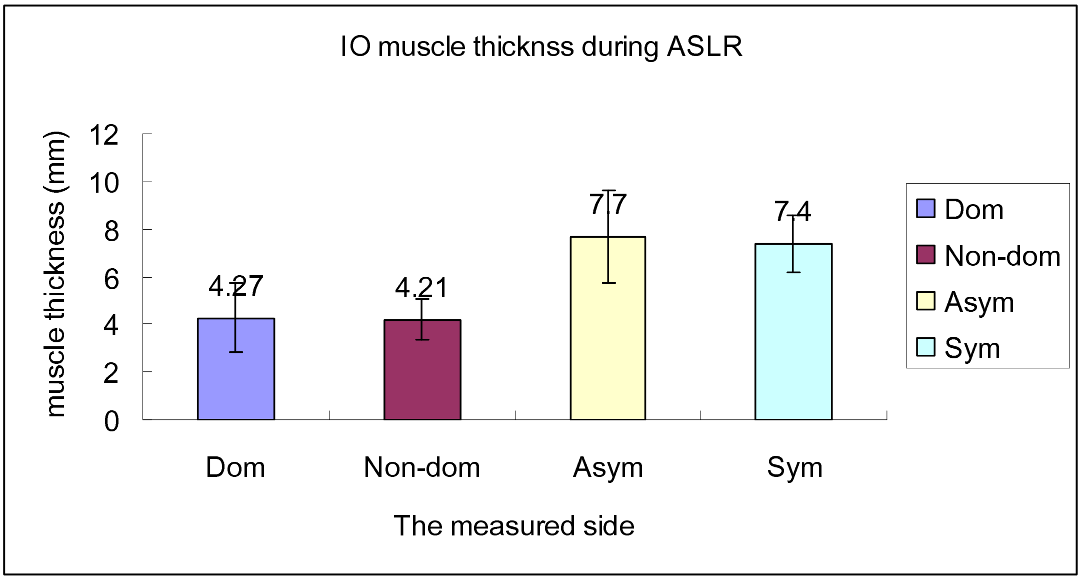
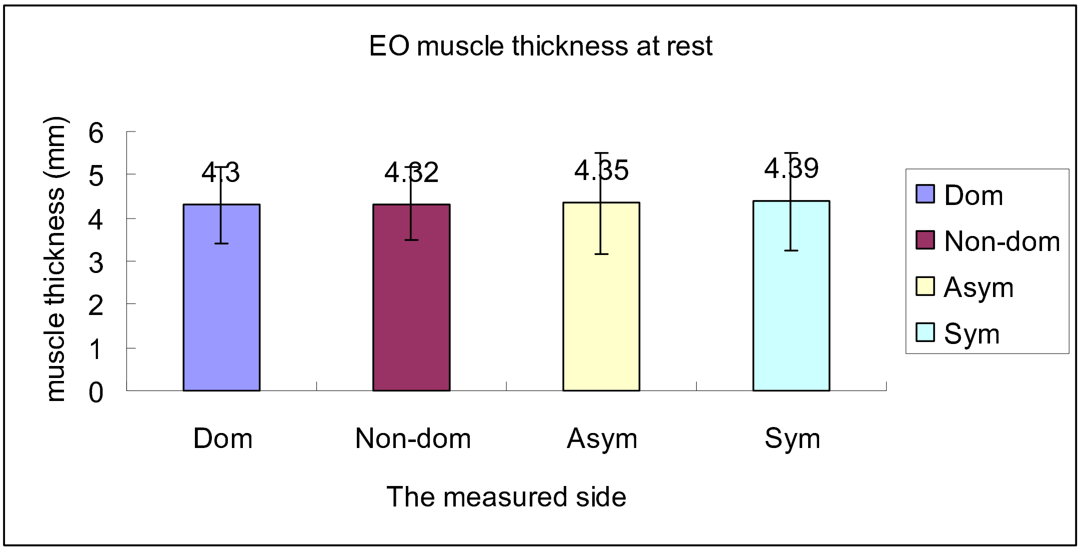



**Figure 5.2. The bar-plots indicate internal oblique (IO) muscle thickness in different muscle contraction states: A- at rest; B- during active straight leg raise (ASLR) in the patients with coccydynia (n=17) and the young healthy group (n=16).**

A.




B.

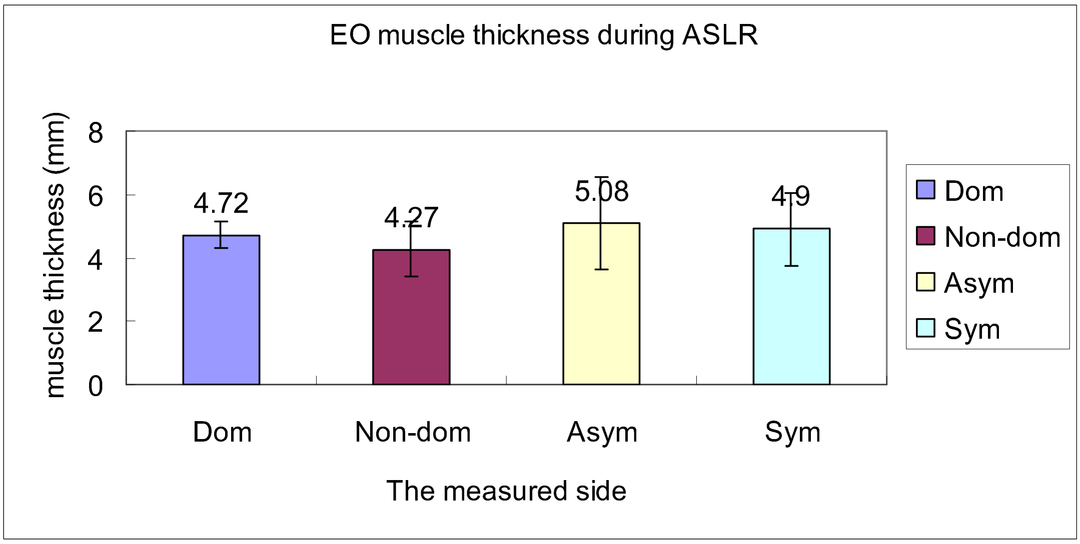



**Figure 5.3. The bar-plots indicate the EO muscle thickness in different muscle contraction states: A- at rest; B- during active straight leg raising (ASLR) in the patients with coccydynia (n=17) and the young healthy group (n=16)**

**Table 5.2. Descriptive findings of muscle thickness of lumbar multifidus (LM) and sacral multifidus (SM), in states of rest and contraction, in patients with coccydynia (n=17) and young healthy participants (n=16)**

| Side-Status | Healthy (16) | | Side-Status | Patients ( 17) | |
|---|---|---|---|---|---|
| **Lt-Rest** | **Mean (mm)** | **SD (mm)** | **Sym-Rest** | **Mean (mm)** | **SD (mm)** |
| LM | 27.37 | 6.08 | LM | 26 | 3.9 |
| SM | 32.31 | 5.31 | SM | 33.9 | 4.78 |
| **Lt-Contraction** | | | **Asym-Rest** | | |
| LM | 31.49 | 5.98 | LM | 26.33 | 3.76 |
| SM | 35.56 | 5.68 | SM | 34.5 | 4.25 |
| | | | **Sym-Contraction** | | |
| | | | LM | 30.28 | 3.59 |
| | | | SM | 37.67 | 4.29 |
| | | | **Asym-Contraction** | | |
| | | | LM | 31.77 | 4.61 |
| | | | SM | 38.37 | 4.71 |

### *5.4.3. Reliability of RUSI muscle thickness measurements in healthy participants*

High ICCs ranging from 0.7 to 0.99 were found between-scans and between-days, both at rest and during contraction for abdominal muscle thickness (Table 5.3). Reliability for the IRD was acceptable at rest (0.86-0.99) between scans and between days, and during contraction between-scans (0.86-0.99) but not between days ICC 0.13 (Table 5.4).

**Table 5.3. Results for intraclass correlations (ICCs), standard error measurement (SEM) and smallest detectable change (SDC) in the lateral abdominal muscles in healthy young participants (n=16)**

**Between-scans measurements**

| | **TrA** | | | **EO** | | | **IO** | | |
|---|---|---|---|---|---|---|---|---|---|
| Side/States | ICCs | SEM (mm) | SDC (mm) | ICCs | SEM (mm) | SDC (mm) | ICCs | SEM (mm) | SDC (mm) |
| Rt/Rest | 0.91 | 0.22 | 0.15 | 0.95 | 0.22 | 0.16 | 0.96 | 0.21 | 0.15 |
| Rt/ASLR | 0.91 | 0.24 | 0.16 | 0.93 | 0.41 | 0.29 | 0.94 | 0.28 | 0.2 |
| Lt/Rest | 0.9 | 0.18 | 0.13 | 0.9 | 0.23 | 0.16 | 0.94 | 0.25 | 0.17 |
| Lt/ASLR | 0.94 | 0.15 | 0.11 | 0.99 | 0.06 | 0.05 | 0.99 | 0.12 | 0.09 |

**Between-days measurements**

| | **TrA** | | | **EO** | | | **IO** | | |
|---|---|---|---|---|---|---|---|---|---|
| Side/States/ Day | ICCs | SEM (mm) | SDC (mm) | ICCs | SEM (mm) | SDC (mm) | ICCs | SEM (mm) | SDC (mm) |
| Rt/Rest | 0.9 | 0.22 | 0.15 | 0.83 | 0.36 | 0.25 | 0.77 | 0.44 | 0.3 |
| Rt/ASLR | 0.75 | 0.33 | 0.22 | 0.84 | 0.57 | 0.4 | 0.7 | 0.52 | 0.36 |
| Lt/Rest | 0.87 | 0.23 | 0.15 | 0.83 | 0.35 | 0.24 | 0.91 | 0.09 | 0.06 |
| Lt/ASLR | 0.89 | 0.19 | 0.13 | 0.83 | 0.36 | 0.25 | 0.75 | 0.5 | 0.35 |

$1^{st}$ and $2^{nd}$ = mean of scans on the first and second days respectively;

Rt and Lt = mean values for the right and left sides.

Reliability for the lumbar and sacral multifidus muscles was excellent, both between scans and between days, at rest and during contraction (ICC 0.96-0.99), as seen in Table 5.4.

**Table 5.4. Results for intraclass correlations: (ICCs), standard error measurement (SEM) and smallest detectable change (SDC) in the inter-rectus distance (IRD), lumbar multifidus (LM) and sacral multifidus (SM) in young healthy participants**

| **Between-scans measurement** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **IRD** | | | **LM** | | | **SM** | | |
| States | ICCs | SEM (mm) | SDC (mm) | ICCs | SEM (mm) | SDC (mm) | ICCs | SEM (mm) | SDC (mm) |
| Rest | 0.99 | 0.35 | 0.25 | 0.99 | 0.52 | 0.36 | 0.99 | 0.6 | 0.42 |
| Contraction | 0.99 | 0.91 | 0.63 | 0.99 | 0.77 | 0.54 | 0.99 | 0.54 | 0.38 |
| **Between-days measurement** | | | | | | | | | |
| | **IRD** | | | **LM** | | | **SM** | | |
| States | ICCs | SEM (mm) | SDC (mm) | ICCs | SEM (mm) | SDC (mm) | ICCs | SEM (mm) | SDC (mm) |
| Rest | 0.86 | 1.89 | 1.31 | 0.95 | 1.39 | 0.96 | 0.98 | 0.81 | 0.56 |
| Contraction | 0.13 | 6.87 | 4.76 | 0.93 | 1.54 | 1.07 | 0.96 | 1.1 | 0.76 |

1$^{st}$ and 2$^{nd}$ = mean of scans on the first and second days respectively

The SEM and SDC values were calculated and listed in Tables 5.4 and 5.5. For TrA, the SEM ranged between 0.06-0.33 mm and the SDC ranged between 0.04-0.22 mm, between-scans and between-days in both states. For EO, the SEM ranged between 0.05-0.57 mm and the SDC ranged between 0.04-0.33 mm were found between-scans and between-days in both states. For IO, the SEM ranged between 0.09-0.52 mm and the SDC ranged between 0.06-0.36 mm, between-scans and between-days in both states. In general, all SEM and SDC values were small. The values for EO and IO were greater than for TrA, and again the values during contraction were greater than at rest.

The Bland-Altman analyses for between-scans and between-days reliability showed good agreement, with the mean differences being close to zero. The 95% limits of agreement for the thickness measurements of all investigated muscles between-scans and between-days were calculated and listed in Appendix 13.3. An example Bland-Altman plot for between-scans reliability of left TrA at rest is shown in Figure 5.4.

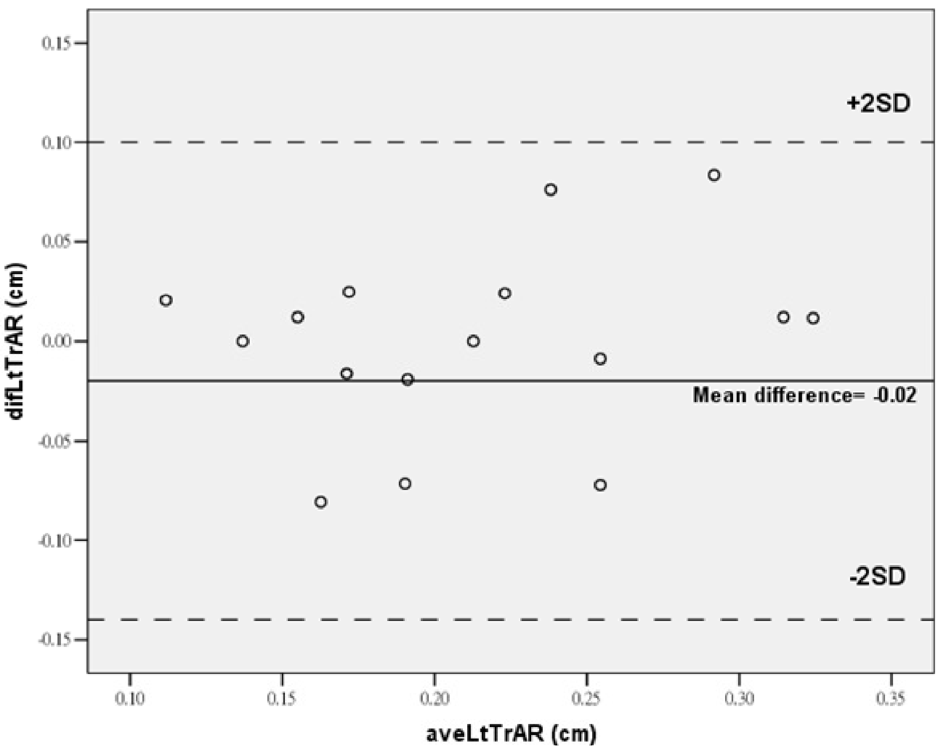



**Figure 5.4. An example Bland-Altman plot for between-scans reliability of left transversus abdominis (TrA) at rest**

For further examination of the reproducibility of muscle thickness measurements of the lateral abdominal muscles on both sides, a two-way ANOVA was used to calculate the effects of sides and muscle states on thickness measurements. The significant difference was reported if $p<0.05$. In the findings, the p values, for the measurements of the lateral abdominal muscles, were 0.26-0.76, all greater than 0.05, so no significant difference was reported for either sides or muscle states.

### *5.4.4. Reliability of muscle thickness measurements in patients with coccydynia*

High ICCs ranging 0.81-0.99 were reported between-scans both at rest and during contraction, but poor to good ICCs (0.42-0.87) were found between-days, in particular during contraction. The SEM and SDC values were calculated and listed with ICCs in Tables 5.6 and 5.7. For TrA, the SEM ranged between 0.12-0.53mm and the SDC ranged between 0.32-1.42mm, between-scans and between-days in both states. For EO, the SEM ranged between 0.12-0.91mm and the SDC ranges between 0.32-2.45 mm. For IO, the SEM ranges between 0.12-0.69mm and the SDC ranged between 0.32-1.85mm. In general, all SEM and SDC values were small but the values were larger between-days than between-scans. The values for EO and IO were greater than for TrA. The symptomatic side tended to show larger variation rather than the asymptomatic side. An interesting finding was that the between-days reliability of TrA and IO were poorer at rest than during contraction. The detailed results are displayed in Tables 5.5 and 5.6.

**Table 5.5. Results for intraclass correlations (ICCs), standard error measurement (SEM) and smallest detectable changes (SDC) in the abdominal muscles of patients. (N=17)**

| **Between-scans measurement** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **TrA** | | | **EO** | | | **IO** | | |
| Side/States | ICCs | SEM (mm) | SDC (mm) | ICCs | SEM (mm) | SDC (mm) | ICCs | SEM (mm) | SDC (mm) |
| Sym/Rest | 0.94 | 0.13 | 0.35 | 0.94 | 0.27 | 0.73 | 0.96 | 0.21 | 0.56 |
| Sym/ASLR | 0.94 | 0.28 | 0.75 | 0.84 | 0.48 | 1.29 | 0.87 | 0.47 | 1.26 |
| Asym/Rest | 0.94 | 0.19 | 0.51 | 0.95 | 0.35 | 0.94 | 0.99 | 0.15 | 0.4 |
| Asym/ASLR | 0.86 | 0.37 | 0.99 | 0.98 | 0.27 | 0.73 | 0.96 | 0.39 | 1.05 |
| **Between-days measurement** | | | | | | | | | |
| | **TrA** | | | **EO** | | | **IO** | | |
| Side/States | ICCs | SEM (mm) | SDC (mm) | ICCs | SEM (mm) | SDC (mm) | ICCs | SEM (mm) | SDC (mm) |
| Sym/Rest | ***0.42*** | 0.3 | 0.81 | 0.87 | 0.4 | 1.07 | ***0.55*** | 0.67 | 1.8 |
| Sym/ASLR | 0.72 | 0.53 | 1.42 | 0.91 | 0.33 | 0.89 | 0.71 | 0.65 | 1.75 |
| Asym/Rest | ***0.68*** | 0.4 | 1.07 | 0.86 | 0.45 | 1.21 | 0.78 | 0.66 | 1.77 |
| Asym/ASLR | 0.81 | 0.39 | 1.05 | ***0.63*** | 0.91 | 2.45 | 0.87 | 0.69 | 1.85 |

1$^{st}$ and 2$^{nd}$ = mean of scans on the first and second days respectively; Sym and asym = mean values for the symptomatic and asymptomatic sides; ASLR= active straight leg raise; poor ICC scores are in italics

**Table 5.6. Results for intraclass correlations (ICCs), standard error measurement (SEM) and smallest detectable change (SDC) in inter-rectus distance (IRD), lumbar multifidus (LM) and sacral multifidus (SM) in patients**

| **Between-scans measurements** | | | | | | |
|---|---|---|---|---|---|---|
| | **Lumbar multifidus** | | | **Sacral multifidus** | | |
| Side/States | ICCs | SEM (mm) | SDC (mm) | ICCs | SEM (mm) | SDC (mm) |
| Sym/Rest | 0.991 | 0.685 | 1.84 | 0.988 | 0.53 | 1.425 |
| Sym/Contr. | 0.969 | 0.69 | 1.855 | 0.987 | 0.715 | 1.925 |
| Asym/Rest | 0.987 | 0.43 | 1.155 | 0.99 | 0.305 | 0.82 |
| Asym/ Contr. | 0.978 | 0.88 | 2.365 | 0.964 | 0.95 | 2.555 |
| IRD/Rest | 0.994 | 0.9 | 2.455 | | | |
| IRD/Contraction | 0.954 | 1.76 | 4.745 | | | |
| **Between-days measurements** | | | | | | |
| | **Lumbar multifidus** | | | **Sacral multifidus** | | |
| Side/States | ICCs | SEM (mm) | SDC (mm) | ICCs | SEM (mm) | SDC (mm) |
| Sym/Rest | 0.7 | 2.15 | 5.78 | 0.866 | 1.75 | 4.7 |
| Sym/ Contr. | 0.749 | 1.8 | 4.84 | 0.94 | 1.05 | 2.82 |
| Asym/Rest | 0.789 | 1.73 | 4.65 | 0.766 | 2.3 | 6.18 |
| Asym/ Contr. | 0.767 | 2.22 | 5.97 | 0.801 | 2.1 | 5.64 |
| IRD/Rest | ***0.68*** | 5.83 | 15.67 | | | |
| IRD/Contraction | 0.715 | 4.38 | 11.77 | | | |

Sym and asym = mean values for the symptomatic and asymptomatic sides.
Contr.= contraction; IRD= inter-rectus distance; poor ICC scores are in italics

For further examination of muscle thickness measurements of the lateral abdominal muscles on both sides, the paired sample t-test was used to calculate the effects of sides and muscle states on the thickness measurements. All p values were >0.05, so no significant difference was reported for sides or muscle state in each group.

### *5.4.5. Thickness changes and percentage of thickness changes in abdominal muscles in healthy young participants and patients*

The descriptive findings of the thickness changes and percentage thickness changes on these muscles are listed in Tables 5.7 and 5.8, respectively. In patients, larger thickness changes were found than in the younger healthy participants.

**Table 5.7. Difference in muscle thickness between rest and contraction in transversus abdominis (TrA) muscle, external obliquus (EO) muscles and internal obliquus (IO) and inter-rectus distances (IRD)**

| **Side-Status** | **Young healthy (N=16)** | | **Side-Status** | **Patients (N= 17)** | |
|---|---|---|---|---|---|
| **Dominant** | **Mean (mm)** | **SD (mm)** | **Sym** | **Mean (mm)** | **SD (mm)** |
| **TrA** | 0 | 0.36 | TrA | 1 | 1 |
| **IO** | 0.2 | 0.35 | IO | 0.9 | 0.8 |
| **EO** | 0.46 | 0.87 | EO | 0.5 | 0.8 |
| **Non-dominant** | | | **Asym** | | |
| **TrA** | 0.11 | 0.35 | TrA | 0.8 | 0.8 |
| **IO** | 0.24 | 0.45 | IO | 1.1 | 1.2 |
| **EO** | -0.1 | 0.33 | EO | 0.73 | 1.2 |
| **IRD** | 0.84 | 3.1 | IRD | -3.8 | 3.4 |

Sym and asym = mean values for the symptomatic and asymptomatic sides.

TrA= transversus abdominal muscle; IO=internal obliquus muscle; EO=external obliquus muscle ; IRD= inter-rectus distance

**Table 5.8. Descriptive findings of the percentage of thickness change between rest and contraction in the transversus abdominis (TrA) muscle, external obliquus (EO) muscles and internal obliquus (IO) and inter-rectus distances (IRD)**

| Side-Status | Healthy (N=16) | | Side-Status | Patients (N= 17) | |
|---|---|---|---|---|---|
| **Dominant** | Mean (%) | SD (%) | **Sym** | Mean (%) | SD (%) |
| TrA | 1.77 | 16.36 | TrA | 46 | 48.3 |
| IO | 3.73 | 6.74 | IO | 14.9 | 13.7 |
| EO | 10 | 17.32 | EO | 14.2 | 18.3 |
| **Non-dominant** | | | **Asym** | | |
| TrA | 8.18 | 20.37 | TrA | 34.8 | 32.3 |
| IO | 4.65 | 8.52 | IO | 17.1 | 18.4 |
| EO | **-2.15** | 7.21 | EO | 16.78 | 30 |
| IRD | 56.32 | 38.26 | IRD | **-15.1** | 10 |

- indicates the muscle thickness during contraction is less than at rest.

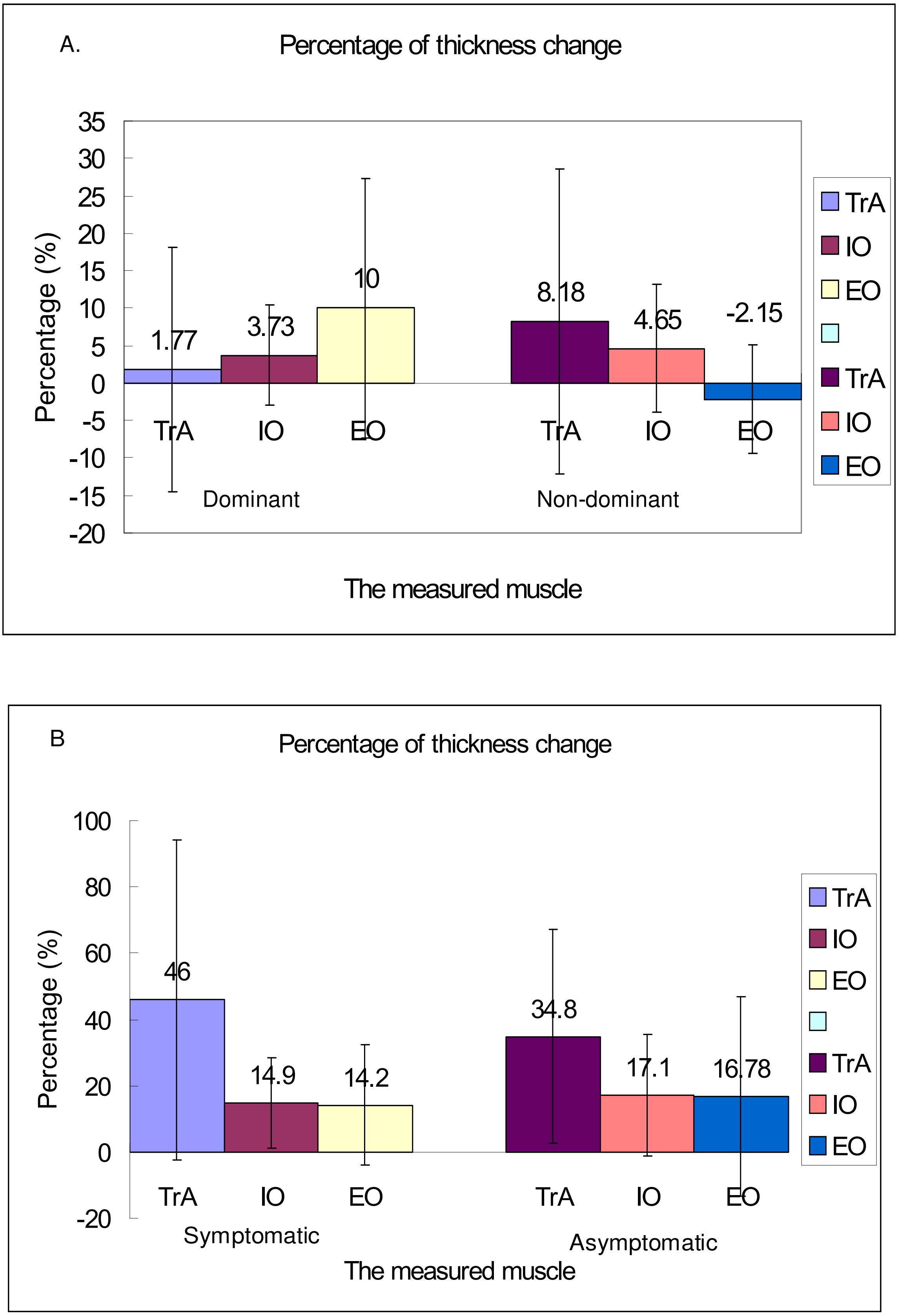



**Figure 5.5. Percentage of thickness changes in A) young healthy and B) patients**

### *5.4.6. Comparisons between patients and age-matched healthy controls*

In the main study, there were 17 patients involved in the RUSI studies and another 17 older healthy controls. The total number of healthy people studied was n=33 and the demographic data of participants are listed in Table 5.9.

**Table 5.9: Demographic data of all participants; healthy participants are further classified into young (23-34 years) and old (38-64 years)**

| | **Healthy participants (N=33)** | | **Patients (N=17)** |
|---|---|---|---|
| Mean Age (years old) | 36.8 ± 7.8 (23-65) | | 47.1±12 (23-65) |
| Mean Height (cm) | 1.59 ± 0.07 (1.43-1.68) | | 1.58±0.06 (1.43-1.67) |
| Mean BW (kg) | 54.4 ± 8.2 (39-72) | | 55.9±8.6 (40-72) |
| Mean BMI | 21.5 ± 2 (17.1-30.6) | | 22.4±3.7 (17.8-30.6) |
| Age group | **Young** | **Older** | |
| Numbers | 16 | 17 | |
| Age | 25.9 ± 3.26 (23-34 ) | 52.71±8.06 (38-64) | |
| Mean Height (cm) | 1.6±0.08 (144.5-167.5) | 1.58± 0.07 (1.5-1.68) | |
| Mean BW (kg) | 52.8±7.6 (39-65) | 55.91± 8.76 (45-72) | |
| Mean BMI | 20.63±0.1 (17.1-25.8) | 22.53±3.6 (18-31) | |

The ultrasound protocols for the abdominal area were exactly the same for the different groups, and the average thicknesses of abdominal muscles are presented in Table 5.10, in relation to the different age groups. Due to all participants being right side dominant, the right side is equal to the dominant side and the left side is the non-dominant side. Body mass index (BMI) may have accounted for the difference in muscle size. The paired sample t-test was used to compare the difference in muscle thickness between sides, and no significant differences were found.

**Table 5.10: Actual thickness on the abdominal muscles in young and older healthy participants**

| | **Young** | | **Older** | |
|---|---|---|---|---|
| Side-Status | **Mean (mm)** | **SD (mm)** | **Mean (mm)** | **SD (mm)** |
| **Dominant-Rest** | | | | |
| TrA | 2.1 | 0.67 | 2.03 | 0.64 |
| IO | 5.91 | 0.99 | 5.65 | 0.9 |
| EO | **4.38*** | 1.07 | **3.64*** | 0.94 |
| **Non-dominant Rest** | | | | |
| TrA | 2.21 | 0.71 | 1.8 | 0.5 |
| IO | 5.68 | 1 | 5.57 | 1.12 |
| EO | 4.39 | 1.03 | 3.91 | 0.69 |
| **Dominant –ASLR** | | | | |
| TrA | 2.13 | 0.81 | 2.94 | 1.48 |
| IO | 6.31 | 1.38 | 6.14 | 1.05 |
| EO | 4.93 | 1.73 | 4.83 | 1.37 |
| **Non-dominant ASLR** | | | | |
| TrA | 2.41 | 0.75 | 2.77 | 0.95 |
| IO | 5.94 | 1 | 6.49 | 1.58 |
| EO | **4.3*** | 1.08 | **3.59*** | 0.8 |

* $p<0.05$ statistically significant between young and older groups

ASLR= active straight leg raise

TrA= transversus abdominal muscle; IO=internal obliquus muscle; EO=external obliquus muscle

To further identify thickness changes during the same task, actual thickness changes and percentage thickness change were calculated to provide more objective information (See Tables 5.11 and 5.12). The independent sample t test was used to compare the two groups. Significant differences were found for IO and TrA, between the young and older groups. It showed the possibility of the influence of age on muscle recruitment during the same task.

**Table 5.11: Actual thickness changes on the abdominal muscles in young and older healthy participants**

| | Young | | Older | |
|---|---|---|---|---|
| Side | **Mean (mm)** | **SD (mm)** | **Mean (mm)** | **SD (mm)** |
| **Rt** | | | | |
| TrA | **0.03*** | 0.64 | **0.91*** | 1.21 |
| IO | **0.4*** | 0.65 | **0.49*** | 0.52 |
| EO | 0.55 | 1.08 | 1.18 | 0.93 |
| **Lt** | | | | |
| TrA | **0.19*** | 0.59 | **0.94*** | 0.97 |
| IO | **0.26*** | 0.63 | **0.92*** | 1.13 |
| EO | -0.08 | 0.66 | -0.32 | 0.68 |

* $p<0.05$ statistically significant between young and older groups

Rt= right ; Lt=left

TrA= transversus abdominal muscle; IO=internal obliquus muscle; EO=external obliquus muscle

**Table 5.12: Percentage of thickness change in the abdominal muscles in young and older healthy participants**

| | Young | | Old | |
|---|---|---|---|---|
| Side | **Mean (%)** | **SD (%** | **Mean (%)** | **SD (%)** |
| **Rt** | | | | |
| TrA | **2.92*** | 30.33 | **46.65*** | 52.03 |
| IO | **6.34*** | 9.52 | **8.81*** | 8.79 |
| EO | 11.78 | 22.73 | 34.13 | 26.93 |
| **Lt** | | | | |
| TrA | **11.98*** | 27.78 | **58.03*** | 59.56 |
| IO | **5.43*** | 12.76 | **17.23*** | 21.17 |
| EO | -1.01 | 13.53 | -7.7 | 16.75 |

Rt= right ; Lt=left

TrA= transversus abdominal muscle; IO=internal obliquus muscle; EO=external obliquus muscle

Due to no significant difference between dominant and non-dominant sides in healthy participants, the values for average muscle thickness from the two sides were used to compare with the symptomatic and asymptomatic sides in patients, using the independent sample t-test. The thickness changes in the three muscles are shown in Table 5.13, and a significant difference was found in IO between groups.

**Table 5.13: Thickness changes in patients and age-matched healthy controls**

| Side-Status | Controls (N=33) | | Side-Status | Patients (N= 17) | |
|---|---|---|---|---|---|
| **Dominant** | **Mean (mm)** | **SD (mm)** | **Sym** | **Mean (mm)** | **SD (mm)** |
| TrA | 0.37 | 1.02 | TrA | 1 | 1 |
| IO | **0.45*** | 0.58 | IO | **0.9*** | 0.8 |
| EO | 0.88 | 1.04 | EO | 0.5 | 0.8 |
| **Non-dominant** | | | **Asym** | | |
| TrA | 0.58 | 0.88 | TrA | 0.8 | 0.8 |
| IO | **0.6*** | 0.97 | IO | **1.1*** | 1.2 |
| EO | -0.27 | 0.59 | EO | 7.2 | 1.2 |

* indicates significant difference.

TrA= transversus abdominal muscle; IO=internal obliquus muscle; EO=external obliquus muscle

### *5.4.7. Correlation between BMI, actual muscle thickness and thickness change in the healthy participants*

Due to the wide range of age in the healthy participants, they were divided into three BMI groups, as Low (BMI<18.5), Normal (BMI 18.5-25) and High BMI (BMI>25). The demographic data of the three groups are displayed in the Table 5.14.

**Table 5.14.: Demographic data of three BMI (body mass index) groups**

| | **Low BMI** | **(N=6)** | **Normal (N= 22)** | | **High BMI (N=5)** | |
|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | Mean | SD |
| Age (y/o) | 28.17 (23-40) | 6.37 | 36.23 (23-66) | 13.65 | 50.4 (30-62) | 13.3 |
| BMI ($kg/m^2$) | 17.5 (17-18) | 0.55 | 21.05 (19-24) | 1.5 | 27.4 (25-31) | 2.51 |

To further consider the actual thickness of the abdominal muscles, descriptive statistics were applied and listed in Table 5.15. No significant differences for muscle thickness, thickness change and percentage of thickness change were found among the three groups,

**Table 5.15 Descriptive findings of bilateral muscle thickness based on the classification of BMI from transversus abdominis (TrA) muscle, external obliquus (EO) muscles and internal obliquus (IO), in states of rest and contraction during an active straight leg raise (ASLR).**

| | **Low BMI (N=6)** | | **Normal BMI (N=22)** | | **Higher BMI (N=5)** | |
|---|---|---|---|---|---|---|
| Side-Status | **Mean (mm)** | **SD (mm)** | **Mean (mm)** | **SD (mm)** | **Mean (mm)** | **SD (mm)** |
| **Dominant –Rest** | | | | | | |
| TrA | 2.33 | 0.68 | 1.86 | 0.54 | 2.62 | 0.68 |
| IO | 5.48 | 1.25 | 5.83 | 0.92 | 5.88 | 0.72 |
| EO | 4.22 | 0.94 | 4 | 1.16 | 3.76 | 0.82 |
| **Non-dominant –Rest** | | | | | | |
| TrA | 2.45 | 0.5 | 1.88 | 0.61 | 2.1 | 0.74 |
| IO | 5.15 | 1.5 | 5.59 | 0.75 | 6.36 | 1.46 |
| EO | 4.17 | 1.3 | 4.17 | 0.84 | 4.02 | 0.65 |
| **Dominant –ASLR** | | | | | | |
| TrA | 2.17 | 0.41 | 2.55 | 1.26 | 3 | 1.87 |
| IO | 5.6 | 1.06 | 6.41 | 1.28 | 6.16 | 0.9 |
| EO | 4.47 | 0.85 | 4.94 | 1.79 | 5.12 | 0.88 |
| **Non-dominant ASLR** | | | | | | |
| TrA | 2.86 | 0.62 | 2.4 | 0.78 | 3.1 | 1.29 |
| IO | 5.88 | 1.31 | 6.1 | 0.79 | 7.14 | 2.76 |
| EO | 4 | 1.27 | 3.86 | 0.99 | 4.2 | 0.84 |

TrA= transversus abdominal muscle; IO=internal obliquus muscle; EO=external obliquus muscle

**Table 5.16 Thickness changes on the abdominal muscles in the three different BMI groups**

| | Low BMI (N=6) | | Normal BMI (N=22) | | Higher BMI (N=5) | |
|---|---|---|---|---|---|---|
| Side-Status | **Mean (mm)** | **SD (mm)** | **Mean (mm)** | **SD (mm)** | **Mean (mm)** | **SD (mm)** |
| **Dominant** | | | | | | |
| TrA | -0.2 | 0.67 | 0.68 | 1 | 0.38 | 1.49 |
| IO | 0.1 | 0.21 | 0.57 | 0.58 | 0.28 | 0.72 |
| EO | 0.3 | 0.43 | 0.94 | 1.15 | 1.36 | 0.78 |
| **Non-dominant** | | | | | | |
| TrA | 0.4 | 0.96 | 0.53 | 0.74 | 1 | 1.36 |
| IO | 0.7 | 0.73 | 0.53 | 0.66 | 0.78 | 2.1 |
| EO | -0.2 | 0.68 | 0.31 | 0.63 | 0.18 | 0.86 |

TrA= transversus abdominal muscle; IO=internal obliquus muscle; EO=external obliquus muscle

**Table 5.17 Percentage of thickness changes on the abdominal muscles in the three different BMI groups**

| | Low BMI (N=6) | | Normal BMI (N=22) | | Higher BMI (N=5) | |
|---|---|---|---|---|---|---|
| Side-Status | **Mean (mm)** | **SD (mm)** | **Mean (mm)** | **SD (mm)** | **Mean (mm)** | **SD (mm)** |
| **Dominant** | | | | | | |
| TrA | -2.93 | 20.97 | 26.04 | 46.29 | 10.03 | 52.04 |
| IO | 2.92 | 4.68 | 9.74 | 9.08 | 5 | 11.68 |
| EO | 7.19 | 12.77 | 24.1 | 27.99 | 39.29 | 28.95 |
| **Non-dominant** | | | | | | |
| TrA | 22.35 | 39.73 | 35.39 | 50.67 | 55.33 | 68.06 |
| IO | 16.53 | 18.43 | 10.26 | 13.05 | 11.62 | 36.06 |
| EO | -2.86 | 15.93 | 13.56 | 18.03 | 5.4 | 20.35 |

TrA= transversus abdominal muscle; IO=internal obliquus muscle; EO=external obliquus muscle

### *5.4.8. Scoliosis in patients*

In the patient group, 10 of the 17 patients were found to have scoliosis. An Independent sample t-test was used to compare the muscle thickness between patients with and without scoliosis. Significant differences were found on the asymptomatic side for IO (p=0.03) and TrA (p=0.009) during ASLR, and no significant differences were reported in others (See Table 5.18).

**Table 5.18. Results from the independent sample t test between patients with and without scoliosis**

| Side-States | Independent sample t test (p value) |
|---|---|
| Sym-Rest | |
| TrA | 0.095 |
| IO | 0.74 |
| EO | 0.557 |
| LM | 0.405 |
| SM | 0.136 |
| Sym-Contraction | |
| TrA | 0.672 |
| IO | 0.223 |
| EO | 0.997 |
| LM | 0.472 |
| SM | 0.078 |
| Asym-Rest | |
| TrA | 0.095 |
| IO | 0.084 |
| EO | 0.178 |
| LM | 0.329 |
| SM | 0.055 |
| Asym-Contraction | |
| TrA | **0.009*** |
| IO | **0.03*** |
| EO | 0.25 |
| LM | 0.799 |
| SM | 0.275 |

* indicates significant difference; Sym= symptomatic; Asym=asymptomatic; TrA= transversus abdominal muscle; IO=internal obliquus muscle; EO=external obliquus muscle; LM=lumbar multifidus; SM=sacral multifidus

### 5.5. Discussion

The results revealed that the test-retest reliability of the RUSI technique was lower in patients with coccydynia than in healthy young participants but was acceptable (ICC>0.7). In healthy groups, the young group was found to show less thickness changes in the TrA muscles than the older group during the same ASLR functional task. Patients were reported to demonstrate thicker TrA muscles at rest than in the age-matched healthy control group. The symmetry of the TrA muscles between sides was evaluated in both the patients and older healthy group, and no significant difference was found between sides for either group.

### *5.5.1. Reliability*

This study used ultrasound imaging to measure the thickness of the lateral abdominal muscles on both sides during the unilateral active straight leg raise (ASLR) test. This functional task is a type of spinal loading which can be used to assess the stability of the lumbopelvic region. Several studies have used ultrasound imaging as a reliable technique. Repeatability of muscle thickness measurements was generally good for different muscles during different tasks, confirming previous studies (Bunce et al., 2002, Kidd et al., 2002, McMeeken et al., 2004, Teyhen et al., 2005, Ainscough-Potts et al., 2006, Rankin et al., 2006, Hides et al., 2007, Koppenhaver et al., 2009). Small values of SEM demonstrate the stability of the measurement skills.

In the pilot study, all ICC values were high (>0.7) except the between-days measurements of IRD during contraction, indicating that the technique generally has good reliability. Similar muscle thickness of TrA at rest was found on both sides and no significant difference between dominant and non-dominant sides was found, in line with previous studies (Teyhen et al., 2007). The greater ICC values for measurements made at rest than during contraction were consistent with existing published work for voluntary contractions of the abdominal muscles at different tasks in the different population (Hides et al., 2007, Rankin et al., 2006). The lower ICCs during contraction are still acceptable (>0.7). In general, the SEM and SDC values were very small and tended to be greater for measurements made during contraction than at rest. The SDC is interpreted as a “real” change (Terwee et al., 2007), so the small values of SEM and SDC found in the results can be justified as small variations.

Reliability studies of IRD measurement are few, and no published studies have examined the reliability in both rest and during contraction. Coldron et al. (2007) carried out a study to investigate the correlation of cross-section area (CSA) of rectus abdominis (RA) and inter-rectus distance (IRD). However, they did not carry out the reliability of these measurements (Coldron et al., 2007). In the present findings, the high ICCs of IRD measurement at rest were reported between-scans and between days, but ICCS were low during contraction between-days. No studies investigated the reliability of IRD during contraction so far. The explanation may be that the muscle boarders of rectus abdominis muscles during contraction were not clear and difficult to distinguish (see Figure 5.6.).

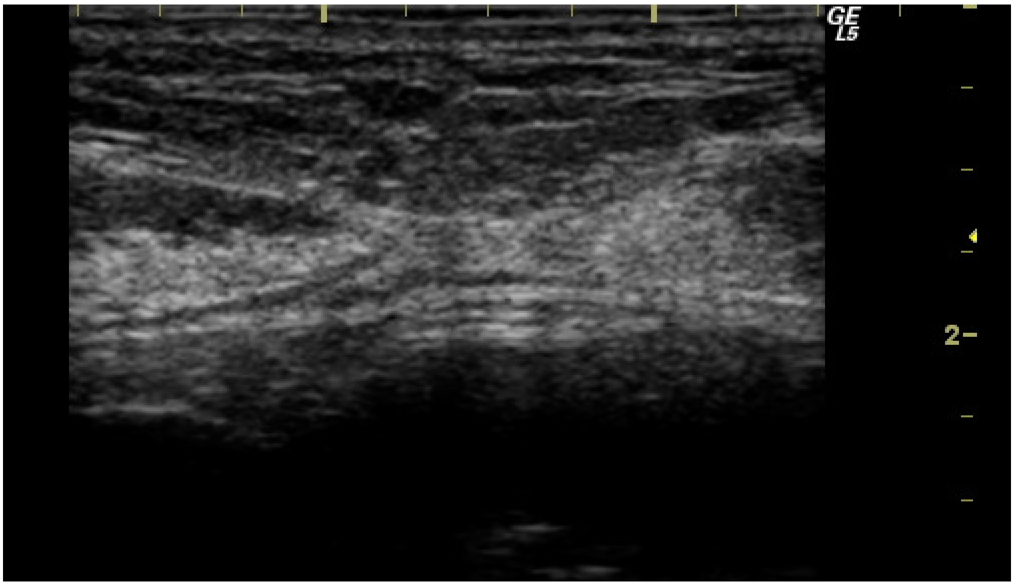



**Figure 5.6. Ultrasound scan of the inter-rectus distance (IRD) during contraction. The muscle boarders of the bilateral rectus abdominis muscles shown in this picture are not clear, making measurement of the IRD difficult.**

Lower between-days ICCs were found in patients with coccydynia than in healthy participants. The findings accepted the research hypothesis and agreed with the studies on low back pain or sacroiliac joint dysfunction (Table 5.19). However, the present study presents lower ICCs than other studies on low back pain but it is still moderate reliability. Therefore, the skill of the examiner was shown to be adequate to carry out this technique. As for the poor reliability index, the target population may be one of the factors which affect the results. The majority of previous studies were on healthy controls. Possible factors affecting the result could be unstable symptoms and duration of pain. In the clinical situation, the common classification of coccydynia relies on the pain course. Chronic coccydynia is defined as the presence of symptoms for over three months. The symptoms could impact progressively on the lumbopelvic region. No consideration was given to other co-existing symptoms, such as low back pain or ischial tubersitis to divide patients into sub-groups, due to the small sample size of 17 patients.

**Table 5.19. Reliability for muscle thickness measurements from other studies**

| Researcher | Population/Muscle states | Results: ICC/SEM |
|---|---|---|
| Bunce et al. (2002) | -Healthy participants<br>-TrA at three positions: supine, stand and walk | ICC: 0.88-0.94<br>SEM: 0.35-0.66 mm |
| Kidd et al. (2002) | -Healthy Participants<br>-TrA during the ADIM | ICC: 0.9-0.96<br>SEM:0.29-0.57 mm |
| McMeeken et al (2004) | - Healthy participants<br>-TrA at rest and during the abdominal hollowing | ICC: b-mode: 0.99; m-mode:0.98; b-mode versus m-mode 0.82 |
| Teyhen et al.(2005) | -- Patients with LBP<br>-TrA at rest and during the ADIM | ICC 0.93-0.98<br>SEM: 0.13-0.31 mm |
| Ainscough-Potts et al. (2006) | - Healthy participants<br>-TrA and IO during inspiration and expiration | ICC: 0.97-0.99 |
| Rankin et al. (2006) | - Healthy participants<br>-TrA, IO,EO,RA at rest | Between-scans: 0.98-0.99<br>Between-days:0.96-0.99 |
| Hides et al.(2007) | - Participants without LBP<br>-TrA and IO thickness at rest and during the ADIM | -Between-scans 0.62-0.82<br>-Between-days: 0.63-0.85<br>-Between-scans SEM:<br>IO 0.37-0.66 mm;<br>TrA 0.4-0.5 mm |
| Koppenhaver et al. (2009) | -Current LBP Patients<br>-TrA and lumbar multifidus at rest and during contraction | - Between-scans 0.96-0.99<br>- Between-days 0.87-0.98 |

### *5.5.2. Difference between patients and healthy older controls*

The results showed that patients had thicker TrA muscles than controls and control of the local muscles was lacking. The importance of TrA in motor control was discussed in Chapter 2. A series of studies by Hodges demonstrated the role TrA in the equilibrium of the body (Hodges and Richardson, 1997, Hodges et al., 1999, Hodges et al., 2001). During the functional ASLR task, patients demonstrated less thickness changes in the TrA muscle than the healthy participants. No significant differences between sides in the two groups were reported. The changes may be in keeping with the pain-adaptation theory to develop compensatory strategies, and then result in changes in muscle morphology.

In the present study, the actual thickness of TrA muscles during ASLR was reported to be significantly thicker in healthy older participants than in younger participants. It may be interpreted that age can have an impact on motor control. Older controls were found to use more effort to carry out the task than younger participants. The factors related to functional performance are very broad and need to be explored in the future. BMI was found not to be relevant to muscle thickness measurements/changes in healthy participants. Due to the limited number of participants, this issue could not be really answered. In this study, 10 out of 17 patients with coccydynia also presented with scoliosis. Scoliosis can be classified into to many types, such as functional scoliosis, structural scoliosis and S type scoliosis. Due to the small number of patients, the classification could not be used to examine any differences in the type of scoliosis but differences were examined between those with and without scoliosis. Patients demonstrated a significant difference on the thickness measurement of TrA during contraction on the asymptomatic side between two patients groups.

### 5.3. Conclusions

In this present study, RUSI has been demonstrated to be a highly reliable technique in healthy participants and patients with coccydynia, both at rest, and during a unilateral ASLR task, in line with the findings from existing studies. The reliability of RUSI measurement during contraction was lower than at rest in both groups, but the ICC values were all good (>0.7). A significant difference TrA muscle thickness characteristics was found between the younger healthy cohort (mean age = 25.9 SD=3.26) compared to the older healthy cohort (mean age =47.06 SD=12.07) during contraction, but no significant difference was shown at rest. This indicates an alteration of contractile ability with age can be detected by RUSI. Patients had thicker TrA muscles than controls at rest but showed lower increases in thickness change during the ASLR task, indicating loss of contractile ability and motor control.

# Chapter 6: Consistency of thickness changes of abdominal muscles at different levels of contraction effort during abdominal drawing-in manoeuvre

## 6.1. Introduction

Rehabilitative ultrasound imaging (RUSI) is a non-invasive method to detect or measure muscles, in particular deep muscles (Whittaker et al., 2007a). Studies using EMG (Hodges et al., 2003, McMeeken et al., 2004) and MRI (Hides et al., 1995) to examine the validity of ultrasound imaging to measure change in contraction level were discussed in Chapter 3 (Section 3.2.1). Most published studies have evaluated thickness changes in a single muscle that responded to a functional task, such as abdominal drawing-in activity (Teyhen et al., 2005). However, the correlation between awareness of effort and the degree of effort used at specific levels of contraction is unknown. Whether the subjects do the task with sufficient awareness of effort under the instruction of the investigator is another concern.

In the ultrasound experimental protocol, active straight left raising (ASLR) was the task of spinal loading used to activate the abdominal muscles, which are recognised as the spinal stabilisers in the lumbo-pelvic region (Chapter 4, Section 4.4.1). The transversus abdominis (TrA) muscle is located in the deepest area and thought to play a particularly important role in the dynamic control of lumbar stabilisation, as discussed in the Chapter 2 (Section 2.3). Re-education of motor control of the TrA muscle is a popular exercise in the physiotherapy treatment of low back pain (LBP), as a result of extensive research into the role of this muscle (Barr et al., 2005). The evidence showed that people have difficulty performing isolated contractions of TrA from IO and EO during a gross task, and although isolated contraction may not be necessary, it has been established that contraction of TrA benefits the stability of spine (Hodges, 1999). People with acute LBP have been found to have muscle wasting of TrA and reduced ability to contract the muscles (Norasteh et al., 2007, Hides et al., 1994). Since TrA is a deep muscle, its contraction cannot be observed or palpated easily, so it is a challenging muscle to re-educate, for both the therapist to teach and the patient to know whether they are contracting the muscle effectively, if at all. This problem of awareness of contraction is also true of healthy people without back pain.

In our study, the investigator asked participants performing an ASLR to slightly draw-in their abdomen and squeeze their gluteal muscles, during the protocol of scanning the lateral abdominal wall, as in previous studies (Coldron et al., 2007, Koppenhaver et al., 2009, Teyhen et al., 2009). However, the level of effort of the drawing-in activity may affect the results but the awareness of effort is too subjective to standardise. There is no standardised way of teaching a person how to contract their deep abdominal muscles but it is agreed that contractions for the purposes of providing postural stability need to be at a low level of effort (Barr et al., 2005). Commands to activate TrA vary in different studies, with non-specific phrases relating to the level of effort required to produce the contraction, such as to ‘gently’ or ‘slightly’ pull in the lower abdomen.

In the research environment, various tools can be used for biofeedback of level of muscle activity or effort, such as RUSI to provide visual feedback on the scanner’s screen (Hides et al., 1998, Stokes, 2005, Teyhen et al., 2007, Whittaker, 2007, Teyhen et al., 2008) , pressure biofeedback (Richardson et al., 2002, Richardson et al., 2004b, Richardson et al., 2004a) or electromyography (EMG) to produce signals reflecting the electrical activity of muscle (Koh et al., 2008, Silkman and McKeon, 2010). In the clinical situation, the level of effort required to produce a desired contraction is difficult to achieve, when no means of feedback is available. This study addressed the question of whether different levels of effort could be reproduced reliably, in an attempt to standardise the way in which TrA contractions might be taught.

Knowledge of the correlation between change in muscle thickness and different levels of contraction is limited and studies have involved very small numbers of participants, as discussed in Chapter 3 (Section 3.2.1). Existing studies have investigated the relationship between muscle thickness changes and EMG activity of individual muscles in normal subjects (Hodges et al., 2003, McMeeken et al., 2004). McMeekeen et al. (2004) reported the average measurements of TrA thickness during different force levels of lower abdominal hollowing were highly correlated with EMG. A linear relationship was reported between the change in muscle thickness and EMG activity during low abdominal hollowing at all levels of contraction. Their findings were consistent with those of Hodges et al (2003) at lower levels of contractions, but a non-linear relationship at higher levels of contraction opposed the results from McMeekeen et al. (2004). The different tasks employed in the two studies were a possible explanation for these divergent observations because different tasks demand different types of muscle contraction, such as isometric muscle shortening or muscle elongation. However, the limited sample size was another issue. In the study of McMeeken et al. (2004), nine participants were involved and may be as a better representation of the relationship between muscle thickness change and EMG muscle activity on TrA rather than the results from Hodges et al. (2003) with only three participants while investigating abdominal muscles.

Kiesel et al. (2007) carried out a study to investigate the relationship between muscle thickness change in lumbar multifidus (LM) and EMG activity in normal subjects during four levels of contra-lateral arm lifting (Kiesel et al., 2007). A linear relationship was consistent with the findings from McMeeken et al. (2004). The inter-rater and intra-rater reliability of the manual measurement were established in a pilot study (Kiesel et al., 2007). However, the repeatability of change in muscle thickness of LM was not given according to the graduated trials.

The findings from the above studies on healthy participants showed linear and curvilinear relationships between specific muscle thickness and different efforts for contracting muscles (Kiesel et al., 2007, McMeeken et al., 2004, Hodges et al., 2003). This means that contraction force may affect the outcome measurement of muscle thickness during a task.

The reproducibility of the RUSI technique has been show to be acceptable in various muscles under stable conditions (Whittaker et al., 2007). A systematic review of reliability of abdominal muscle RUSI found that reliability was good to excellent for single measures of thickness and poor to good for measures of thickness change (reflecting the muscle activity (Costa et al. 2009). The review criticised current research for the lack of research on reliability in patients, as the majority of studies were on healthy populations.

## 6.2. Aim, Research Questions and Hypothesis

### *6.2.1. Aim*

To examine the test-retest reliability within a session and on different days for measuring the thickness of the abdominal muscles at different levels of contraction during the drawing-in manoeuvre in healthy young participants and patients with coccydynia.

### *6.2.2. Research question*

Do people show good test-retest reliability of contracting the abdominal muscles, using visualisation to achieve different levels of effort during the drawing-in manoeuvre, as measured by change in abdominal muscle thickness on ultrasound images?

### *6.2.3. Hypothesis*

Patients with coccydynia will show less consistent repeatability of contraction of the abdominal muscles when instructed to achieve different levels of contraction, compared with healthy participants.

## 6.3 Study design and experimental protocol

### *6.3.1. Subjects*

This study involved 15 young healthy Taiwanese women in Southampton (aged 23-31) and 15 patients with coccydynia in Taiwan (aged 23-63). Their demographic characteristics are shown in Table 6.1. The healthy young participants were recruited from the Taiwanese Students' Society of the University of Southampton. The patients were recruited from the Department of Orthopaedic Surgery and the Department of Physical and Rehabilitation Medicine in the China Medical University Hospital (CMUH), at Taichung in Taiwan. The recruitment processes for the two groups are described in Chapter 4 (Section 4.4.1). The inclusion and exclusion criteria for the healthy participants and patients were as described Chapter 4 (Sections 4.4.2 & 4.4.3, respectively; summarised in Table 4.2). The studies were approved by the local ethics committees in Southampton and Taiwan (Section 4.4.4 & Appendix 13.1), and written, informed consent was obtained from all participants (Appendix 13.2). All participants attended sessions for testing on two different days.

### *6.3.2 The experimental protocol*

Each participant lay in a supine hook-lying position with their arms by their sides and their head in the midline. The ultrasound scanner and the investigator were positioned on the right side of the participant, following the standardised protocol described in Chapter 4 (Section 4.4.1). A linear transducer was used to capture images of the lateral abdominal muscles on the right and left sides, separately, following the protocol of Rankin et al (2006) and described in Chapter 4.

The drawing-in exercise commonly used in clinical practice (Teyhen et al., 2005, Hides et al., 2006, Hides et al., 2007a, Endleman and Critchley, 2008, Teyhen et al., 2008) was taught at two contraction levels; maximal voluntary effort (MVE) and approximately 20% of maximal. The lower level is more similar to that used clinically but the maximal level was used as a reference for achieving the lower level, and for comparison in terms of reliability for the present study. Simultaneous contraction of the pelvic floor muscles was also performed via the imagination of stopping voiding. To achieve a given level of contraction, the participant was asked to visualise a 10 storey building and to imagine an elevator going up to the 10th floor during a maximal contraction and to the 2nd floor to achieve 20% MVE. The participant was allowed to practice contractions so that they were familiar with them before imaging commenced, although this was limited to three contractions so as not to induce fatigue.

The three contraction states: resting, 20% MVE and 100% MVE were each performed twice in random order and a scan was taken during the steady state of contraction, which was held for 5 seconds. Muscle thickness was scanned at the end of exhalation to standardise the influence of respiration (Ainscough-Potts et al., 2006). Three-minute rests were taken between trials to minimise fatigue. Alignment of the transducer was maintained as consistently as possible during the drawing-in manoeuvres, but some relative motion was unavoidable. Small deviations in transducer angle (below 10 degrees) do not cause significant changes in abdominal muscle thickness (Whittaker et al., 2009)

Images were stored on a computer and muscle thickness was measured off-line using Image-J software (http://rsb.info.nih.gov/ij/). Measurement of TrA was taken as the vertical distance between the superior and inferior muscle borders, with the cursor being placed on the inside edges of the borders. This measurement was made at the middle point of the horizontal scale on the scan, i.e. in the centre of the image. .All measurements were recorded in millimetres.

## 6.4. Outcome measurement

### *6.4.1. Actual thickness, thickness change and percentage thickness change*

Muscle thickness was measured at rest, 20% MVE and MVE. Thickness change at 20% MVE and MVE are defined as the change of TrA thickness from rest. Index of thickness changes to normalise the measures was obtained following the formula:

*Index of thickness change = Thickness changes/ actual thickness at rest*

### *6.4.2. Statistical strategy*

To determine the reliability between the two scans taken at each level of effort, intra-class correlation coefficients (ICCs) and Bland-Altman plots were used. The standard error of measurement (SEM) was calculated to evaluate the variation of measurement error and the smallest detectable change (SDC) was calculated to reflect the smallest within-group changes in values. Both the SEM and SDC provide an indication of clinically meaningful variations in measurements (see Chapter 4, Section 4.5.2).

To examine differences between results found on the two sides within groups, a paired-sample t-test was applied to examine the three thickness parameters (actual, change and percentage change) following the test of normality. An independent sample t-test was used to compare the between-side differences between the two groups.

## 6.5 Results

### *6.5.1. Descriptive findings in controls and in patients*

The characteristics of participants are listed in the Table 6.1. Independent sample t-test showed a significant difference for age, body weight and BMI between groups.

**Table 6.1: Demographic data of participants**

| **Characteristics** | **Healthy group (N=15)** | | | **Patient group (N=15)** | | |
|---|---|---|---|---|---|---|
| | Range | Mean | SD | Range | Mean | SD |
| **Age (years)** | 23-31 | *26.5 | 2.9 | 23-63 | *42.5 | 12.2 |
| **Height (cm)** | 153.5-170 | 161.5 | 4.6 | 150-169 | 158.8 | 5.6 |
| **Body Weight (kg)** | 46-59 | *52.6 | 4.5 | 45-74.9 | *60 | 8.6 |
| **BMI(kg/m$^2$)** | 18.3-22.1 | *20.1 | 1.2 | 20-31.6 | *23.3 | 3.5 |

* p<0.05

The descriptive findings of actual thickness in different muscle status in the two groups are illustrated in Figures 6.1 and 6.2. The test of normality was carried out and normal distribution was reported (see Appendix 13.4.). Paired sample t test was used to compare side to side, and the *p* value smaller than 0.05 indicates a significant difference.

There was no significant difference in muscle thickness between sides in controls (Fig 6.1) but in patients significant differences occurred at rest (p= 0.033) and MVE (p=0.02; Fig 6.2 & Table 6.2). However, no significant difference for thickness changes and thickness change index were found (see Table 6.4).

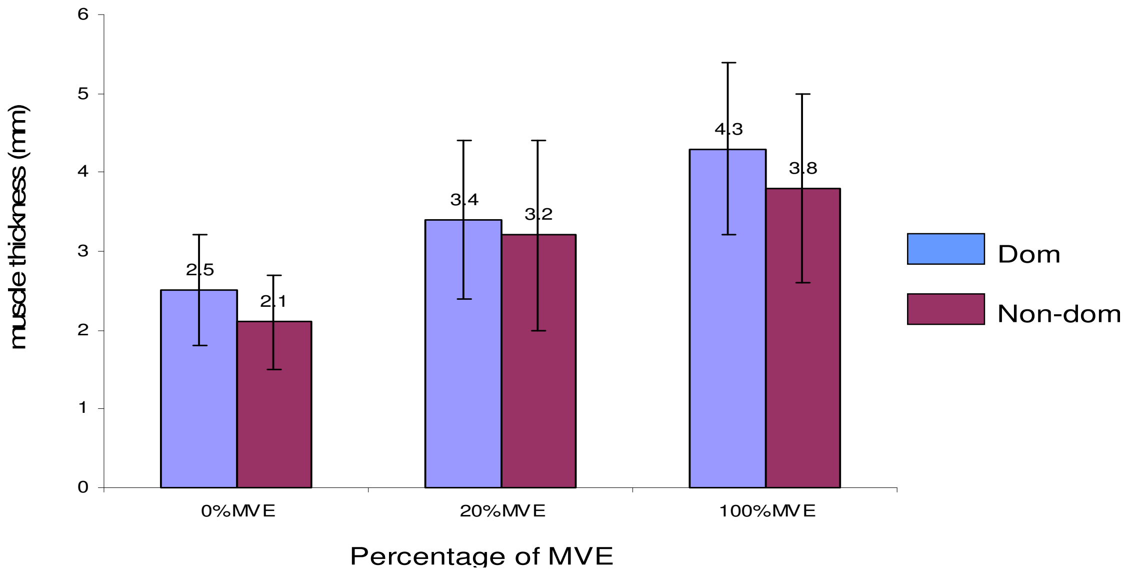



**Figure 6.1. Thickness of transversus abdominis at different of levels contraction in healthy participants (* p<0.05)**

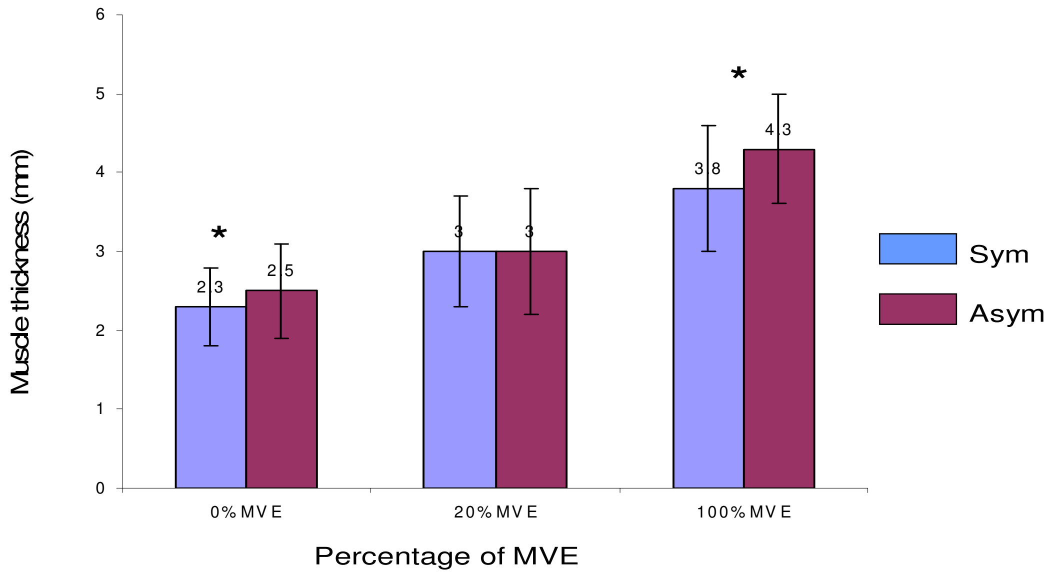



**Figure 6.2. Thickness of transversus abdominis at different of level contraction in patients (* p<0.05)**

**Table 6.2: Thickness of transversus abdominis at different levels of contraction**

| Healthy participants (N=15) | | | | | Patients (N=15) | | | |
|---|---|---|---|---|---|---|---|---|
| **Muscle state** | **Side** | **Mean (mm)** | **SD (mm)** | **Range** | **Side** | **Mean (mm)** | **SD (mm)** | **Range** |
| **Rest** | **Dom** | 2.5 | 0.7 | 1.4-4.1 | **Sym** | 2.3 | 0.5 | 1.6-3.5 |
| | **Non-D** | 2.1 | 0.6 | 1.2-3.2 | **Asym** | 2.5 | 0.6 | 1.7-3.9 |
| **20% MVE** | **Dom** | 3.4 | 1 | 1.4-4.7 | **Sym** | 3 | 0.7 | 1.8-4.5 |
| | **Non-D** | 3.2 | 1.2 | 1.6-5.5 | **Asymp** | 3 | 0.8 | 1.8-4.6 |
| **MVE** | **Dom** | 4.3 | 1.1 | 1.9-6 | **Sym** | 3.8 | 0.8 | 2.6-5.4 |
| | **Non-D** | 3.8 | 1.2 | 1.8-5.8 | **Asym** | 4.3 | 0.7 | 2.9-5.6 |

**MVE = maximal voluntary effort; sym= symptomatic; asym = asymptomatic;**

**Table 6.3: Between-side comparisons of muscle thickness at different contraction levels**

| | **Healthy Participants** | **Patients** |
|---|---|---|
| | **Sig. (p value)** | **Sig. (p value)** |
| **Rest** | 0.06 | 0.033* |
| **20%MVE** | 0.48 | 0.59 |
| **MVE** | 0.11 | 0.016* |

* indicates significant difference p<0.05

**Table 6.4. Between-side difference in muscle thickness changes from rest to contraction examined with a paired sample t-test**

| | **Thickness change** | | **Percentage change** | |
|---|---|---|---|---|
| | Healthy | Patients | Healthy | Patients |
| | *p* value | *p* value | *p* value | *p* value |
| **20%MVE** | 0.47 | 0.25 | 0.19 | 0.15 |
| **MVE** | 0.51 | 0.3 | 0.59 | 0.85 |

**Table 6.5. Actual thickness change and index of thickness change during different levels of contraction**

| Healthy Participants | | | | | | Patients | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | **Thickness change (mm)** | | **% change** | | | **Thickness change (mm)** | | **% change** | |
| **Trial** | **Side** | Mean | SD | Mean | SD | **Side** | Mean | SD | Mean | SD |
| **20% MVE** | Dom | 0.9 | 0.7 | 37.5 | 28.2 | Sym | 0.7 | 0.4 | 31.6 | 18.1 |
| **20% MVE** | Non-D | 1.1 | 0.7 | 49.6 | 26.8 | Asym | 0.5 | 0.5 | 22 | 18.6 |
| **MVE** | Dom | 1.8 | 0.8 | 76.7 | 35.3 | Sym | 1.6 | 0.5 | 71.4 | 22.2 |
| **MVE** | Non-D | 1.7 | 0.7 | 81.2 | 29 | Asym | 1.8 | 0.5 | 73 | 25.2 |

MVE = maximal voluntary effort

### *6.5.2. Reliability of actual TrA thickness: in healthy participants and patients*

High ICC values ranged 0.84-0.99 for between-scans reliability in the healthy group and in patients. As for the between-days reliability (see Table 6.6), good ICCs and small values of SEM and SDC are presented in controls, but lower ICC values were found in patients at rest whether symptomatic or asymptomatic sides.

**Table 6.6: Between-day reliability in healthy participants and patients**

| Healthy Participants | | | | Patients | | | |
|---|---|---|---|---|---|---|---|
| **Side/States** | **ICC** | **SEM (mm)** | **SDC (mm)** | **Side/States** | **ICC** | **SEM (mm)** | **SDC (mm)** |
| **Dominant** | | | | **Sym.** | | | |
| **Rest** | 0.95 | 0.2 | 0.6 | Rest | ***0.63**** | 0.29 | 0.78 |
| **20%MVE** | 0.94 | 0.2 | 0.6 | 20%MVE | 0.79 | 0.33 | 0.89 |
| **MVE** | 0.94 | 0.3 | 0.8 | MVE | 0.88 | 0.27 | 0.73 |
| **Non-domin.** | | | | **Asym** | | | |
| **Rest** | 0.93 | 0.2 | 0.6 | Rest | ***0.61**** | 0.35 | 0.94 |
| **20%MVE** | 0.94 | 0.3 | 0.8 | 20%MVE | 0.99 | 0.08 | 0.21 |
| **MVE** | 0.97 | 0.2 | 0.6 | MVE | 0.74 | 0.27 | 0.74 |

*:moderate to poor reliability (under 0.7); MVE = maximal voluntary effort

In the Bland and Altman plot, the limit of agreement is defined as the range of 95% confidence interval and results are shown in Table 6.7. An example Bland and Altman plot is shown in Figure 6.3. In the figure, the central line indicates the mean difference between measurements taken on two different days, and the range between the two dotted lines indicates the limits of agreement, as the range of 95% confidence interval (CI). In this example, the limit of agreement is large (around 2.5 cm), and each dot is located far from the mean although it still in the range of 95% CI. It indicates that the between-day reliability for symptomatic TrA at rest is accepted but not excellent. The finding reflected the moderate ICC value of 0.63 which is considered to be moderate and below the accepted ICC value of 0.7 for clinical purposes..

**Table 6.7. Bland & Altman results for between-contraction reliability at different contraction levels in the two groups**

| **Between-days measurement** | | | | | |
|---|---|---|---|---|---|
| **Patients** | | | **Controls** | | |
| | $\bar{d}$ (cm) | 95% CI for $\bar{d}$ | | $\bar{d}$ (cm) | 95% CI for $\bar{d}$ |
| **Sym /Rest** | .0172 | 0.133→-0.082 | Dom/Rest | -.025 | 0.095→-0.145 |
| **Sym/ 2** | -.0042 | 0.065→-0.131 | Dom/2 | -.001 | 0.111→-0.112 |
| **Sym/MVE** | .0041 | 0.004→0 | Dom/10 | -.025 | 0.086→-0.135 |
| **Asym /Rest** | -.0015 | 0.072→-0.148 | Non-dom/Rest | .012 | 0.069→-0.045 |
| **Asym/ 2** | -.0010 | 0.002→-0.007 | Non-dom/2 | .017 | 0.15→-0.115 |
| **Asym/MVE** | .0113 | 0.122→-0.01 | Non-dom/10 | .028 | 0.186→-0.13 |

Dom. →Dominant; Non-dom side → non-dominant side

MVE→ maximal voluntary effort

2→ 20% MVE

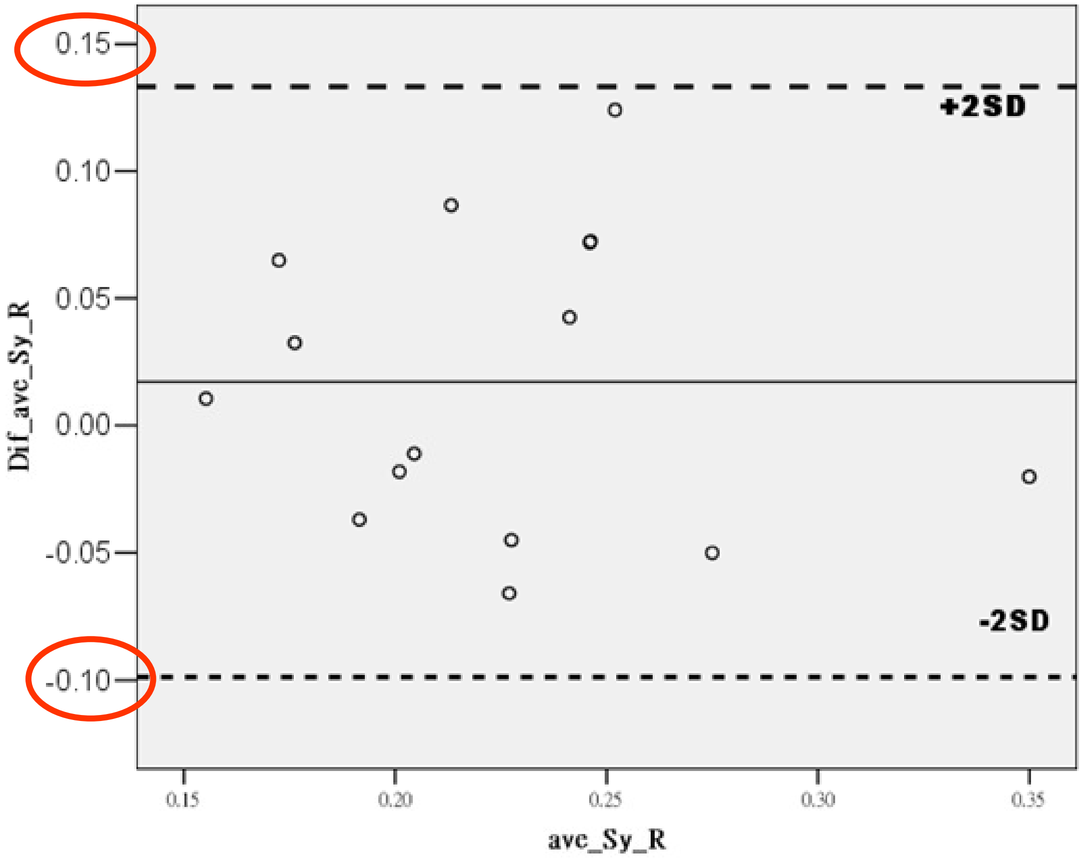



**Figure 6.3. Example Bland-Altman plot of the difference between measurements of TrA on the symptomatic side at rest. Each dot indicates an individual difference. The "ave_Sy_R" is the mean measurement on the symptomatic side taken on two different days, and the "Dif_ave_Sy_R" is the difference between measurements taken on the two days**

### *6.5.3. Comparisons between patients and healthy participants*

An independent sample t-test was used to compare the two groups. Due to no significant differences being found between sides in the healthy group, the mean of measurements from the two sides was used to compare with the symptomatic and asymptomatic sides in patients separately. There was no significant difference in actual muscle thickness between the groups at three different contraction states. A significant difference was found in the thickness change of TrA on the asymptomatic side at 20% MVE (Table 6.8).

**Table 6.8. The results from independent sample test to compare the difference between patients and healthy participants**

| | *P* value |
|---|---|
| **Sym_Rest** | 0.78 |
| **Sym_2** | 0.232 |
| **Sym_10** | 0.444 |
| **Asym_Rest** | 0.368 |
| **Asym_2** | 0.375 |
| **Asym_10** | 0.563 |
| **Sym_Change_2** | 0.126 |
| **Sym_Change 10** | 0.385 |
| **Asym_Change_2** | **0.024*** |
| **Asym_Change_10** | 0.927 |

* Indicates significant difference p<0.05

## 6.6. Discussion

### *6.6.1. Reliability of TrA muscle thickness measurements in healthy and patient groups*

Reliability was generally good, with ICCs >0.8 for between contractions at the same level of effort (20%MVE or MVE), in both the healthy participants and patients with coccydynia. These findings were consistent with previous studies in patients that did not use the elevator analogy to achieve a sub-maximal contraction (Teyhen et al., 2005, Costa et al., 2009a, Costa et al., 2009b). However, lower ICC values (<0.7) in the bilateral TrA at rest were found for between-days reliability. Costa et al. (2009) did a systematic review on the reproducibility of measurements in abdominal muscles. They found only six studies that investigated the reliability of thickness changes that reflect the activity of muscles, and no studies tested the reliability of thickness changes over time to monitor the effects of interventions. This aspect will be discussed in Chapter 10.

The exceptions in the present results were moderate reliability (p<0.7) of TrA thickness at rest on the two sides. Patients' symptoms may affect their resting TrA, either being thinner than normal due to muscle wasting or appearing to be thicker on another occasion due to an inability to relax. Such reasons for variations between days would lead to lower ICC values. The findings indicate that TrA muscles in patients with coccydynia could be repeated reliably at the two contraction levels but may have difficulty relaxing to provide consistent measurements of muscles at rest.

Changes in muscle thickness on RUSI are correlated with changes in EMG activity at low levels of contraction, up to approximately 30% of maximal effort (Hodges et al., 2003, McMeeken et al., 2004), but with little change in thickness thereafter. Thickness changes for maximal efforts would therefore be expected to be more reliable than those at 20% MVE, due to the limited change in thickness in the strong contraction range. The present finding that 20% MVE contractions were as reliable as maximal contractions suggests that the technique of using the elevator analogy is robust.

In the example of the Bland and Altman plot in Figure 6. 3, the limit of agreement is large (around 2.5 cm), and each dot is located far from the mean, although it still in the range of 95% CI. It indicates that the between-day reliability for symptomatic TrA at rest is only acceptable and not good, and reflected the ICC value of 0.63.

The patients showed higher SEM and SDC values than controls, so may indicate insufficient ability to control muscles following the same instruction in a more consistent way. As discussed in the Chapter 5, age and BMI may affect the recruitment of TrA during the task. In the patient group, the ranges of age and BMI are wider than in healthy participants, so could contribute to the large variation between groups.

### *6.6.2. Comparison of muscle thickness and changes in thickness between sides in the two groups*

As expected, muscle thickness increased with level of effort in both groups. Since the actual thickness of TrA was different between the two groups (Table 6.3.), percentage changes were useful for comparing between groups. Generally, no significant difference in the percentage of thickness change was reported. The only exception was on the asymptomatic side of 20% MVIC.

Changes in thickness within the patient group were variable between individuals at 20% MVE in terms of direction of change, with some not changing at all and others decreasing in thickness (see Figure 6.4). Some patients may lack awareness of low level contractions or lack motor control completely, hence a lack of change in thickness. The deficiency of motor control is known to occur in people with LBP (Hodges and Richardson, 1996, Hodges and Richardson, 1999a, Hodges, 2001). Patients with dysfunction may have difficulty relaxing their muscles when at rest or muscle spasm may be part of an involuntary mechanism (ref), which might explain the lack of further thickness change during voluntary activity at 20% MVE in some patients. Another possible explanation for lack of thickness change may be use of other muscles to compensate for lack of motor control of TrA. The current findings support the suggestion that muscles with good motor control can generate mild contractions and those with poor motor control may result in hyperactivity and/or compensation strategies using other muscles.

There were no significant differences of actual muscle thickness between dominant and non-dominant sides in the healthy group (Table 6.2), or between symptomatic and asymptomatic sides in patients (Table 6.2).

### 6.7 Conclusions

High ICC values were reported at three different levels of contractions in TrA muscles in patients. The findings indicate that TrA muscles can be repeated reliably at the two contraction levels tested (20% MVE and MVE) in healthy controls. This indicates that the instructions could have an influence on the level of efforts to contract muscle under a specific condition. This factor may affect the reliability of RUSI, so this method could be applied clinically to standardise the protocol of ultrasound imaging. In patients, the lower reliability reported at rest may indicate that they have difficulty relaxing sufficiently to provide consistent measurements of muscles at rest or muscle thickness may be affected by symptoms on different days. Reduced ability to control muscle recruitment in TrA was found in patients.

# Chapter 7: Measurement of the biomechanical angles in the lumbopelvic region using a motion capture system

## 7.1 Introduction

The angle changes in the lumbar (flexion/extension) and pelvic (tilting) bony structures during functional tasks are presented here. In the theory mentioned in Chapter 2 (Section 2.4), the alignment of lumbar and pelvic joints may be altered in patients with coccydynia who may use different strategies to carry out functional. In this chapter, the reliability of the experimental protocol in healthy controls and patients in the two countries, UK and Taiwan, was examined.

## 7.2 Aims, Research Questions and Hypothesis

### *7.2.1. Aims*

1. To examine the intra-rater reliability within a session and on different days for measuring the change in lumbopelvic angles during the functional task of one leg standing in healthy young participants and patients with coccydynia.
2. To compare the difference in change in lumbopelvic angles during the functional task of one leg standing between patients with coccydynia and healthy age-matched controls

### *7.2.2. Research question*

Is there a difference in change in the lumbopelvic angles during the one leg standing task between patients with coccydynia and healthy participants?

### *7.2.3. Research hypothesis*

Patients with coccydynia will demonstrate less change in lumbopelvic angles during the functional task to maintain their balance

## 7.3 Methods

### *7.3.1 Participants*

Three groups took part in the studies included in this chapter: the reliability study included 13 young healthy women in Southampton and 14 patients with coccydynia in Taiwan (Table 7.1); the comparative study included 14 patients with coccydynia and 30 age-matched controls (Table 7.2). The recruitment processes for the two groups are described in Chapter 4 (Section 4.4.1). The inclusion and exclusion criteria for the healthy participants and patients were as described Chapter 4 (Sections 4.4.2 & 4.4.3, respectively; summarised in Table 4.2). The studies were approved by the local ethics committees in Southampton and Taiwan (Section 4.4.4 and Appendix 13.1), and written, informed consent was obtained from all participants (Appendix 13.2).

**Table 7.1. Demographic data of participants for the two reliability studies**

| | **Healthy Participants (n=13)** | | **Patients (n=14)** | |
|---|---|---|---|---|
| | Mean | SD | Mean | SD |
| **Age (y/o)** | 26 (23-34) | 3.26 | 40.9 (23-62) | 11.7 |
| **Height (m)** | 1.59 (1.5-1.67) | 0.08 | 1.59 (152-169) | 0.05 |
| **BW (kg)** | 51.8 (39-65) | 7.55 | 59.9 (50-75) | 8.1 |
| **BMI (kg/m$^2$)** | 20.4 (17.09-25.84) | 2.42 | 23.9 (21-31.8) | 3.4 |

As shown in the Table 7.2. , the participants' characteristics in the age-matched control group and patient group are presented. ,

**Table 7.2. Demographic data of the participants in the age-matched control group and patient group**

| | **Healthy Controls (30)** | | **Patients (14)** | |
|---|---|---|---|---|
| | Mean | SD | Mean | SD |
| **Age (y/o)** | 36 (23-65) | 7.8 | 40.9 (23-62) | 11.7 |
| **Height (cm)** | 162(143-167.5) | 6.88 | 158.6 (152-169) | 5.1 |
| **BW (kg)** | 55.2 (39-72) | 9.2 | 59.9 (50-75) | 8.1 |
| **BMI (kg/m$^2$)** | 21 (17.1-30.6) | 1.9 | 23.9 (21-31.8) | 3.4 |

### *7.3.2 Vicon motion analysis equipment*

The VICON motion analysis system used 22 lightweight reflective 25mm diameter markers (balls) to define the bony landmarks of the lumbar spine, the pelvis and the lower extremities (see Figure 4.4 in Chapter 4). Lumbar curvature was defined by the two baseplates with the rig directly over T12 and S2 and a reflective ball over the spinal process of L3. The pelvic outlet was defined by the bilateral anterior superior iliac spines (ASIS), bilateral posterior superior iliac spines (PSIS) and base plates over S2.

The camera and two wand calibrations were carried out in the VICON workstation, as described in Chapter 3 (Section 3.2.3). After applying of the tracking markers, the subject was asked to stand with slightly abducted arms, in order not to hinder the markers, and the 'static standing' data were collected under the trial type listed as 'static'. The first task was 'right leg standing', whilst flexing the left knee to the height of the waist (90°). In consideration of safety, the participants were allowed to abduct their arms to maintain balance. The examiner instructed ‘Ready’, pressed the button to start the data collection, and then instructed ‘Start’ notifying the subject to flex her left leg up to 90 degrees and to maintain it until the examiner said ‘Stop’ (Figure 4.4). The second task was followed using the same procedure, standing on the right leg and lifting the left. In the third task, ‘stand from sitting’, an adjustable chair without a backrest was adjusted to allow the thighs and legs to be at a right angle. The participants were requested to rise from the chair whilst abducting the arms to avoid hindering the markers on the ASISs. Each task was carried out three times in each session. The EMG and VICON data were collected synchronously during the tasks.

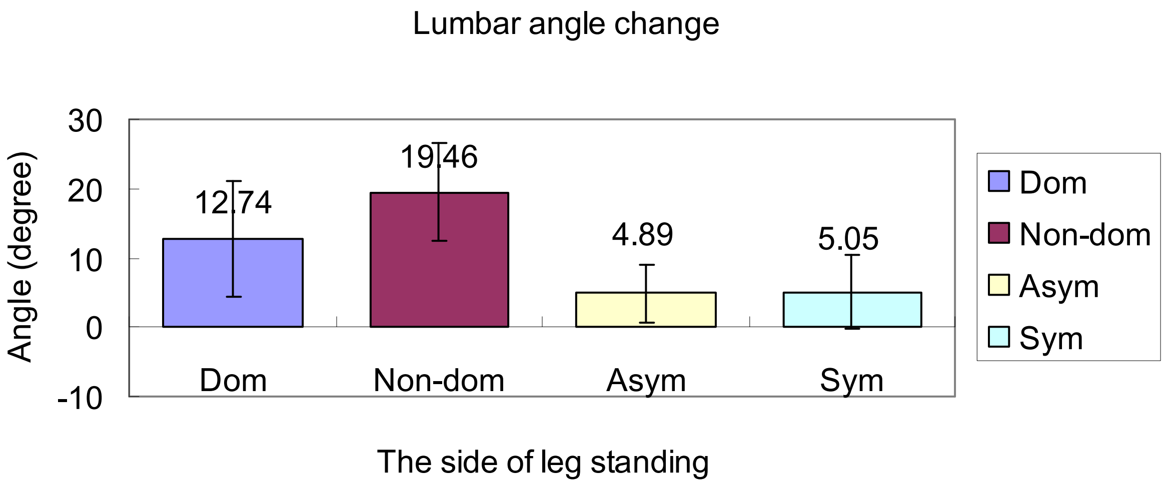
### *7.3.2. Measurement of angles and reliability of motion analysis in the pilot project*

The method of motion analysis is described in detail in Chapter 4 (Section 4.6.3).The absolute values of angle changes in lumbar position and pelvic tilting were calculated by subtracting the average angle of static standing from the average angle of holding phases of hip flexion during one leg standing. The reliability of motion analysis in healthy controls was established in Southampton to allow the author to apply the techniques in Taiwan. As for reliability in patients, the same experimental protocol using the VICON was carried out in Taiwan. In the motion analysis session, the application of 22 markers in the trials in Taiwan was exactly the same as the pilot study in Southampton. Herein, the reliability of VICON in Southampton and in Taiwan is presented.

## 7.4 Results

### *7.4.1 Changes in angles of the lumbar spine and pelvic tilting*

In the control group, the mean value of angle changes in the lumbar spine during dominant leg standing was 12.74° ±SD 8.3°, and the mean value during non-dominant leg standing was 19.46°± SD 6.99°. For the angle changes in pelvic tilting, the mean angle change was 12.92°± SD 7.24° during dominant leg standing and 21.42° ± SD 5.49 ° during non-dominant leg standing (see Figure 7.1). In the patient groups, the mean value of angle changes in the lumbar spine during symptomatic-leg-standing is 5.05° ± SD 5.25°, and the mean value during asymptomatic-leg-standing is 4.89° ± SD4.2°. As for the angle change in the pelvic tilting, the value of 4.23° ±SD3.49° in symptomatic-side leg and 5.49° ±SD 3.3° in asymptomatic-side leg standing are presented (see Figure 7.1).



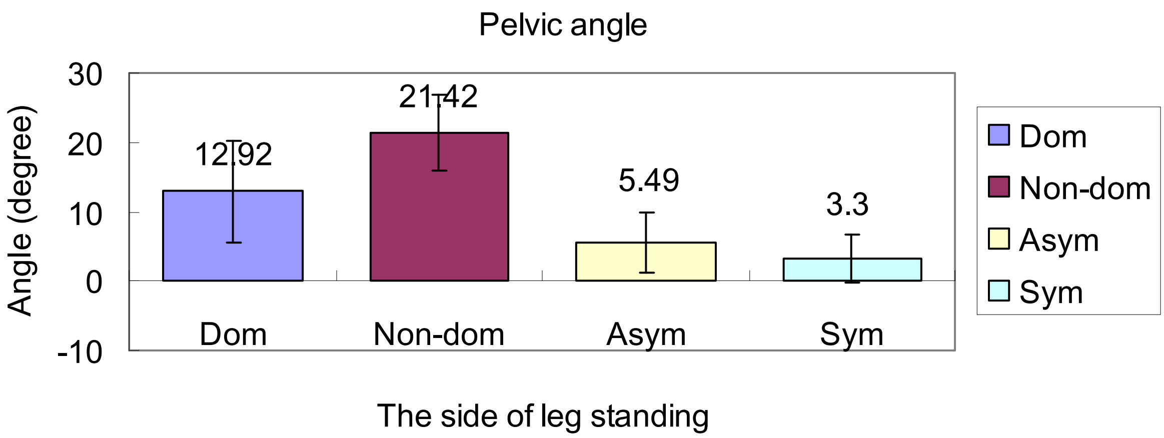




**Figure 7.1. Changes in lumbopelvic angles during the one leg standing task in reliability studies in healthy participants (dominant and non-dominant sides) and patients (symptomatic and asymptomatic sides)**

The test of normality was applied for all data sets and the W value was considered. The W values for all scores were <0.05, indicating normal distribution of data. Paired sample t test was used to examine the difference between sides in the two groups. There was no significant difference found between sides in controls in the two angle changes, and the findings were similar in the patient group.

### *7.4.2. Reliability of changes in lumbar and pelvic angles between-trials and between-days in controls in Southampton*

In Table 7.3., the between-trials and between-days reliability of changes in lumbar and pelvic angles in controls are presented. High ICC values (>0.94) for between-trials reliability were reported, indicating that the applied technique was highly reliable. Lower ICC values (0.5-0.7) were reported for between-days reliability, and were consistent with higher values of SEM and SDC.

**Table 7.3. Results for intraclass correlations (ICCs) in angle changes in lumbar position and pelvic tilting in healthy participants**

| **Between-trials reliability** | **Values** | | |
|---|---|---|---|
| **Trial name** | **ICC** | **SEM** | **SDC** |
| **Lumbar** | | | |
| **Dominant leg stand** | 0.95 | 1.76 | 4.73 |
| **Non-dom leg stand** | 0.97 | 1.26 | 3.39 |
| **Pelvic tilting** | | | |
| **Dom leg stand** | 0.95 | 1.53 | 4.11 |
| **Non-dom leg stand** | 0.94 | 1.35 | 3.63 |
| **Between-days reliability** | **Values** | | |
| **Lumbar** | | | |
| **Dom leg stand** | -0.67 | 4.77 | 12.82 |
| **Non-dom leg stand** | -0.51 | 4.89 | 13.14 |
| **Pelvic tilting** | | | |
| **Dom leg stand** | 0.71 | 3.9 | 10.48 |
| **Non-dom leg stand** | 0.52 | 3.8 | 10.21 |

The Bland-Altman analyses for between-trials showed good agreement, with the mean differences being close to zero (see Table 7.4). However, for between-days reliability, the Bland and Altman plots demonstrated poor agreement, specifically in the lumbar angles and are consistent with the results of ICCs.

**Table 7.4. Bland and Altman analysis for angle changes in lumbar and pelvic tilting: mean difference (d) and 95% limits of agreement in healthy participants**

| **Between-trials measurement** | | |
|---|---|---|
| **Measurement** | $\bar{d}$ | 95% CI for $\bar{d}$ |
| **1st_dom leg stand-Lumbar angle** | -1.34 | -6.38 →3.7 |
| **1st_non-dom leg stand-Lumbar angle** | 0.5 | 3.19 → -3.19 |
| **1st_dom leg stand-Pelvis angle** | -1.07 | -6.1 → 3.96 |
| **1st_non-dom leg stand-Pelvis angle** | -0.47 | -4.24→3.31 |
| **2nd_dom leg stand-Lumbar angle** | 0.26 | -3.16 →3.68 |
| **2nd_non-dom leg stand-Lumbar angle** | -0.55 | -3.75 → 2.65 |
| **2nd_dom leg stand-Pelvis angle** | -0.4 | -2.34 → 1.35 |
| **2nd_non-dom leg stand-Pelvis angle** | -0.02 | -4.27 → 4.22 |
| **Between-days measurement** | | |
| **Measurement** | $\bar{d}$ | 95% CI for $\bar{d}$ |
| **Dom leg stand-Lumbar angle** | -3.11 | -30.37 → 24.15 |
| **Non-dom leg stand-Lumbar angle** | -0.75 | -23.57 →22.07 |
| **Dom leg stand-Pelvis angle** | -0.15 | -13.67 →13.37 |
| **Non-dom leg stand-Pelvis angle** | -0.58 | -13.8 → 12.64 |

1st and 2nd = trials on the first and second days respectively

### *7.4.3. Reliability of angle changes on lumbar and pelvic positions between-trials and between-days in patients in Taiwan*

The reproducibility of angle changes in lumbar and pelvic positions were examined and reported in the Table 7.5. Good ICC values (0.7-0.9) were found for the between-trials reliability, but poor between-days reproducibility (ICC= 0.3-0.6) was demonstrated as similar findings in controls. The SEM and SDC values to assess the stability of scores showed similar results.

**Table 7.5. Results for intraclass correlations (ICCs) in angle changes in lumbar position and pelvic tilting in patients**

| Between-trials reliability | Values | | |
|---|---|---|---|
| **Trial name** | **ICC** | **SEM** | **SDC** |
| **Lumbar** | | | |
| Symptomatic leg stand | 0.898 | 1.12 | 3 |
| Asymptomatic leg stand | 0.9 | 0.9 | 2.42 |
| **Pelvic tilting** | | | |
| Symptomatic leg stand | 0.876 | 1.41 | 3.79 |
| Asymptomatic leg stand | 0.7 | 1.74 | 4.68 |

The Bland-Altman analyses for between-trials at the first day showed moderate agreement, with the mean differences being close to zero (see Table 7.6).

**Table 7.6. Bland and Altman analysis for angle changes in lumbar and pelvic tilting: mean difference (d) and 95% limits of agreement in patients**

| Between-trials measurement: 1st Day | | |
|---|---|---|
| **Measurement** | $\bar{d}$ | 95% CI for $\bar{d}$ |
| **symptomatic side leg standing -Lumbar angle** | -1.76 | -20.52 → 17 |
| **Asymptomatic side leg standing -Lumbar angle** | -0.7 | -16.32→14.92 |
| **symptomatic side leg standing -Pelvis angle** | 0 | -8.58→ 8.58 |
| **Asymptomatic side leg standing -Pelvis angle** | -0.3 | -9.66→9.06 |

### 7.5. Comparison of angle changes in the two groups (controls and patients)

The characteristics of the participants in the age-matched control group and in the patient group are listed in the Table 7.2. The descriptive statistics of the angle changes in lumbar and pelvic titling during the functional task of one leg standing were shown in Figure 7.2. In the age-matched control group, the mean values of angle changes during dominant leg standing were 10.06° ±SD 7.5° in lumbar and 10.92° ±SD 7.26° in pelvic joints, and the mean value during non-dominant leg standing are 16.5° ±SD 7.8° in lumbar and 16.5° ±SD 6.8° in pelvic joints. The findings from the patient group are the same as in the reliability study of patient.

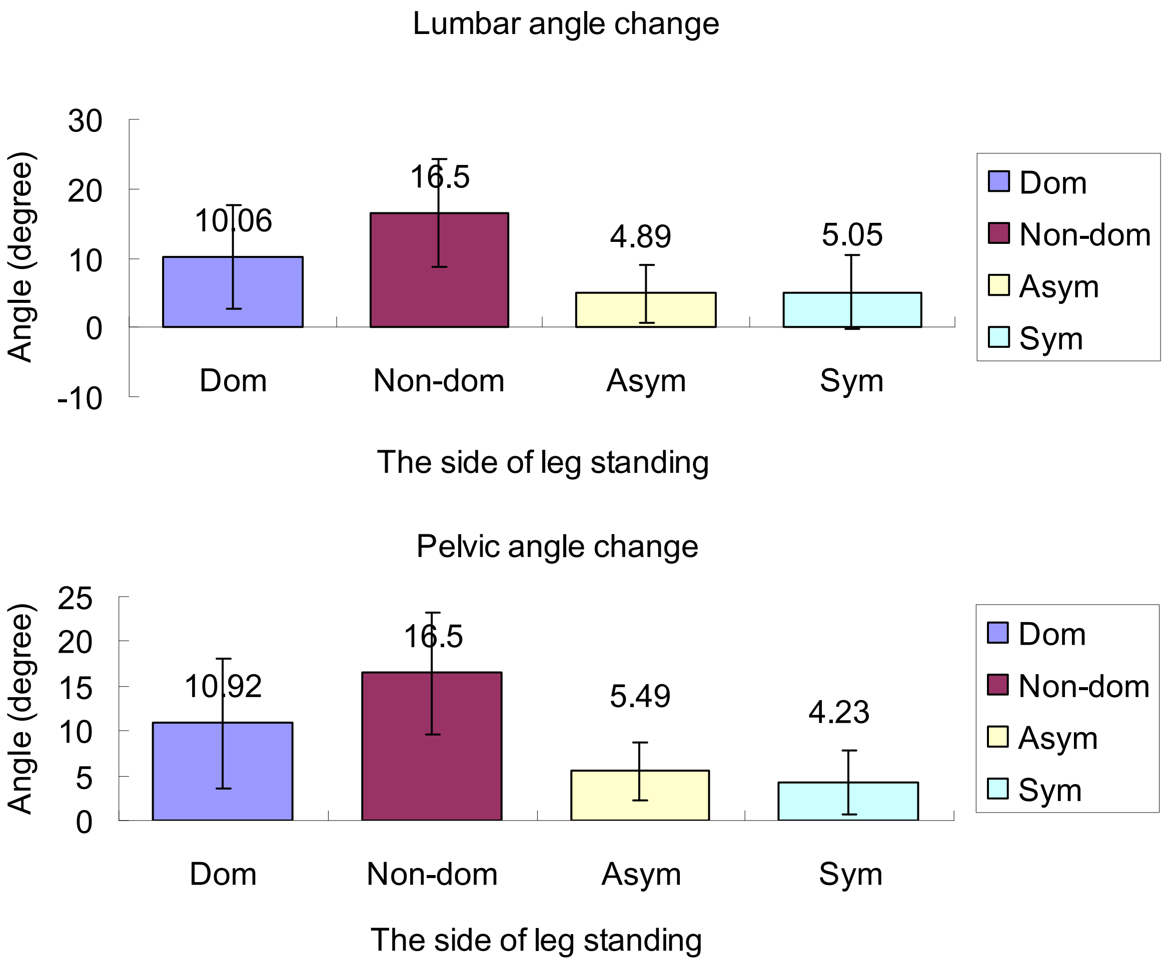



**Figure 7.2. Changes in the lumbopelvic angles during the task in age-matched control and patient group**

## 7.6. Discussion

In the healthy young participants, between-trial reliability of changes in lumbopelvic angles during the functional task of one leg standing within the same session was acceptable (ICC>0.7), but the between-days reliability was generally poor (0.51-0.71). This indicates that the technique is reliable for measuring outcome on the same day but not over time and may be due to many factors. The between-trial reliability of changes in lumbopelvic angles in patients was also acceptable (ICC >0.7) but poor between days (ICC<0.6).

### *7.6.1 Differences between patients and controls*

'One-leg-standing' is a clinical functional task for examining the performance of the lumbopelvic region by the co-contraction of the pelvis and lumbar spine (Hungerford et al., 2007). For patients with coccydynia, the balance of the lumbopelvic region is altered and demonstrates a smaller angle change in the lumbar spine and in pelvic tilting during the task.

The observed movement strategies can be divided into lumbar-dominant and pelvic-dominant according to the angle changes. Lumbar-dominant is defined as the tendency to use the lumbar joints and associated muscles to maintain balance and lead to larger angle changes; pelvic-dominant is defined as the tendency to rely on the pelvis to overcome the imbalance. The two values of angle changes in the lumbar spine and pelvis are respectively higher in one angle and lower in the other angle. However, more variation in movement strategies was found in patients. Three patients showed large angle changes during symptomatic leg standing, and six patients had larger angle changes during asymptomatic leg standing. Three patients tended to have no angle changes during the movement task, but five patients showed larger angle changes during all tasks.

There have been many studies for investigating lumbar motion during different tasks i.e. walking and running (Saunders et al., 2005, Schache et al., 2003, Schache et al., 2001, Schache et al., 2002a, Vogt et al., 2002). The tasks were varied including ambulation and running. However, the outcome measurements were focused on the lumbar positions rather than the functional changes. The angle changes during a functional task tend to present a quantitative method of assessing the result of integration of the relevant systems, not only a single variable.

However, different limitations were reported. The unavoidable limitations of surface landmarks involve considerable fascia and skin movements. Schache et al. (2002) used a strap to fix the markers over the T12 during running, but this might inhibit or stimulate the diaphragm and IAP, and activity of abdominal muscles might be increased, resulting in abnormal motion and breathing patterns (Schache et al., 2002a). Therefore, their methodology was not used in the study reported in this thesis.

In the present study, the methodology was adopted from Whittle and Levine (1997) to measure angular changes during tasks. Due to the limitation of accuracy of the VICON system at that time, the restricted trajectories of small markers of 20mm were reported to be difficult to differentiate. The same methodology in the present study showed different results because the upgraded VICON system now enables much more sophisticated analysis and precision.

## 7.7. Conclusions

The biomechanical findings from this motion analysis study demonstrated a difference between patients and controls, with lower angle changes found in patients. It could be concluded that most of the patients with coccydynia demonstrated rigid strategies to perform the task. The findings in patients with coccydynia matched the theory that patients tend to increase the stability of the spine once a dysfunction in the lumbopelvic region is present. The good between-trails reliability (ICC> 0.9) and poor between-day reproducibility (ICC= 0.71 to -0.51) found in the control group could have been due to many factors. In the patient group, lower but acceptable reliability of angular changes were found (ICC= 0.7- 0.9).

# Chapter 8: Investigation of onset of abdominal muscle activation using surface electromyography (EMG) during a functional task

## 8.1. Introduction

Since the 1960s, the central nervous system (CNS) has been known to prepare for predictable challenges to posture by recruiting the deep muscles, e.g. transversus abdominis (TrA) prior to the initiation of prime limb movement (Hodges et al., 1999). This strategy is called "feedforward" due to muscle recruitment patterns occurring in advance of the onset of activity of the muscles responsible for limb movement (Hodges and Richardson, 1999b, Hodges et al., 1999, Hodges and Richardson, 1996, Hodges and Richardson, 1999a).

The activation of TrA was consistently reported as the first muscle to respond during different tasks, such as "rapid unilateral arm and leg movements". This suggests that TrA contributes to the preparation of the spine for the perturbation, resulting from the reactive forces on the spine under the control of the CNS (Hodges et al., 1999). In patients with low back pain (LBP), the TrA was reported to have delayed activation or be absent during the tasks (Hodges and Richardson, 1999b; Hodges, 2001). Altered recruitment in LBP in the lumbopelvic region was therefore demonstrated the feedforward mechanism was delayed or absent. However, investigation of the activation of TrA relies on using needle EMG, which is an invasive method. In the present study, a non-invasive method was preferred. The internal obliquus muscle (IO) is well-known to attach to the TrA muscle directly and may respond in a similar way to TrA. Therefore, investigation of the IO muscle was carried out in the present study.

## 8.2. Aims, Research Question and Hypothesis

### *8.2.1. Aims*

1. To establish the reliability of the experimental protocol for data collection
2. To establish the reliability of measurement of onset of EMG activity of IO
3. To investigate the timing of IO onset during functional tasks in healthy participants
4. To compare IO EMG onset between healthy participants and patients with coccydynia.

### *8.2.2. Research questions*

1. Does the IO muscle activate before the onset of hip flexion during functional tasks in healthy participants?
2. Does the onset latency of IO EMG activity differ between healthy participants and patients with coccydynia?

### *8.2.3. Research hypotheses*

1. The IO muscles will activate prior to the functional task of one leg standing.
2. Patients with coccydynia will have a longer latency of IO muscle onset compared with healthy participants

## 8.3. Methods

Surface electromyography (sEMG) and VICON motion analysis data (reported in Chapter 7) were captured synchronously. The pattern of superficial muscle activity can be obtained by sEMG during functional tasks (Hodges et al., 1999, Hodges and Richardson, 1999b, Hodges et al., 2001b, Moseley et al., 2002). The chosen tasks were initially "one leg standing" and "sit to stand and level walking" (see Chapter 4, Section 4.5.2.) but only one leg standing was used after pilot testing (see below).

### *8.3.1. Participants*

Three groups of participants were involved in the two studies presented in this chapter: young healthy controls in Southampton (n=13; aged 23-34 years) took part in a reliability study of the experimental protocol to record EMG during a one leg standing task; a study in Taiwan then compared EMG onset times between patients with coccydynia (n=14; aged 23-62 years) and healthy age-matched controls (n=17; aged 35-65 years).   Demographic characteristics are given in Section 8.4.1 below. The recruitment processes for the three groups are described in Chapter 4 (Section 4.4.1). The inclusion and exclusion criteria for the healthy participants and patients were as described in Chapter 4 (Sections 4.4.2 & 4.4.3, respectively; summarised in Table 4.2). The studies were approved by the local ethics committees in Southampton and Taiwan (Section 4.4.4 and Appendix 13.1), and written, informed consent was obtained from all participants (Appendix 13.2 ).

### *8.3.2. Experimental protocol*

The reliability of surface EMG was established in Southampton in 2009 both between-trials (within the same session) and between-days. This pilot work focused on the muscle activation of the internal oblique (IO) muscle and lower extremities which are attached to the pelvic floor muscles directly. Due to difficulty in managing the interference of the EMG signal caused by the task of "sit to stand and level walking", the investigated muscles were changed to IO, EO and multifidus (see Chapter 4, Table 4.5). After applying the electrodes, the relative maximum voluntary contraction (MVC) of each muscle was obtained (see Chapter 4, Section 4.5.1).

Due to difficulty in data normalisation and the interference in the two studies, only the timing of IO muscle firing was reported. As the author was new to the EMG field, the intra-rater reliability of IO firing determination was examined to establish her ability to judge the onset of muscle firing. In this section, the intra-rater and inter-rater reliability (against a more experienced examiner) of IO onset determination and the latency of IO from the point of hip-flexion are presented in the following paragraphs. Any onset timings that could not be recognised were withdrawn from the data, and were not included in the reliability analysis.

## 8.4. Results

### *8.4.1. The characteristics of healthy participants and patients*

The participants are listed in Table 7.1 in Chapter 7. In the reliability study, the mean age for the healthy young participants was 26 years (SD= 3.26), height was 1. 59m (SD=0.075m), and body weight was 51.8kg (SD=7.55kg). In patients, the mean age was 40.9 years (SD= 11.7), height was 1.59 m (SD= 0.05m) and body weight was 59.9kg (SD= 8.1kg). Data from IO in the two healthy groups was combined to for an age-matched control group for comparison with patients.

### *8.4.2. Intra-rater reliability for IO firing determination in the pilot study*

Because the author in this study was new to EMG measurements, the inter-rater reliability for IO onset determination between the author and an experienced examiner (Experimental Officer, Mr. Martin Warner) was carried out before investigating all trials. The intra-rater reliability for the two examiners was examined and found the author to be highly reliable in measuring IO onset determination, with ICC values 0.999 and 0.989 respectively. The Bland-Altman plots of intra-rater reliability also showed good agreement between the measurements from each of the two examiners. The ICC value for inter-rater reliability of IO onset determination was 0.84. The Bland-Altman plots of inter-rater reliability demonstrated good agreement between the two investigators, as 95% CI for $\bar{d}$ lay around zero (0.15 mV- 0.25 mV) in Figure 8.1. The majority of the results were within the expected limit of agreement, but the findings from two trials fell outside of the limit of agreement. The plot still showed good agreement of findings between the two examiners, so the ability of the author to make EMG measurements was acceptable and sufficient to carry out the measurements in this study.

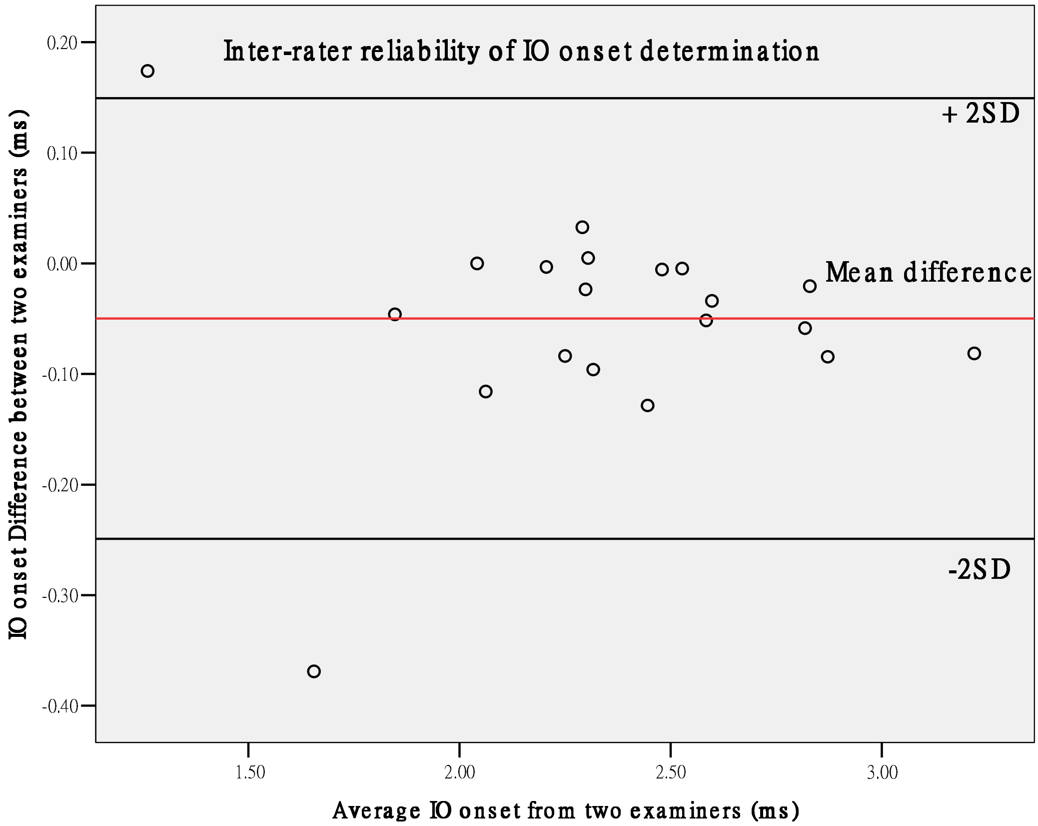



**Figure 8.1 Bland and Altman plot for inter-rater reliability of internal oblique (IO) onset determination**

### *8.4.3. Intra-rater reliability for IO firing determination in the pilot study*

In Table 8.1., the between-trials and between-days intra-rater reliability of IO onset determination by the author are presented. High ICC values (0.98-0.80) for between-trials reliability were reported and indicated that the applied technique was highly reliable. Lower ICC values (0.53-0.20) were reported for the between-days reliability.

**Table 8.1. Results for the reliability index in the latency of IO during one leg standing**

| **Between-trials reliability** | **Values** | | |
|---|---|---|---|
| **Trial name** | **ICC** | **SEM** | **SDC** |
| $1^{st}$ _Dominant_ latency | 0.80 | 1.06 | 2.84 |
| $1^{st}$_Non-dom_ latency | 0.98 | 0.04 | 0.09 |
| $2^{nd}$_Dominant_ latency | 0.95 | 0.11 | 0.29 |
| $2^{nd}$ _Non-dom_ latency | 0.80 | 0.06 | 0.02 |
| **Between-days reliability** | | | |
| Dominant_ latency | 0.20 | 0.25 | 0.66 |
| Non-dom_ latency | 0.53 | 0.12 | 0.32 |

The Bland-Altman analyses for between-trials showed good agreement, with the mean differences being close to zero (see Table 8.2). However, for between-days reliability, the Bland and Altman plots demonstrated poor agreement (see Figure 8.2). All data points fell within the 95% limits of agreement, but the data points were too far from the mean. The 95% limits of agreement in the latency were wide, so poor agreement of IO latency between days was indicated. This was consistent with the findings from the reliability index (see Table 8.1), which showed a poor ICC (0.20) and larger values of standard error of measurement (SEM) and smallest detectable change (SDC).

**Table 8.2. Bland and Altman analysis for the timing of IO onset : mean difference (d) and 95% limits of agreement**

| **Between-trials measurement** | | |
|---|---|---|
| **Measurement** | $\bar{d}$ **(min)** | **95% CI for** $\bar{d}$ |
| 1st_ Dominant _latency | 0.057 | -0.379 - 0.493 |
| 1st_ Non-dom _latency | 0.0073 | -0.136 - 0.151 |
| 2nd _ Dominant _ latency | -0.064 | -0.497 – 0.369 |
| 2nd_ Non-dom _latency | 0.035 | -0.2 - 0.271 |
| **Between-days measurement** | | |
| Dominant _latency | 0.187 | -0.771 – 1.145 |
| Non-dom _latency | 0.033 | -0.462 – 0.528 |

1st and 2nd = trials on the first and second days respectively

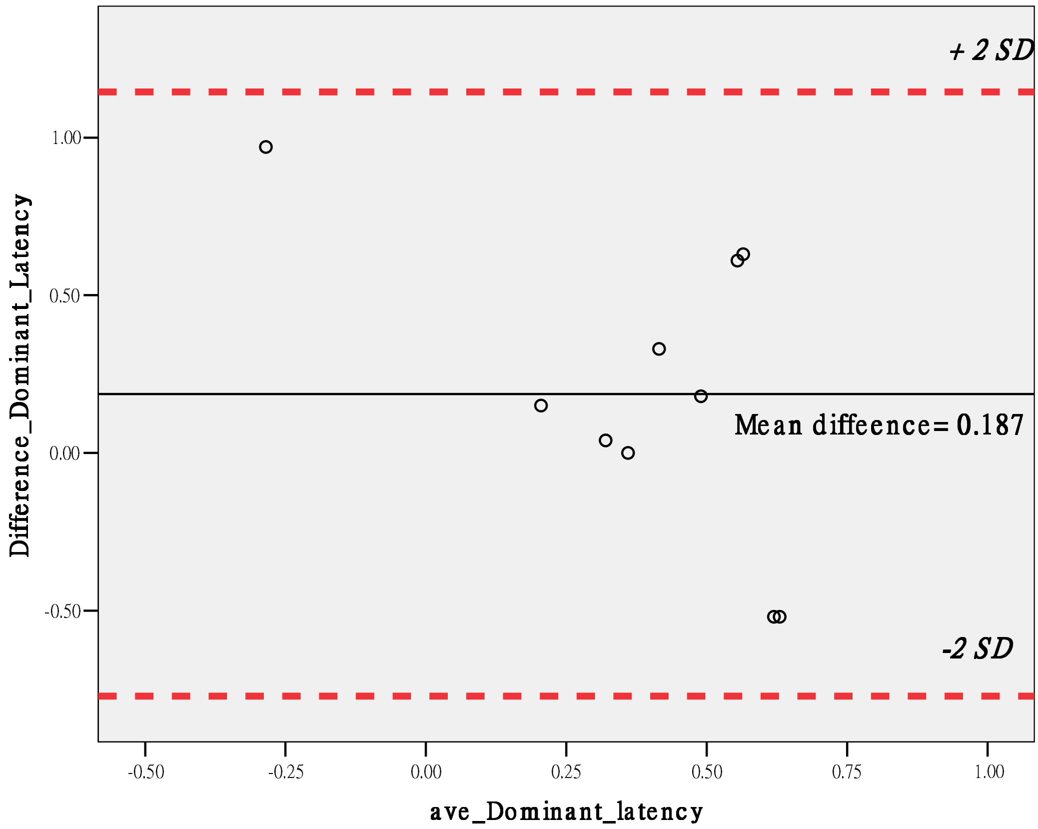



**Figure 8.2. Bland and Altman plot for between-days intra-rater reliability of latency of IO onset on the dominant side**

### *8.4.4. The latency of IO onset within the two studies*

Latencies are computed by subtracting the time to first hip movement detection from the time to IO activity. In the young control group, the mean latency of the group was 53 ms (SD 47 ms), with IO muscles firing later than hip motion. Due to some of the participants in the study in Taiwan presenting noisy data, not all of the results could be used for interpretation. The available data from patients (6 of 14 patients) showed a mean latency of 75 ms of muscle firing, which indicates that patients with coccydynia showed delayed muscle activation in comparison with the control participants.

## 8.5. Discussion

Reliability was found to be high for both inter- and intra-rater data. Patients showed delayed onset of IO compared with healthy controls but due to the difficulties in data normalisation and noisy data, the participant numbers are small and these limitatins are discussed here.

### *8.5.1. Reliability*

The inter-rater reliability for IO firing determination was high enough (ICC=0.84) to prove the author has sufficient ability to interpret the EMG signal, compared with a more experienced examiner. The intra-rater reliability was high between-trials (ICC= 0.80-0.98) but poor (ICC= 0.20-0.53) between-days. It is a well known phenomenon with the EMG technique that reliability is poor between days (Basmajian and De Luca, 1985).

### *8.5.2. Evidence of altered recruitment in the patient group*

The timing of IO onset was found not to occur prior to the task of one leg standing in healthy participants or in patients, which rejected the hypothesis. Existing studies used needle EMG to detect the activation of TrA muscle, and reported earlier activation of TrA during the task (Hodges and Richardson, 1999b, Hodges et al., 1999, Hodges and Richardson, 1996, Hodges and Richardson, 1999a). As mentioned in the earlier section (Section 8.1), IO and TrA muscles were assumed to activate together to be a spinal stabiliser. The interpretation for the findings may be the more superficial location of IO than TrA, so the timing of IO onset could be longer during the task of "one leg standing". Patients with coccydynia demonstrated longer latency of IO in comparison with controls. This is in keeping with the delayed onset of TrA activation observed in patients with LBP (Hodges and Richardson, 1999b, Hodges et al., 1999).

## 8.6. Conclusion

The high intra-rater reliability between the author and the experienced examiner proved that the author had sufficient ability to interpret the EMG signal to carry out the study. The timing of IO onset during one leg standing occurred later than initiation of hip movement in both controls and patents but a longer latency of was found in patients. This indicates that the feedforward mechanism was deficient in patients.

# Chapter 9: Case studies: preliminary intervention study to examine the effects of a pelvic belt on pain and function in individuals with coccydynia

From a biomechanical viewpoint, the muscular system surrounding the coccyx, in particular the local muscle system mentioned in Chapter 2 (Section 2.2.1) is activated to provide stability by supporting the sacroiliac joint (SIJ) ligaments. When a deficiency of function occurs in an active system, this may result in such regional conditions as lower back pain (LBP) or pelvic girdle pain (PGP). A common intervention for these disorders is recruitment of the transversus abdominis (TrA) muscle in combination with the pelvic floor muscles. However, the application of a pelvic belt has been shown to relieve symptoms in patients with postpartum PGP who failed to show improvement following an exercise intervention (Wu et al., 2004).

## 9.1. Background of pelvic belt

The theory behind the pelvic belt is that it can help to decrease SIJ laxity, which can thus improve the stability of the lumbopelvic region. Pelvic belt interventions have also been found to be effective in treating female patients with postpartum PGP and SIJ dysfunction. The symptoms have been relieved but altered motion or muscle characteristics have not yet been observed due to a lack of research (Mens et al., 2001, Mens et al., 2006c, Pel et al., 2008). Snijder et al. (1993) indicated that the direction of spinal loading is in line with the orientation of the SIJ, which induces a high shear force between the sacrum and the coxal bones. A pelvic belt could provide additional compression force to push the SIJs together, and may place the pelvis in an extreme, fixed position which further supports the stability of the SIJs. Considering the issue in a more specific manner, it may be that applying a pelvic belt could affect different muscles, ligaments and joint forces.

### *9.1.1. Different types of pelvic belt application*

The height of pelvic belt application can be divided into three levels: coxal, ASIS and greater trochanter (see Figure 9.1). To further evaluate the biomechanical parameters at different application levels, a series of studies *in vitro* and *in vivo* have been conducted to evaluate the neuromuscular changes during the application of the pelvic belt. In the i*n vitro* study, the belt significantly decreased SIJ mobility whilst a tension of 50 N was applied to a human cadaver (Vleeming et al., 1992). In the *in vivo* study, Damn et al (2002) reported the mobility of pelvic joints was reduced and Mens et al. (2006) indicated patients with PGP improved their ability to perform an active straight leg raising (ASLR) manoeuvre.

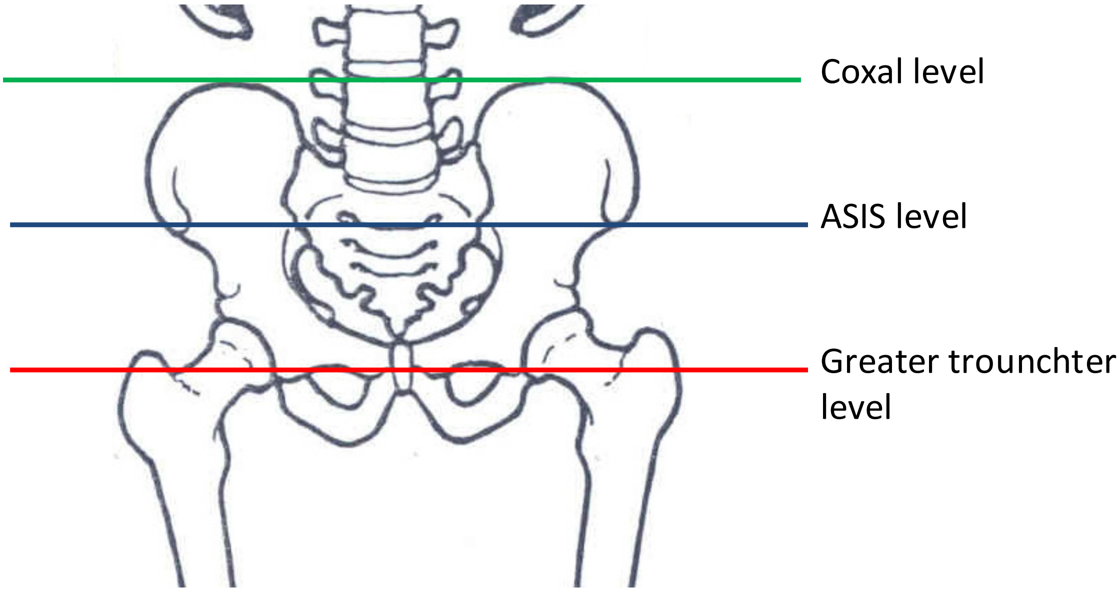
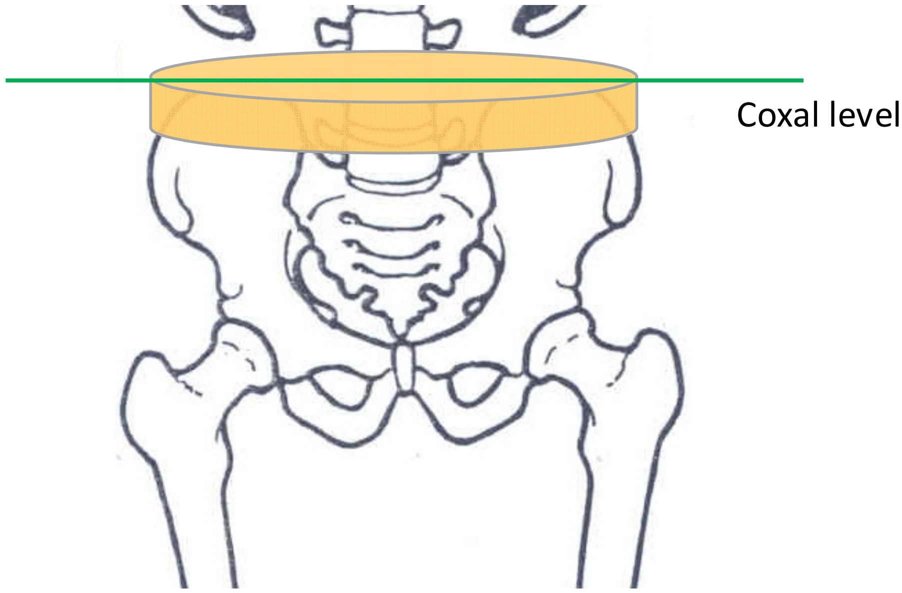



**Figure 9.1. The external force of pelvis stability provided by the belt at three different levels of coxal, anterior superior iliac spines (ASISs) and greater trounchter.**

When the pelvic belt is applied in a high position (at coxal level) it may simulate the action of the TrA muscles and multifidus, and in a low position (at greater trochanter level) may induce the action of pelvic floor muscles. The features of belt application at two levels are summarised in Figure 9.2 and Figure 9.3, based on the study of Pet et al (2008). The testing position for both patients and healthy volunteers was 'prone'. Therefore, an issue arises due to the fact that most of the important stabilisers in this region are relaxed in the lying position. These studies presented the possibility for improving the stability of the SIJs in prone, but the effect of the belt may or may not occur with the patient in a more functional posture. Pel et al (2008) further used the static 3-D pelvic simultaneous model to present the muscle activation patterns and SIJ stability parameters during the different levels of pelvic belt which were applied. The applied model could be used as a tool to investigate the general relationship between muscles, ligaments and forces in the pelvic region (Hoek van Dijket., 1999). This model has demonstrated a good correlation with EMG activity levels in humans during the three previous experiments involving functional tasks, in comparison with muscle force distribution (Seroussi and Pope, 1987, McGill, 1991, Andersson et al., 1996).




•Simulate the action of TrA muscles and multifidus
•Increase the activation of EO and IO muscles
•Increased SIJ compression force

**Figure 9.2. The functions of pelvic belt applied on the coxal level**

Pel et al (2008) concluded that the external compression force at the coxal position results in an increased SIJ compression force, a decreased load of the sacrotuberal ligament and an increased load of the iliolumbar and the sacrospinal ligaments. The activations of EO and IO muscles are presented to support this increase due to their anatomical features of transversal orientation. The altered forces and activation patterns are also apparent at a lower position. The double initial SIJ compression force was found at a lower position, and the action of the pelvic floor muscles was simulated to provide support. Their studies inform us that the application of a pelvic belt in a lower position can effectively increase the SIJ compression force, and simultaneously induce the contraction of the transversus abdominis and pelvic floor muscles. However, their findings are limited since they only are derived from a static standing model. In order to properly substantiate the findings, the study should be further explored in a more functional task.

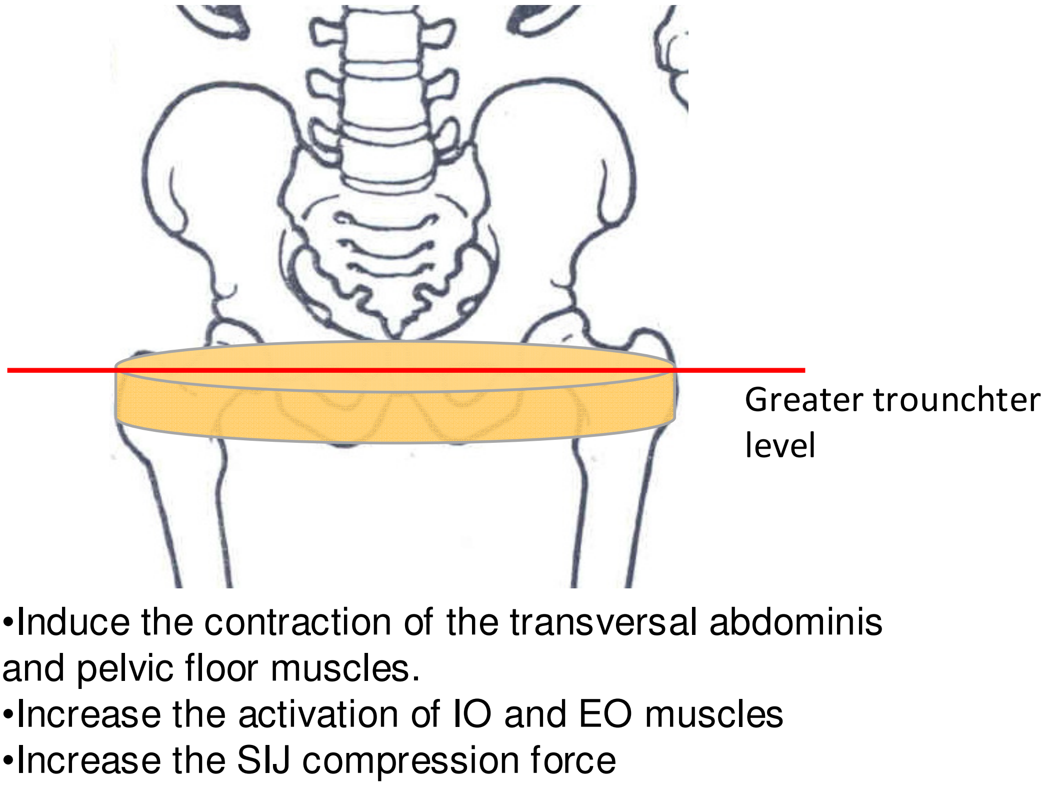



**Figure 9.3. The functions of pelvic belt applied on the greater trounchter level**

### *9.1.2. Objective assessment of function of the pelvic belt*

Due to insufficient understanding of the function of the pelvic belt, Hu et al. (2010) applied EMG to assess muscle activity during the ASLR, and how it changes with the application of the pelvic belt during treadmill walking at an accelerating speed, compared with wearing no pelvic belt during the same tasks. The muscles were investigated by fine-wire EMG on TrA, illiacus and psoas, and by surface EMG on the external oblique (EO), internal oblique (IO), rectus abdominis (RA), erector spine muscles, gluteus maximus, rectus femoris, adductor longus and biceps femoris. The findings showed that the TrA, EO and IO were less active in people wearing belts than those without belts, in both tasks. While the pelvic belt was applied, the contra-lateral biceps femoris was more active during the ASLR, and the gluteus maximus showed higher activity in treadmill walking. It could be interpreted as a hip flexor contraction producing a forward rotation that was prevented by the counter force of the active abdominal muscles. It is suggested that the reduced activity of the abdominal muscles during the application of the belt could provide a function such as “force closure”, which confirms Snijders’ hypothesis. The population Hu’s study (2010) was young healthy people, of whom the women were nulligravida. The mean age was 28.7±2.8 years and the numbers for each gender are unknown. Although information regarding the impact of age and gender is insufficient, the function of the pelvic belt in substituting or improving the stabilising ability was confirmed.

Jansen et al. (2010) conducted a study to detect the influence of the pelvic belt on abdominal muscle thickness activity in patients with long-standing groin pain (LSGP). They used ultrasound imaging to investigate thickness changes of abdominal muscles both at rest, and during ASLR and the squeeze test, which is used for differential groin pain. No correlation between abdominal muscle thickness changes and pelvic belt application was found. The different pelvic positions lead to different muscle activation patterns Jansen et al. (2010). Pelvic belt application could assist patients in maintaining a better alignment and may remind them to utilise abdominal muscles during functional tasks. However, Jansen et al. (2010) only demonstrated effects on muscle EMG activity at the time of application; the impact following a period of application was not mentioned. It could be summarised that the initial application of a pelvic belt can incite an immediate response in EMG findings, but not in US thickness.

The final outcome of the measurements during application was limited regarding changes in symptoms, but this could lead to bias. A more objective assessment method should be applied to further support the hypothesised function of the pelvic belt and to assess the effectiveness of the pelvic belt in patients. The existing studies emphasise the changes pain but more objective assessment is unfortunately lacking. In the case of coccydynia, neuromuscular control mechanisms may be defective, causing muscle imbalance and so instability of the SIJ could result from this. If the hypothesis is correct, a pelvic belt could be used to adjust the alignment and help to increase the stability of the SIJ and relieve symptoms in people with coccydynia.

### 9.2. Aim

The aim of six case studies was to investigate the effectiveness of pelvic belt application based on the observation of neuromuscular performance. Patients with coccydynia may demonstrate an altered pelvic position and this may impact the alignment of the lower extremities. These alterations of body alignment may keep aggravating the painful area, so the application of a pelvic belt may passively inhibit the vicious cycle and induce the activation of relevant muscle systems.

### 9.3. Study design

The study was an A-B-A design, consisting of baseline assessments, six weeks of intervention of a pelvic belt, followed by post-intervention assessments. The experimental protocol for the six case studies is explained in Chapter 4 (Section 4.7) and outlined below. There are four possible ways to wear the pelvic belt, depending on the orientation of the pelvis found on assessment (see below).

## 9.4. Methodology

### *9.4.1 Participants*

Female Taiwanese patients aged 20-65 years who were diagnosed with coccydynia were eligible for the study (Chapter 4, Section 4.4.3,). Six patients were requested to take part in case studies. The demographic details of these patients are presented below (Section 9. 5.1.). The clinical characteristics for each patient are presented in Section 9.6.

### *9.4.2. Baseline data collection*

Basic data for age, height and body weight were recorded. The McKenzie method, a type of mechanical examination, was used to rule out the possibility of symptoms originating from the lumbar region. The patient was asked to perform forward bending, backward bending and lateral bending of the trunk to observe any subsequent symptom changes. If the symptoms did not change during these tasks, it indicated that the symptoms were originating from local coccygeal problem, rather than the lumbar region. Each patient's posture was assessed and recorded following the alignment observation stated in Chapter 2 (Section 2.4), which was a procedure used to observe static posture.

The following tests examined form closure and force closure of the pelvic girdle, as described in Chapter 2 (Section 2.2). Form closure analysis requires an evaluation of two zones of motion, the neutral zone and the elastic zone (Figure 2.12) (Panjabi, 1992). Four types of tests involved were: positional tests, passive mobility tests, pain provocation tests and functional tests.

#### *9.4.2.i Positional tests of innominate bones and sacrum*

Positional analysis of these bony markers in the lumbopelvic region was required in order to provide information on starting positions, which may show altered joint mobility in patients. For example, if the innominate bone is posteriorly rotated relative to the sacrum, then the amplitude of the neutral zone will be reduced compared to the other side. The tests and assessments used in this project were adopted from the textbook "*The Pelvic Girdle: an approach to the examination and treatment of the lumbopelvic-hip region*" by (Lee, 2005) pp81-120).

Positional tests of innominate bones were used to assess the positions of bilateral anterior superior iliac spine (ASIS), posterior superior iliac spine (PSIS) and pubic tubercles, as follows:

a. Palpation of ASIS:

   While the investigator palpated the ASIS, the patient was positioned in supine lying with the legs extended. The examiner placed her hands over the ASIS of both innominates (see Figure 9.4.), and then palpated the inferior aspect of ASIS bilaterally toward the superior aspect of pubic tubercles (see Figure 9.5.) to confirm the impression of pelvic girdle. The position of the ischial tuberosities can strengthen the information about the pelvic outlet, e.g. if the innominate bone was rotated one side, the asymmetrical height and increased gap between the ischial tuberosities are reported.

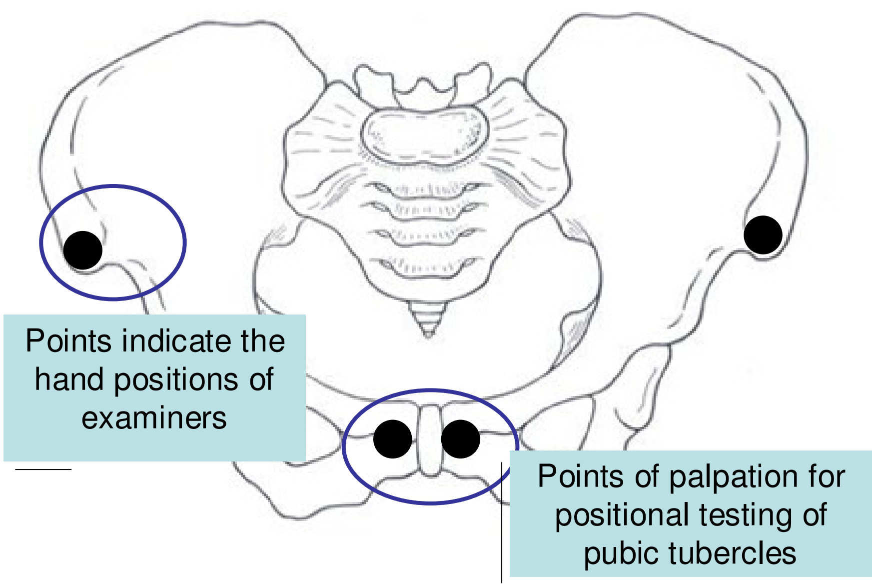



**Figure 9.4. Palpation of anterior superior iliac spine (ASIS) and pubic tubercles. Modified from 'The source of Medical Illustration'.**

b. Palpation of PSIS and ischial tuberosity

   The investigator palpated the inferior aspect of the PSIS of both innominate bones (Figure 9.6), with the thumbs while patient was positioned in prone lying with the legs extended. Palpation was then towards the inferior aspect of the ischial tuberosity bilaterally, with the heels of the hands following the thumbs over the ischial tuberosity.

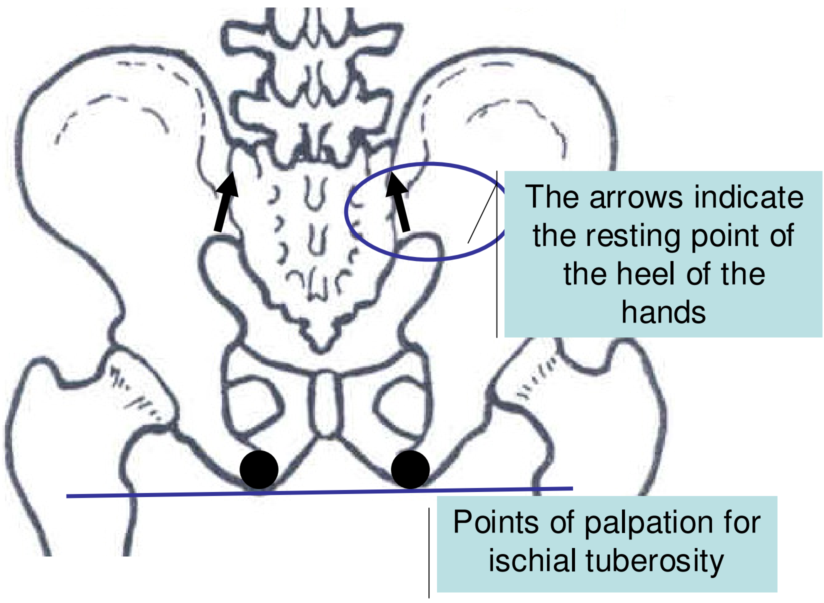



**Figure 9.5. Palpation of posterior superior iliac spine (PSIS) and ischial tuberosity. Modified from 'The source of Medical Illustration'.**

c. Palpation of inferior lateral angle of sacrum:

   To determine the position of the inferior lateral angle of the sacrum, the investigator placed her hands over the medial sacral crest, and then moved inferiorly until reaching the sacral hiatus, which are the unfused spinous processes of S4 and S5. From these points, the heels of the hands moved laterally until the lateral edge of the sacrum was felt (see Figure 9.6.).

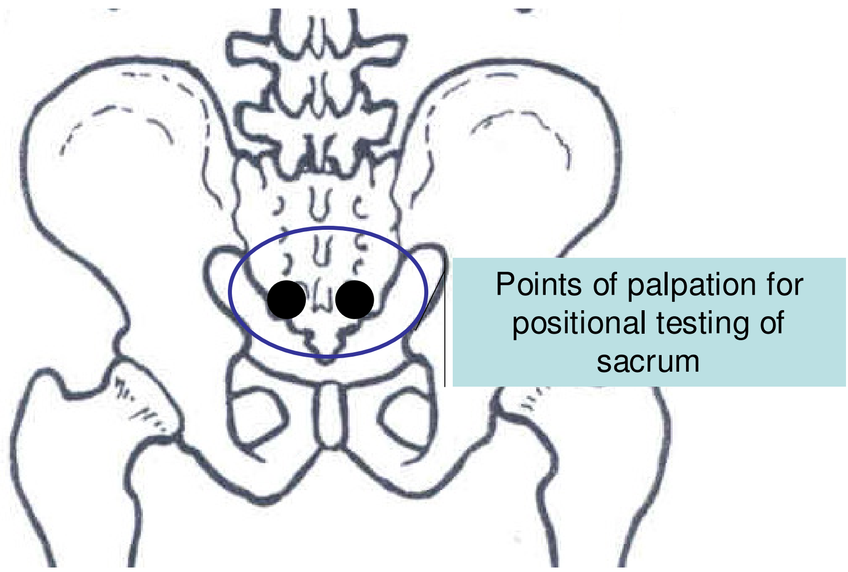



**Figure 9.6. Palpation of inferior lateral angle of sacrum. Modified from 'The source of Medical Illustration' .**

*9.4.2.ii Passive mobility test of innominate bones and sacrum*

Passive mobility of the innominates and sacrum was assessed as well as the sacroiliac joint. These assessments require experience to detect differences between patients and healthy participants.

a. Mobility of innominate bones: Anterior/ posterior rotation

   The patient was positioned in side-lying with the hips and knees slightly flexed, and the side examined was uppermost (see Figure 9.7). The examiner faced the patient and with one hand palpated the ASIS and held the innominate bone with the other, passively rotating the innominate bone anteriorly and posteriorly relative to the sacrum.

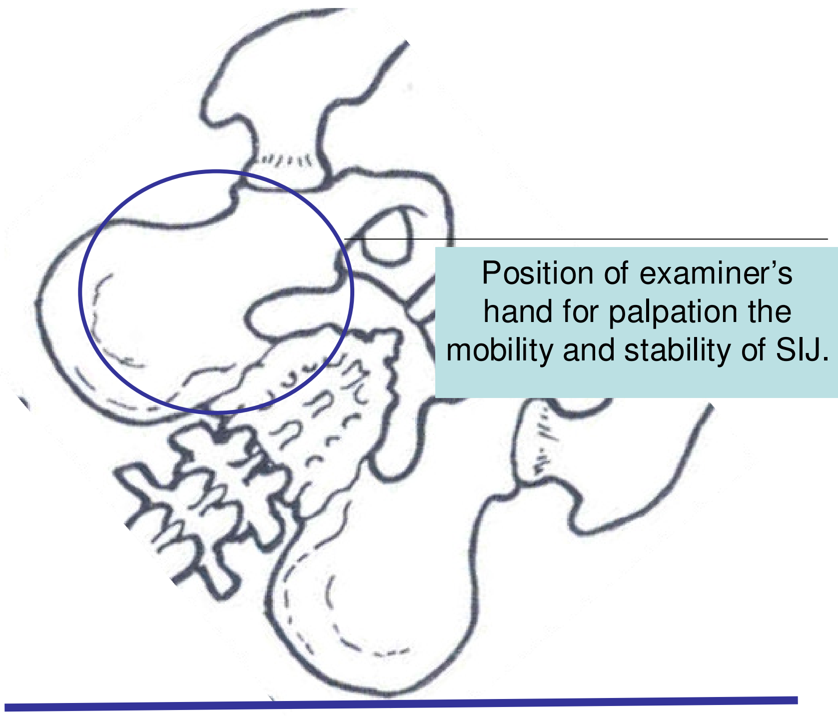



**Figure 9.7. The position of pelvic girdle during the examination of sacrio-iliac joint (SIJ). Modified from 'The source of Medical Illustration'.**

b. Mobility of sacrum: Nutation/counternutation

   The patient was positioned in prone-lying with arms extended by their sides. The examiner placed one hand over the apex of the sacrum and the other hand over the midline of the sacral base, then passively nutated and counternutated the sacrum, relative to the innominates.

c. Mobility of SIJ: Inferoposterior / Superoanterior glide

   The patient was in crook-lying with the knees comfortably supported over a pillow and their arms by their sides. The examiner stood on the examined side and placed a hand over the medial aspect of the posterior iliac crest. The other hand was placed over the ipsilateral ASIS. The examiner applied a small anterior rotation force to the innominate to produce an inferoposterior glide at the SIJ, and then applied a small posterior rotation force to produce a superoanterior glide at the SIJ.

The level of mobility and quality of motion were recorded in comparison with the opposite side. The classification of mobility was divided into hypomobility, normal and hypermobility. The symmetry of mobility was assessed to establish the mechanical diagnosis of coccydynia. As for assessment of the SIJ, the symmetry of both sides was evaluated and recorded as either normal when symmetrical or as dysfunctional when asymmetry, unilateral stiffness or laxity were reported (Buyruk et al., 1995a, Buyruk et al., 1995b, Damen et al., 2002, Lee, 2004).

*9.4.2.iii Pain provocation tests*

There were four provocation tests for the pelvic girdle to identify a painful region or motion. These provocation tests are useful to detect the types of certain activities/exercises that may evoke the symptoms.

a. Test for long dorsal ligament

   The patient lay prone with the head natural and arms by their sides. The examiner placed one hand over the PSIS and palpated the long dorsal ligament with the other hand, to apply a counternutation force to the sacrum. If this motion induced more pain, it indicated that the ligament may be a pain generator when stretched.

b. Test for sacrotuberous ligament

   The patient lay prone with the head natural and arms by their sides. The ischial tuberosity was palpated with one thumb and then moved medially and inferiorly until reaching the inferior arcuate band of the sacrotuberous ligament. The examiner then applied a nutation force to the sacrum. If this motion induced more pain, it indicated this ligament as a source of pain.

c. Test for pelvic girdle: anterior distraction- posterior compression

   The patient was positioned in supine lying with the hips and knees flexed comfortably. The examiner placed the heels of their cross hands over the medial aspect of the ASIS, and then applied a slow, steady, posterolateral force through both the ASISs for 5 seconds. The aim of this test was to distract the anterior aspect of the SIJ and pubic symphysis and compress the posterior structure. The provocation and location of pain were recorded.

d. Test for pelvic girdle: posterior distraction- anterior compression

   The patient was again in side-lying. The examiner placed their hands over the anterolateral aspect of the uppermost iliac crest and then applied a slow, steady, medial force through the pelvic girdle for 5 seconds. The aim of this test was to distract the posterior structure of the SIJ and compress the anterior structure. The provocation and location of pain were recorded.

*9.4.2.iv Pain assessment and Functional assessment:*

a. Pain was rated on the visual analogy scale (VAS) of 0-10, where 0 represented no pain and 10 the worst pain possible. Pain was rated in sitting and standing, and tolerance was recorded. The duration of pain, description of pain, and any functions that relieved or worsened it were recorded.

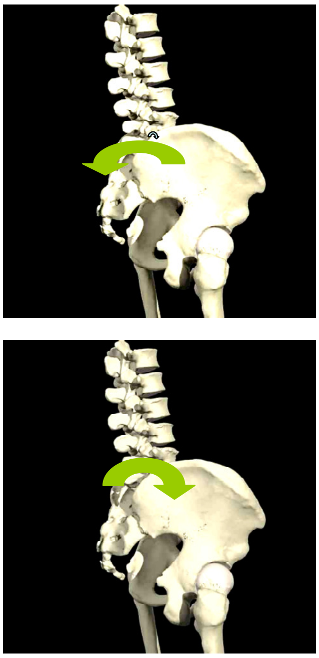
b. Bladder function was assessed through history taking of urinary incontinence and frequency of voiding. Rehabilitative ultrasound imaging (RUSI) was used to assess the ability to contract pelvic floor muscles, following the protocol described in Appendix 13.8.

c. Modified Oswestry Disability Questionnaire was administrated to assess disability. This tool has been found to be reliable in detecting improvement or deterioration in patients with low back pain (Fritz and Irrgang, 2001, Davidson and Keating, 2002). The Oswestry Disability Questionnaire (OSW) is a type of self-reported measurement of stability to be used as an outcome measure for people with back pain. Fairbank et al. (1980) developed and published the OSW. Each item included in the OSW was selected from the experience of the scale's developer and piloted in a sample of 25 patients with low back pain. There are 10 items stating different aspects of function in the OSW. Each item is scored from 0 to 5, and the higher value indicates greater disability. The total score is multiplied by 2 and expressed as a percentage(Fairbank et al., 1980).

The original version of the OSW consisted of a sex life section, which was frequently found to be left blank. Therefore, the modified OSW was developed to include an "Employment/Homemaking" section to substitute the sex life section(Fritz and Irrgang, 2001). A group of 67 patients with back pain were recruited to be examined initially and after 2 and 4 weeks. The modified OSW demonstrated good test-retest reliability (intraclass correlation coefficient, ICC= 0.9, 95% CI=0.78-0.96). Responsiveness describes a scale's ability to detect a clinically meaningful change over time. The sensitivity and specificity of a measurement scale are considered important to interpret the findings. Sensitivity indicates the ability of the scale to detect clinically meaningful changes and specificity indicates the ability to remain stable when no clinically meaningful changes have occurred (Deyo and Centor, 1986, Fritz and Irrgang, 2001). Fritz and Irrgang (2001) reported 6 points for the modified OSW as the minimum clinically important change, which was consistent with the 4 to 6 points for OSW. The modified OSW has been proven as a good disability questionnaire in patients with low back pain, as reported by the International Forum of Primary Care Research in Low Back Pain (Deyo et al., 1998).

d. One-leg standing test

This test is also known as the Gillet test or strik test to examine the ability of the low back, pelvis, and hip to transfer load through the supported leg, as well as for the pelvis to allow intrapelvic rotation (Hungerford 2002). This test can be used to detect relative motion between the innominate bone and the sacrum. The examiner used one hand to palpate the inferior aspect of the PSIS and the iliac crest on the weight bearing side. The other hand palpated the inferior lateral angle of sacrum on the same side. The patient was instructed to flex the hip ipsilateral to the palpated side. As Figure 9.8 shows, the innominate should remain posteriorly rotated relative to the sacrum in normal people. A positive finding occurs when the innominate bone anteriorly rotates relative to the sacrum during the test.



- Relative motion between the innominate bone and the sacrum in supported leg

A. Posterior rotation of the innominate bone relative to the sacrum in healthy subjects

B. Anterior rotation in the patients with pelvic girdle pain

**Figure 9.8. Movement patterns of the pelvic girdle in A. healthy people and B. patients**

### *9.4.3. Experimental protocol*

Each patient took part in the RUSI sessions to measure thickness of the trunk muscles at rest and during a functional activity (see Chapter 4, Section 4.5) and motion analysis using the VICON$^{TM}$ system as described in the methodology in Chapter 4 (Section 4.6). The questionnaires concerning daily activity, pain scales and characteristics, Modified Oswestry Disability Questionnaire (Appendix 13.2.5.) and bladder assessment were completed to provide the baseline information.

### 9.4.4. Protocol for the pelvic belt intervention

There are four ways to apply the pelvic belt, which were described in Chapter 4 (Section 4.7), according to the individual's pelvic position. The author determined the pelvic position by observation. The application of a pelvic belt follows the suggestion of Mens et al. (2006). The belt was positioned just caudal to the anterior superior iliac spines (ASIS), which provides better stability of the sacroiliac joint (SIJ) than at the level of the pubic symphysis, and reduces pain symptoms of pelvic girdle discomfort. Each participant wore a pelvic belt for eight hours a day, over a period of six weeks. They were requested to keep a diary of their use of the belt and to record any changes in symptoms. They returned for follow-up testing consisting of ultrasound imaging and questionnaires after six weeks (immediately after the end of the intervention period) in order to examine any effects resulting from wearing the belt. These six patients were requested to return again six weeks later to re-examine all trials and assess the changes in symptoms, such as pain intensity.

### 9.4.5. Outcome measurements

The outcome measurements included muscle morphology (thickness measurements using ultrasound imaging), angle changes in lumbar and pelvic joints (using motiona analysis) and change in symptoms. The data processing methods have been described in Chapter 4 (Section 4.6). There are difficult issues regarding ultrasound images taken of the bladder shape and function of PFMs. Whether the scans of bladder shape can really represent the function of PFMs is still unknown due to bladder shape being affected by many factors during the observations. Herein the three thickness parameters (muscle thickness, thickness change and percentage change) of the lateral abdominal muscles and angle changes during functional tasks serve as the objective outcome measurements. The subjective information from pain scale changes and function were also taken into consideration. Pain was recorded on a visual analogue scale, which ranged from 0-10, where 0 was no pain and 10 was the worst pain possible.

## 9.5. Results

The results for the six case studies are summarised first and then the findings for the individual cases are presented in detail.

### *9.5.1. Patients' Characteristic*

The characteristic of each patient is listed in Table 9.1, including the information of age, weight, height, BMI and waist-hip ratio.

**Table 9.1. The characteristics of each patient**

| Coding | Age | Weight | Height | BMI | Waist-Hip ratio | History of Childbirth |
|---|---|---|---|---|---|---|
| **TP2** | 23 | 54 | 160 | 21.1 | 0.84 | N |
| **TP5** | 33 | 72 | 169 | 25.2 | 0.87 | N |
| **TP7** | 56 | 56 | 158.5 | 22.3 | 1 | Y |
| **TC8** | 33 | 52 | 153 | 22.2 | 0.84 | N |
| **TP19** | 36 | 50 | 152 | 21.6 | 0.87 | Y |
| **TP28** | 26 | 58 | 155.5 | 24 | 1.2 | N |

### *9.5.2. Changes in symptoms of pain, function and bladder assessment*

In these six patients, the range of pain duration was wide between three months to over 10 years. The pain assessments considered pain intensity and pain tolerance during two functional tasks of sitting and standing (see Table 9.2). The overall functional evaluation was assessed by the Oswestry Disability Index, and the scores for each section are detailed in Table 9.3. For the six cases, they generally subjectively reported improvement in pain symptoms after wearing the pelvic belt, but were not relieved of all discomfort over the six weeks. Pain tolerance was improved and enabled them to be involved in their daily lives with less discomfort.

**Table 9.2. Pain assessments**

| Patient ID Code | Pain intensity (scale 0-10) | | Tolerance in sitting (hours) | | Tolerance in standing (hours) | |
|---|---|---|---|---|---|---|
| | Baseline | **Post** | Baseline | **Post** | Baseline | **Post** |
| **TP2** | 4/10 | **1/10** | 1-2 hr | **Over 4 hr** | Below 1 hr | **Over 1 hr** |
| **TP5** | 7/10 | **4/10** | Under 1 hr | **1-2 hr** | 1 hr | **2 hr** |
| **TP7** | 5/10 | **1/10** | Under 2 hr | **Over 3 hr** | Below 1hr | **Over 2 hr** |
| **TC8** | 4/10 | **2/10** | 1-2 hr | **3 hr** | 1 hr | **Over 2hr** |
| **TP19** | 6/10 | **2/10** | 1-2hr | **4 hr** | Below 1hr | **Over 2hr** |
| **TP28** | 3-4/10 | **1-2/10** | 1-2 hr | **4 hr** | Below 1hr | **1-2 hr** |

**Table 9.3. The Oswestry Disability Index in each section**

| | TP2 | | TP5 | | TP7 | | TC8 | | TP19 | | TP28 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | B | Po | B | Po | B | Po | B | Po | B | Po | B | Po |
| **Pain intensity** | 1 | 1 | 2 | 1 | 1 | 0 | 1 | 1 | 2 | 1 | 1 | 0 |
| **Personal care** | 0 | 0 | 2 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 |
| **Lifting** | 3 | 1 | 3 | 2 | 2 | 1 | 2 | 1 | 3 | 2 | 0 | 0 |
| **Walking** | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 |
| **Sitting** | 2 | 1 | 3 | 2 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 |
| **Standing** | 1 | 0 | 2 | 1 | 1 | 1 | 2 | 1 | 2 | 1 | 0 | 0 |
| **Sleeping** | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 0 |
| **Social life** | 0 | 0 | 1 | 1 | 2 | 1 | 1 | 0 | 1 | 0 | 0 | 0 |
| **Travelling** | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 0 | 1 | 0 | 0 | 0 |
| **Total** | **9** | **4** | **16** | **11** | **12** | **5** | **12** | **6** | **14** | **6** | **3** | **1** |

B=Baseline; Po= post-intervention

In the assessment of bladder function, urinary incontinence and frequency of voiding were considered. The ultrasound imaging technique was used to observe activity of pelvic floor muscles and the shape of the bladder base in the transverse view. The baseline reports are shown in the Table 9.4. After the six-week intervention, patients with urgent incontinence subjectively reported an improvement in their symptoms, and the frequency of voiding was decreased to 4-5 times per day. The activity of the PFMs was improved in some cases, but the asymmetrical bladder base from the ultrasound imaging remained.

**Table 9.4. Baseline findings of bladder assessments**

| Coding | Incontinence type | Frequency of Voiding | PFMs contraction | Bladder base observation |
|---|---|---|---|---|
| **TP2** | Mild mixed type | 6-8 times | Yes | Uneven |
| **TP5** | Mild urgent type | 6-8 times | Yes | Uneven |
| **TP7** | No | 6-8 times | No | Uneven |
| **TC8** | Mild urgent type | 4-5 times | Yes | Uneven |
| **TP19** | Mild urgent type | 6-8 times | Yes | Uneven |
| **TP28** | No | 4-5 times | No | Uneven |

* TC8 is patient with wrong coding due to a mistake.

## 9.6. Objective findings for the six individual case studies

### *9.6.1. Case study 1: TP2*

#### ***TP2* Baseline data**

This patient was a Masters student, aged 23 years, with a low activity level. She had a trauma history of directly falling twice, 12 years ago and 2 years ago. The intervention histories were (1) Traditional Chinese Medicine involving massage and hot pack (2) Physiotherapy involving electrical stimulation and hot pack. However, the improvements were limited and discomfort remained.

#### ***TP2* Chief complaint**

In 2008, she felt pain over her buttocks, in particular while seated, and then symptoms spread to her left lower back. Her pain tolerance in both sitting and standing positions was less than one hour. She also complained that her left hip movements were associated with clicking, in particular during position changes. She had mild symptoms of incontinence during squatting and lifting, and sometimes leaking when she was on the way to a toilet. She reported having difficulty in emptying her bladder during the year previous to the investigation.

#### ***TP2* Physical examination**

From the physical findings, the impression of this patient was coccydynia with left SIJ dysfunction. The results of the physical examination are presented in Table 9.5. The diagnosis was made mainly according to altered mobility of the SIJ joints, i.e. hypermobility or stiffness.

The investigator wore gloves to palpate the tender points, and found a taut band with oedema around the coccyx, in particular over the apex of the coccyx and left anal wall. The pain characteristics were dull and cloudy pain over the sacral area and sharp pain over the coccyx after prolonged sitting or standing were reported. As for assessment of posture, this patient demonstrated asymmetry of PSISs with the left higher than right, and left forward facing ilium with slight internal rotation of the hip, showing a decreased ankle arch (See Figure 9.9.). During the ASLR test, she felt discomfort on the left side.

Table 9.5. Physical examination record of TP2

| Tests | Right (+/-) | Left (+/-) |
|---|---|---|
| **Gillet's test** | --- | + |
| **Passive mobility** | | |
| **Innominate anterior rotation** | Hypomobility | Hypomobility |
| **Innominate posterior rotation** | Hypomobility | Hypermobility |
| **Sacrum nutation** | Hypermobility | |
| **Sacrum counternutation** | Hypomobility | |
| **SIJ Inferoposterior glide** | Stiffness | Laxity |
| **SIJ Superoanterior glide** | Stiffness | Stiffness |
| **Pain provocation test** | | |
| **Long dorsal lig.** | --- | + |
| **Sacrotuberous lig.** | + | + |
| **Anterior distraction** | --- | --- |
| **Posterior distraction** | --- | --- |

+ indicates positive finding; - indicates negative finding

Lig. indicates ligament; SIJ indicates sacroiliac joint

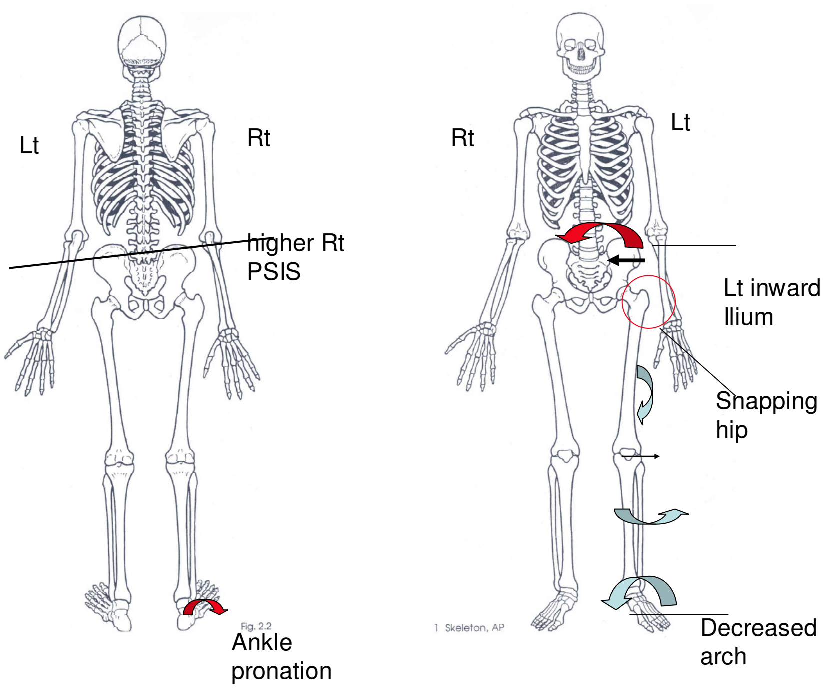



**Figure 9.9. Alignment of pelvis and lower extremities in case TP2**

While observing the bladder shape, an uneven bladder base at rest was found and asymmetrical lifting of the bladder base during contraction (see Figure 9.10).

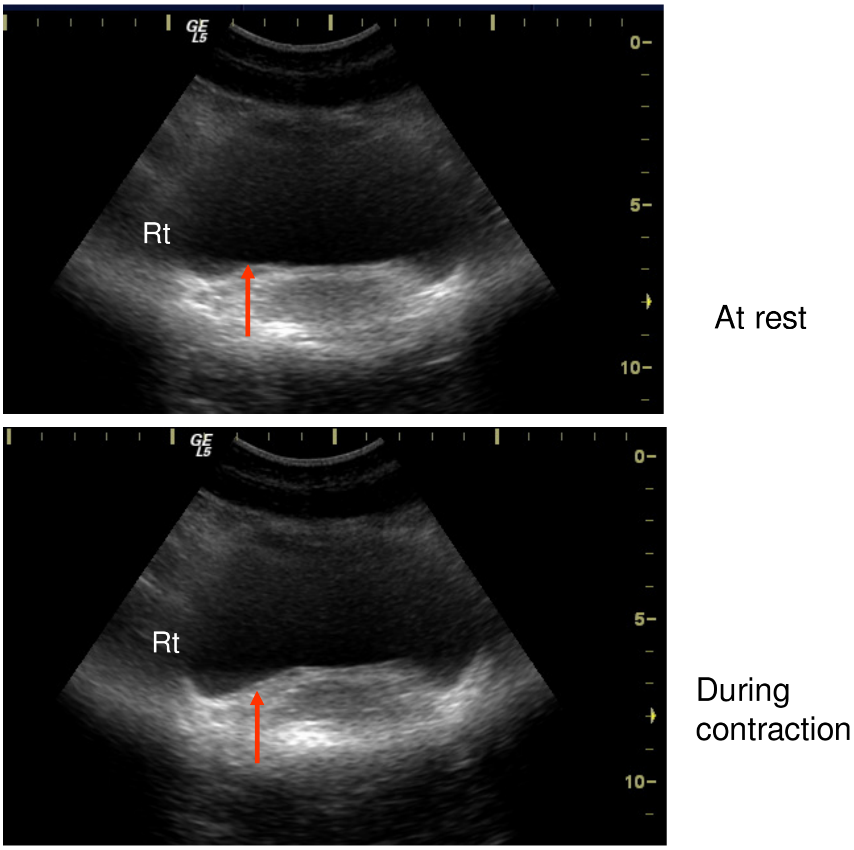



**Figure 9.10. The bladder base at rest and during contraction in *TP2* (transversal view)**

***TP2* Intervention**

The patient was instructed to wear the belt, following the asymmetrical application (see Figure 4.9 in Chapter 4). This involved an additional strap was applied from the front to the back over her left side, and the reverse application of the other strap applied over her right side. She was requested to keep a diary of changes in symptoms and they affected her during daily tasks.

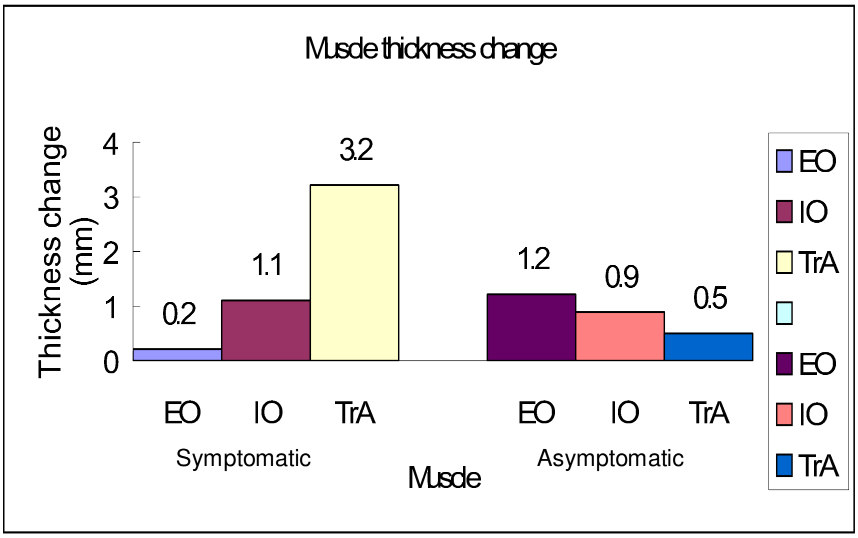
***TP2* Outcome measurements post-intervention:**

As Table 9.2 showed, the intensity of pain had decreased and pain tolerance had increased. Although the Oswestry Disability Index did not show a large change from 9/45 to 4/45, the overall scale has shown a decrease and it indicates symptom relief (See table 9.6.). The alignment of the lower extremity was seen to change. The height of PSISs was now even. The frequency of clicking over her left hip had decreased to a rare occurrence, in particular in the final week of physical examination. Passive mobility of the pelvic girdle became more symmetrical but this change was difficult to quantify. The patient subjectively has no specific feeling about the impact on her symptoms of incontinence, only reporting fewer occurrences. It could be linked to the severity of coccydynia, but there is no strong evidence of a link between the symptoms and the severity of incontinence.

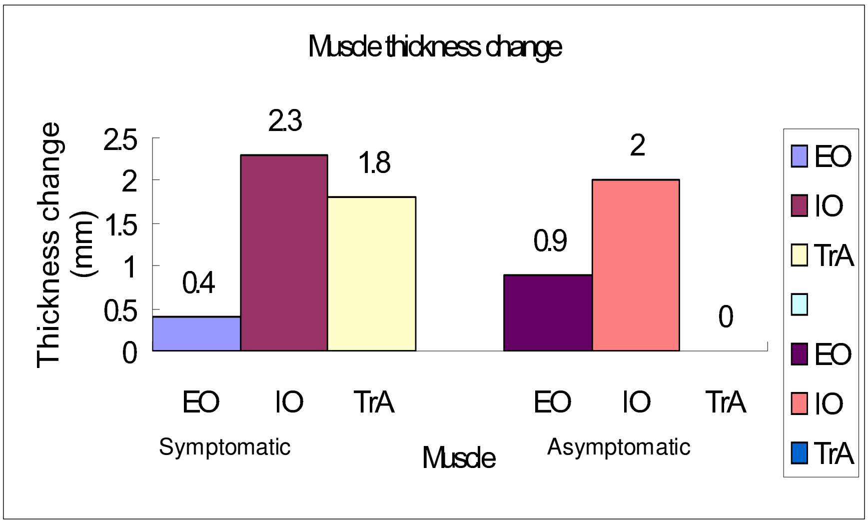
**Table 9.6. Outcome measurement for Case Study 1 Participant TP2**

| **Ultrasound Imaging data – muscle thickness (mm)** | | | | |
|---|---|---|---|---|
| **Baseline measurements** | | **Post-intervention measurements** | | **Healthy reference data** |
| **Side -status** | **Mean** | **Side -status** | **Mean** | **Mean± SD** |
| **Sym-Rest** | | Sym-Rest | | |
| **EO** | 4.7 | EO | 4.5 | 4.07±0.97 |
| **IO** | 6.4 | IO | 5.3 | 5.7±1 |
| **TrA** | 2.7 | TrA | 1.8 | 2.04±0.64 |
| **Sym-ASLR** | | Sym-ASLR | | |
| **EO** | 4.9 | EO | 4.9 | 4.38±1.3 |
| **IO** | 7.5 | IO | 7.6 | 6.22±1.3 |
| **TrA** | 3.7 | TrA | 3.6 | 2.52±1.07 |
| **Asym-Rest** | | Asym-Rest | | |
| **EO** | 3.7 | EO | 3 | 4.07±0.97 |
| **IO** | 7.9 | IO | 7.7 | 5.7±1 |
| **TrA** | 2 | TrA | 3.7 | 2.04±0.64 |
| **Asym-ASLR** | | Asym-ASLR | | |
| **EO** | 4.9 | EO | 3.9 | 4.38±1.3 |
| **IO** | 8.8 | IO | 9.7 | 6.22±1.3 |
| **TrA** | 2.5 | TrA | 3.7 | 2.52±1.07 |
| **Motion analysis** | | | | |
| **Baseline measurements** | | **Post-intervention measurements** | | |
| **Angle -Task** | **Mean** | **Angle –Task** | **Mean** | **Mean± SD** |
| **Lumbar position** | | | | |
| **Sym-leg stand** | 10.65 | Sym-leg stand | 9.94 | 13.25±7.65 |
| **Aym-leg stand** | 13.61 | Asym-leg stand | 12 | 13.25±7.65 |
| **Pelvic position** | | | | |
| **Sym-leg stand** | 10.93 | Sym-leg stand | 10 | 13.71±7.03 |
| **Asym-leg stand** | 12.79 | Asym-leg stand | 11 | 13.71±7.03 |

Sym = symptomatic; Asym = asymptomatic; ASLR active straight leg raise




**A. Baseline data**




**B. Post-intervention**

**Figure 9.11. Thickness changes during active straight leg raise (ASLR) in A. baseline and B. post-intervention in TP2**

Thickness measurements of the abdominal muscles and changes in lumbopelvic angles were used as outcome measures. In this case, the TrA muscle thickness on the symptomatic side decreased at rest, but for the asymptomatic side there was an increase at rest (Figure 9.11). She contracted IO more during the ASLR task. A thickness change in muscle was associated with muscle activation (McMeeken et al., 2004). In Figure 9.11, this patient demonstrated less activity of TrA and more activity of IO on both sides after the six weeks of intervention. The thickness changes for each muscle on the two sides from baseline and post-intervention are displayed separately in Figure 9.11 A and B. As for angle changes in lumbar and pelvic positions, the values of the angle changes were very similar. The data in the first day and after 6 weeks are reported in Table 9.6.

### *9.6.2. Case study 2: TP7*

**Baseline data**

This patient was a 56 years-old civil service officer who was not engaged in exercise and with a low activity level. She had no trauma history and her two children were born naturally. She was referred from the Orthopaedic Surgery Department and the treatment history was oral medication for the relief of symptoms.

***TP7*** **Chief complaint**

Her symptoms of pain were over her buttocks and right low back that began four months previously. She did not remember the conditions that occurred to induce the pain. The average pain intensity was 5/10 (5 out of 10), and she could sit for one hour and stand for two hours on average. The pain was dull and could be specified over the inside of her coccyx. After prolonged sitting, the symptoms were definitely worse.

The investigator palpated the tender points wearing gloves. A taut band with oedema around the coccyx, in particular over the apex of coccyx and right anal wall was found. The pain characteristics were dull and cloudy pain over the bilateral ischial tuberosities, right sacral area in particular over right PSIS, and sharp pain over the coccyx after long periods of sitting was reported. As for assessment of posture, the alignment of lower extremity of this participant is displayed in Figure 9.12. This patient demonstrated asymmetry of PSIS height, the right higher than the left, and left ilium presented a forward and inward tendency, while the right ilium showed slight backward rotation. External rotation of the right hip co-existed with the internal rotated tibia and a supinated talus was observed, and the internal rotated hip occurred simultaneously with an externally rotated tibia and pronated talus.

***TP7*** **Physical examination**

From the physical findings, the impression of this patient was coccydynia with right SIJ dysfunction. The mobility of left SIJ was generally less than the symptomatic side (see Table 9.7).

**Table 9.7. Physical examination record of TP7**

| Tests | Right (+/-) | Left (+/-) |
|---|---|---|
| **Gillet test** | + | --- |
| **Passive mobility** | | |
| **Innominate anterior rotation** | Hypermobility | Hypomobility |
| **Innominate posterior rotation** | Hypermobility | Hypomobility |
| **Sacrum nutation** | Hypomobility | |
| **Sacrum counternutation** | Hypermobility | |
| **SIJ Inferoposterior glide** | Laxity | Stiffness |
| **SIJ Superoanterior glide** | Stiffness | Stiffness |
| **Pain provocation test** | | |
| **Long dorsal lig.** | + | --- |
| **Sacrotuberous lig.** | + | + |
| **Anterior distraction** | + | --- |
| **Posterior distraction** | --- | --- |

* + indicates positive finding; - indicates negative finding

* Lig. indicates ligament SIJ indicates sacroiliac joint

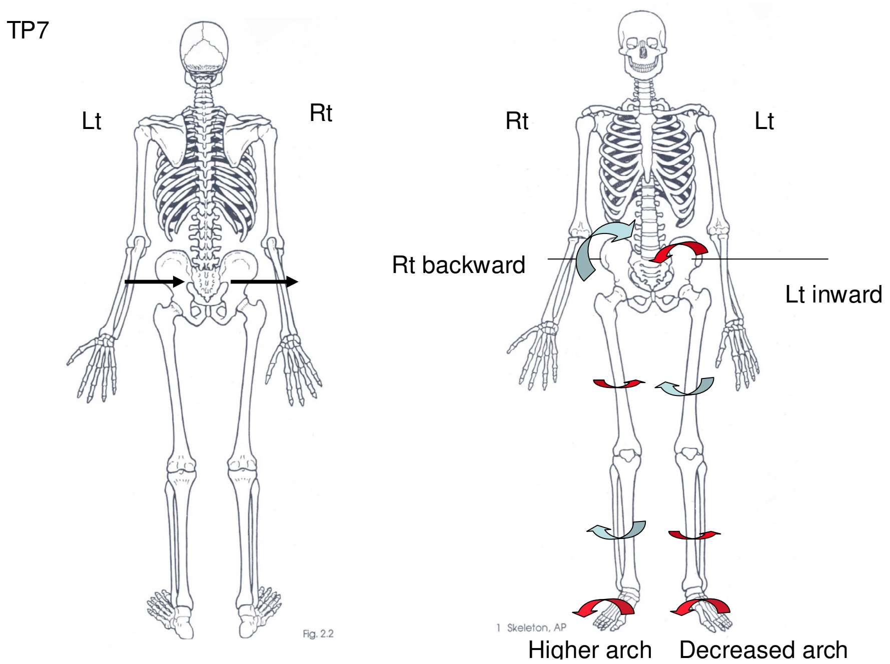



**Figure 9.12. The alignment of pelvis and lower extremities in case TP7.**

This patient had difficulty in sensing contraction of her PFMs, so the motion of the bladder base in the transverse view and bladder neck in the sagittal view were very small (see Figures 9.13 and 9.14). A slightly uneven bladder base at rest was observed in the transverse view (see Figure 9.13).

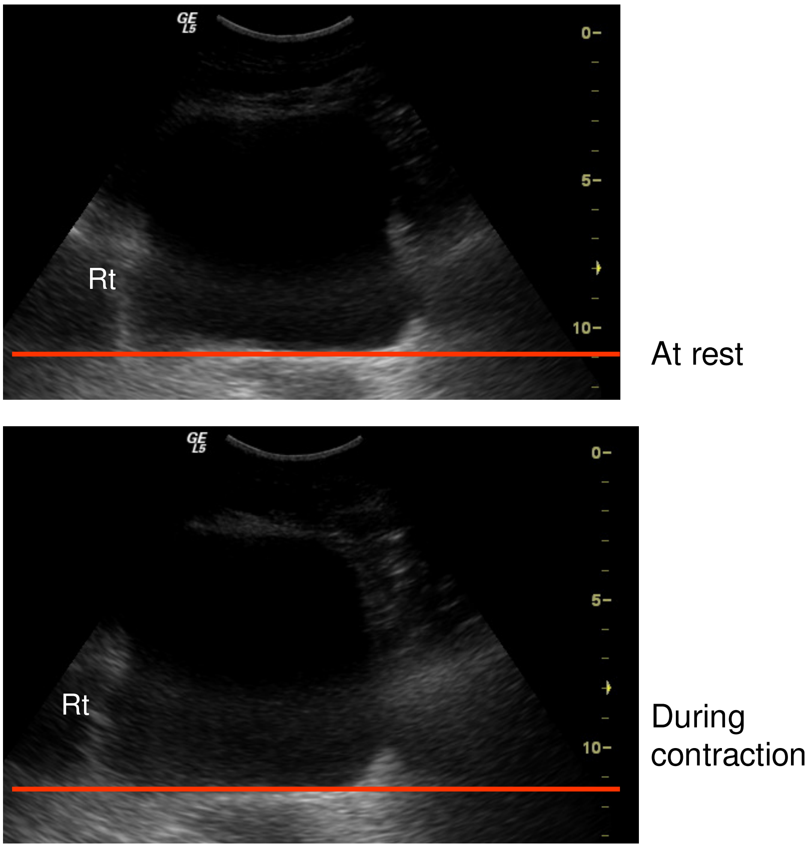



**Figure 9.13. Bladder base in the transversal view - *TP7***

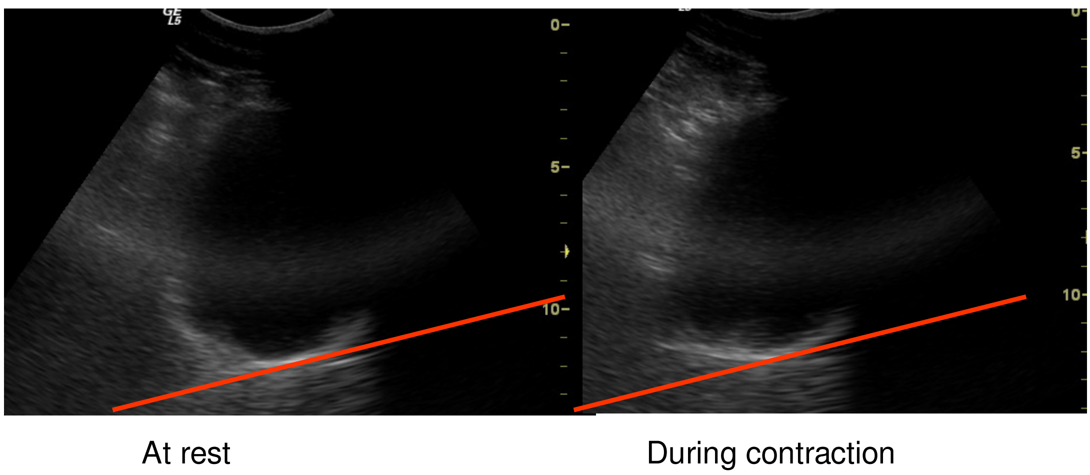



**Figure 9.14. Bladder base in the sagittal view - *TP7***

***TP7* Intervention**

The patient was instructed to wear the belt as appropriate for an asymmetrical pelvis (see Figure 4.10). An additional strap was applied from the front to the back over her right side, and the reverse application of the other strap applied over her left side. She was requested to keep a diary of changes in symptoms and how they affected daily tasks.

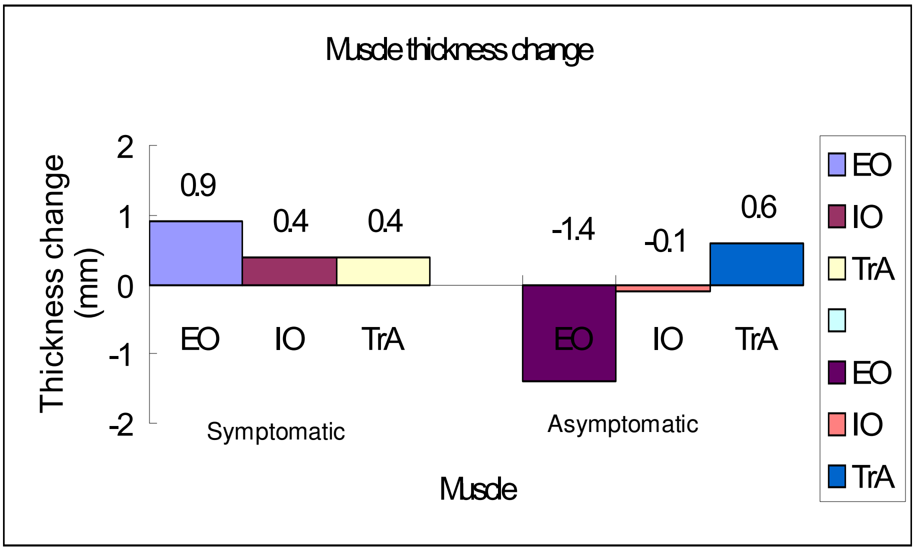
***TP7* Outcome measurement**

After six weeks of intervention, pain intensity decreased from 5/10 to 1/10. Pain tolerance also improved in sitting from under two hours to over three hours, and in standing from around one hour to over two hours. Pelvic alignment improved, with even height of PSISs and the degree of femoral shaft rotation had decreased, but these observational findings were quite subjective due to lack of objective values to confirm these changes.

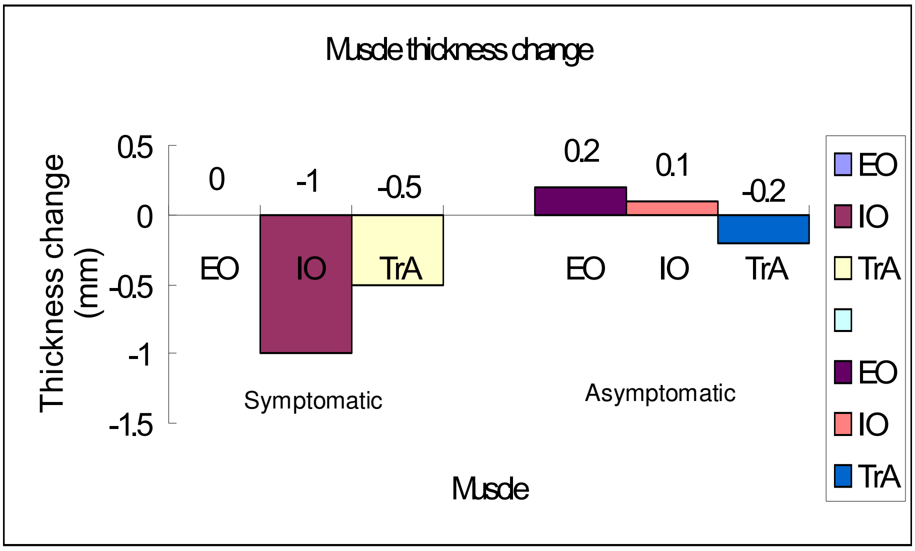
The objective findings post-intervention from ultrasound and motion analysis are given in Table 9.8. In this case, the TrA muscle thickness at rest on the symptomatic side increased, but was decreased on the asymptomatic side. In the baseline, she contracted IO more during the ASLR task. After the six-week intervention, the activity of TrA was increased and activity of IO decreased. These results indicate that this patient may have changed her muscle activation strategies after the intervention. In Figure 9.15 this patient demonstrated less activity of IO and TrA on the symptomatic side, and less activity of TrA in the asymptomatic side. As for angle changes in lumbar and pelvic positions, there were not changes pre- to post- intervention.

**Table 9.8 Outcome measurement for Case study 2 Participant TP7**

| Ultrasound Imaging data – muscle thickness (mm) | | | | |
|---|---|---|---|---|
| **Baseline measurements** | | **Post-intervention measurements** | | **Healthy reference data** |
| **Side -status** | **Mean ± SD** | **Side -status** | **Mean± SD** | |
| **Sym-Rest** | | Sym-Rest | | |
| **EO** | 2.8 | EO | 3.6 | 4.07±0.97 |
| **IO** | 6.7 | IO | 6.3 | 5.7±1 |
| **TrA** | 1.9 | TrA | 3.5 | 2.04±0.64 |
| **Sym-ASLR** | | Sym-ASLR | | |
| **EO** | 3.7 | EO | 3.6 | 4.38±1.3 |
| **IO** | 7.1 | IO | 5.3 | 6.22±1.3 |
| **TrA** | 2.3 | TrA | 3 | 2.52±1.07 |
| **Asym-Rest** | | Asym-Rest | | |
| **EO** | 5.1 | EO | 5.1 | 4.07±0.97 |
| **IO** | 8 | IO | 5.3 | 5.7±1 |
| **TrA** | 4.3 | TrA | 3.2 | 2.04±0.64 |
| **Asym-ASLR** | | Asym-ASLR | | |
| **EO** | 3.7 | EO | 5.3 | 4.38±1.3 |
| **IO** | 7.9 | IO | 5.4 | 6.22±1.3 |
| **TrA** | 4.9 | TrA | 3 | 2.52±1.07 |
| **Motion analysis** | | | | |
| **Baseline measurements** | | **Post-intervention measurements** | | |
| **Angle –Task** | **Mean** | **Angle –Task** | **Mean** | |
| **Lumbar position** | | | | |
| **Sym-leg stand** | 5.42 | Sym-leg stand | 4 | 13.25±7.65 |
| **Aym-leg stand** | 2.85 | Aym-leg stand | 3.57 | |
| **Pelvic position** | | | | |
| **Sym-leg stand** | 5.05 | Sym-leg stand | 5 | 13.71±7.03 |
| **Aym-leg stand** | X | Aym-leg stand | X | |




**A. Baseline data**




**B. Post-intervention**

**Figure 9.15. Thickness changes for each muscle at baseline and post-intervention for TP7 during the active straight leg raise (ASLR) test**

### *9.6.3. Case study 3: TP5*

**Baseline data**

This patient was a 33 year old senior cardiopulmonary physiotherapist in the hospital. She had coccydynia for five years and recent trauma history was a direct impact over her coccyx one year previously. The treatments she experienced were oral medication and physiotherapy.

***TP5*** **Chief complaint**

She reported a dull pain over her coccyx and her left sacral area. The average pain intensity was 7 out of 10, and pain tolerance for both sitting and standing was around one hour. After a whole day working, she felt great discomfort and needed to take medication. She reported higher frequency of voiding, and sometimes unavoidable leaking occurred on the way to the toilet.

***TP5*** **Physical examination**

From the physical findings, the impression of this patient was coccydynia with left SIJ dysfunction.

**Table 9.9. Physical examination record of TP5**

| Tests | Right (+/-) | Left (+/-) |
|---|---|---|
| **Gillet test** | --- | + |
| **ASLR** | --- | + |
| **Passive mobility** | | |
| **Innominate anterior rotation** | Hypomobility | Hypermobility |
| **Innominate posterior rotation** | Hypomobility | Hypermobility |
| **Sacrum nutation** | Hypomobility | |
| **Sacrum counternutation** | Hypermobility | |
| **SIJ Inferoposterior glide** | Stiffness | Laxity |
| **SIJ Superoanterior glide** | Laxity | Laxity |
| **Pain provocation test** | | |
| **Long dorsal lig.** | + | + |
| **Sacrotuberous lig.** | + | + |
| **Anterior distraction** | --- | -- |
| **Posterior distraction** | -- | -- |

* + indicates positive finding; - indicates negative finding

* Lig. indicates ligament; SIJ indicates sacroiliac joint

During palpation, a tender point over the apex of the coccyx was found, and a taut band with oedema around the left anal wall. The pain characteristics were dull pain and soreness over the low back. Sharp pain over the coccyx after prolonged standing at work was reported. As for assessment of posture, the alignment of lower extremity of this participant demonstrated asymmetrical PSIS height, the right being higher than left, and the right ilium presented a forward and inward tendency while the left ilium showed slight backward rotation. External rotation of both hips, external rotation of both tibias and talar pronation were observed. An uneven bladder base at rest and asymmetrical lifting of the bladder base during contraction were found (see Figure 9.16). As shown in Figure 9.16., the thick red line, which indicated the bladder base, was at the level of 10 at rest and was above 10 during contraction. The orientation of the bladder neck during contraction was observed in Figure 9.17., and indicated PFMs contracted in the correct direction.

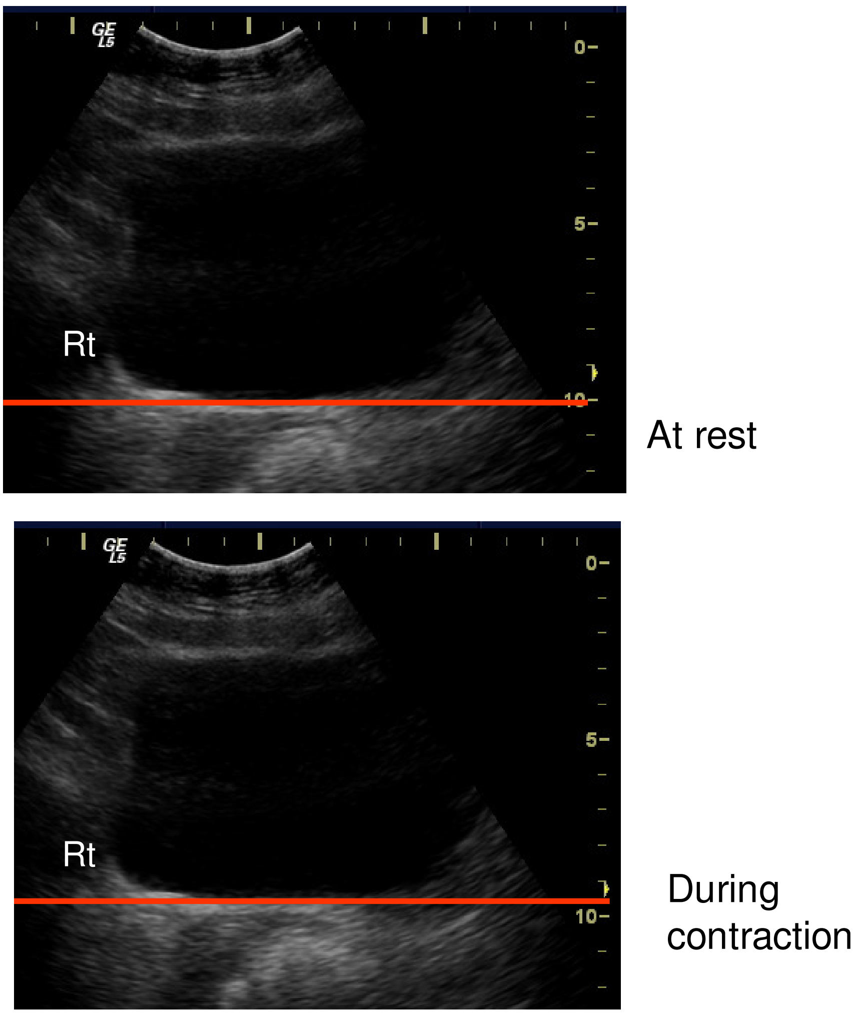



**Figure 9.16. The bladder base at rest and during contraction in *TP5* transverse view)**

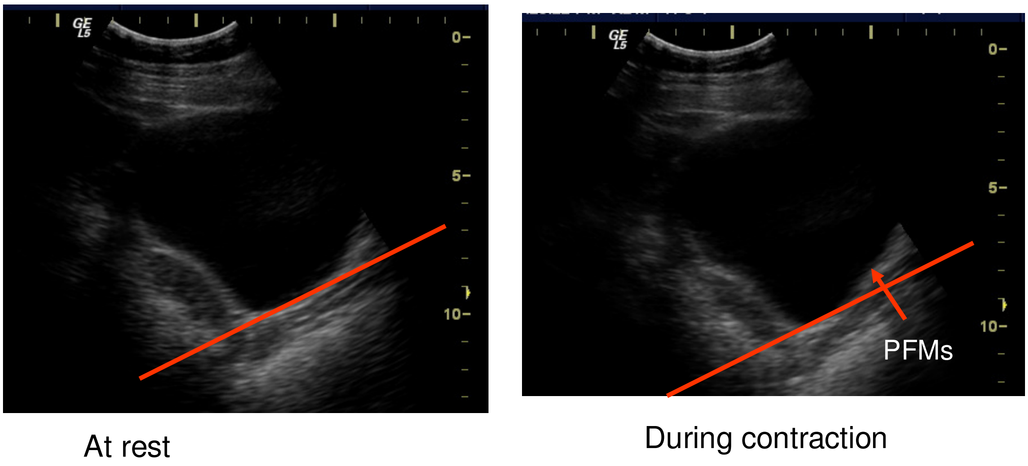



**Figure 9.17. The bladder base at rest and during contraction in the sagittal view in *TP5*. The arrow indicates the direction of pelvic floor muscle (PFM) contraction**

### *TP5 Intervention*

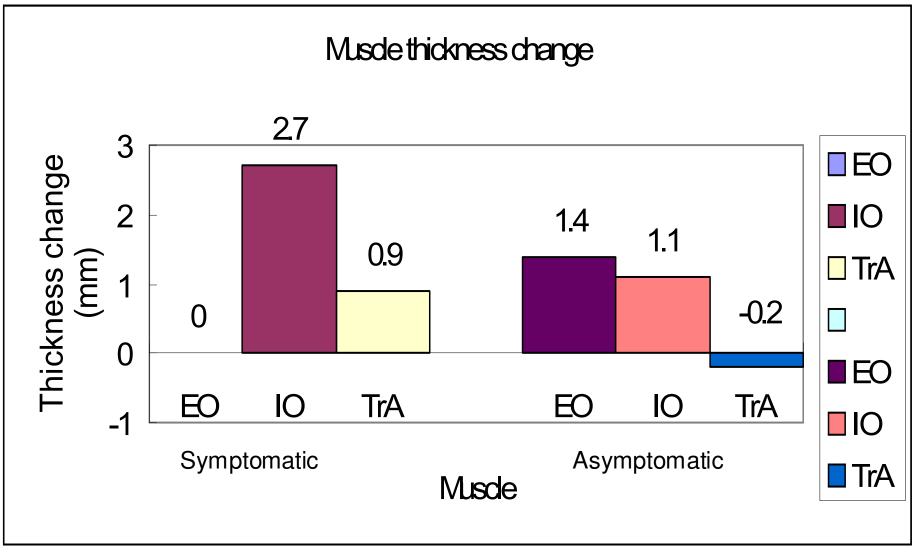
A belt applied as appropriate for a forward facing pelvis was suggested as the intervention (see Chapter 4, Figure 4.8). Greater compression force for the left side was applied. The participant was requested to keep a diary of changes in symptoms how they affected her during daily tasks.

### *TP5 Outcome* measurement

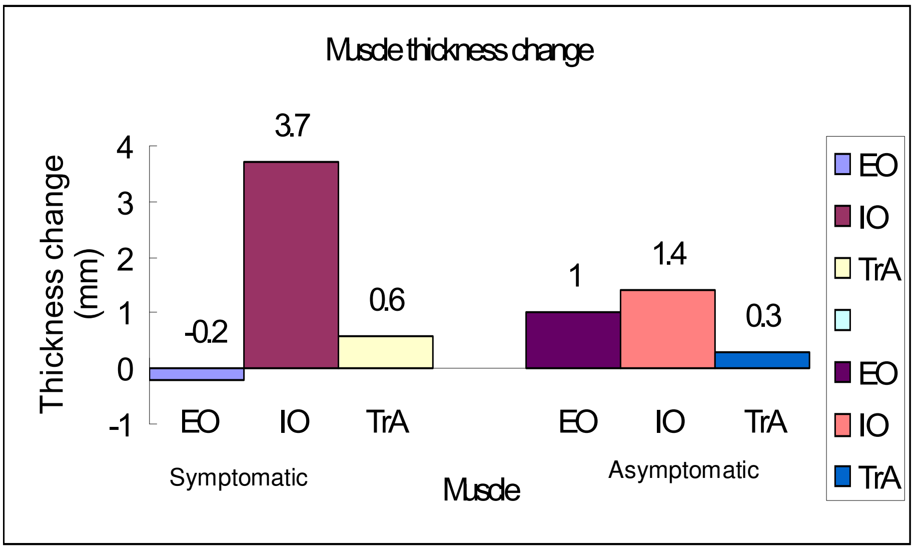
After six weeks of intervention, pain intensity reduced from 7/10 to 4/10. Pain tolerance also improved in sitting from within one hour to 1.5 hours and in standing from one hour to over two hours. The observed alignment of pelvic positions changed, with even PSIS height and the degree of femoral shaft rotation decreased. The objective findings post-intervention from ultrasound and motion analysis are shown in Table 9.10. Muscle thickness in TrA at rest and during contraction did not change. Greater muscle activity of IO and less activity of TrA on the symptomatic side, and more activity of TrA on the asymptomatic side were found (see Figure 9.18). The angle changes in lumbar and pelvic positions did not alter.

**Table 9.10. Outcome measurement from Case Study 3 Participant TP5**

| **Ultrasound Imaging data – muscle thickness (mm)** | | | | |
|---|---|---|---|---|
| **Baseline measurements** | | **Post-intervention measurements** | | **Healthy reference data** |
| **Side -status** | **Mean ± SD** | **Side -status** | **Mean± SD** | |
| **Sym-Rest** | | Sym-Rest | | |
| **EO** | 5.2 | EO | 4.2 | 4.07±0.97 |
| **IO** | 6 | IO | 5.3 | 5.7±1 |
| **TrA** | 1.9 | TrA | 1.8 | 2.04±0.64 |
| **Sym-ASLR** | | Sym-ASLR | | |
| **EO** | 5.2 | EO | 4 | 4.38±1.3 |
| **IO** | 8.7 | IO | 9 | 6.22±1.3 |
| **TrA** | 2.8 | TrA | 2.4 | 2.52±1.07 |
| **Asym-Rest** | | Asym-Rest | | |
| **EO** | 3.8 | EO | 4.8 | 4.07±0.97 |
| **IO** | 5.9 | IO | 6 | 5.7±1 |
| **TrA** | 2.7 | TrA | 2.6 | 2.04±0.64 |
| **Asym-ASLR** | | Asym-ASLR | | |
| **EO** | 5.2 | EO | 5.8 | 4.38±1.3 |
| **IO** | 7 | IO | 7.4 | 6.22±1.3 |
| **TrA** | 2.5 | TrA | 2.9 | 2.52±1.07 |
| **Motion analysis** | | | | |
| **Baseline measurements** | | **Post-intervention measurements** | | |
| **Angle -Task** | **Mean** | **Angle -Task** | **Mean** | |
| **Lumbar position** | | | | |
| **Sym-leg stand** | 0.39 | Sym-leg stand | 0.8 | 13.25±7.65 |
| **Aym-leg stand** | 1.32 | Aym-leg stand | 1.5 | |
| **Pelvic position** | | | | |
| **Sym-leg stand** | 0.74 | Sym-leg stand | 1 | 13.71±7.03 |
| **Aym-leg stand** | 3.69 | Aym-leg stand | 2.89 | |




**A. Baseline data**




**B. Post-intervention**

**Figure 9.18. Muscle thickness change during the active straight leg raise (ASLR) test for each muscle at baseline and post-intervention in *TP5***

### *9.6.4. Case study 4: TC8*

**Baseline data**

This patient was a 33 years old senior neurological physiotherapist and a qualified Pilates teacher in the hospital. She reported that the coccydynia started three years previously after a direct impact over her coccyx. The treatments she experienced were oral medication, physiotherapy, manipulation and exercise therapy.

***TC8* Chief complaint**

She reported a dull and cloudy pain over the coccyx and the right sacral area. The average pain intensity was 4/10, and pain tolerance for sitting was around 1.5 hours and for standing was around one hour. The symptoms worsened if she maintained the same posture, such as in sitting or standing. She did not have any problems of incontinence, and could contract and was aware of her PFMs.

***TC8* Physical examination**

From the physical findings, the impression of this patient was coccydynia with right SIJ dysfunction.

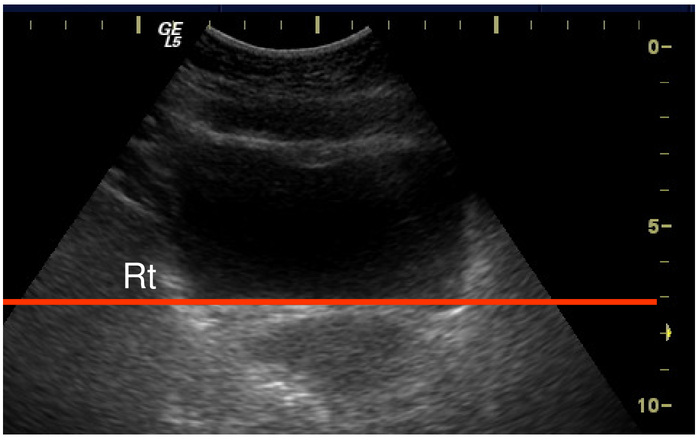
**Table 9.11. Physical examination record of TC8**

| **Tests** | **Right (+/-)** | **Left (+/-)** |
|---|---|---|
| **Gillet test** | + | --- |
| **ASLR** | + | --- |
| **Passive mobility** | | |
| **Innominate anterior rotation** | Hypermobility | Hypomobility |
| **Innominate posterior rotation** | Hypermobility | Hypomobility |
| **Sacrum nutation** | Hypomobility | |
| **Sacrum counternutation** | Hypermobility | |
| **SIJ Inferoposterior glide** | Laxity | Stiffness |
| **SIJ Superoanterior glide** | Stiffness | Stiffness |
| **Pain provocation test** | | |
| **Long dorsal lig.** | + | --- |
| **Sacrotuberous lig.** | + | --- |
| **Anterior distraction** | --- | --- |
| **Posterior distraction** | --- | --- |

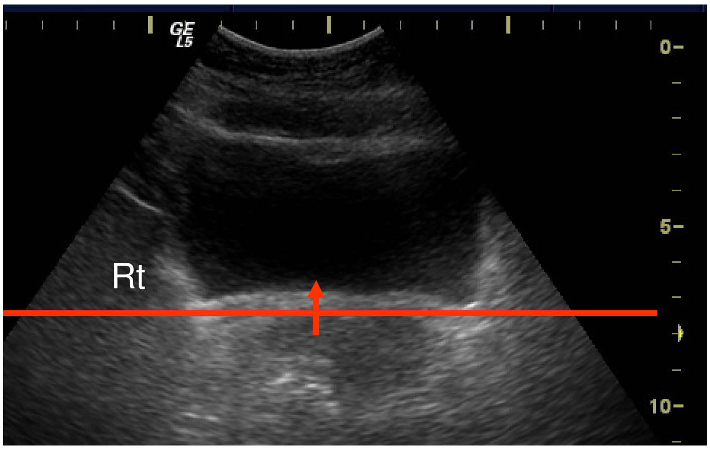
* + indicates positive finding; - indicates negative finding

* Lig. indicates ligament;  SIJ indicates sacroiliac joint

During palpation, a tender point over the apex of the coccyx and slight oedema around the right anal wall were found. The pain characteristics were dull pain and soreness over the low back. Sharp pain over the coccyx was reported after prolonged standing while working. As for assessment of posture, the alignment of the lower extremities of this participant demonstrated asymmetry in PSIS height, with the left higher than the right, and the left ilium presented a forward and inward tendency. In the left lower extremity, external rotation of the hip, external rotation of the tibia and a pronated talus were observed. An uneven bladder base at rest and asymmetrical lifting of the bladder base during contraction were found on ultrasound imaging (see Figure 9.19). The ability to contract the PFMs was confirmed in the sagittal view (see Figure 9.20)

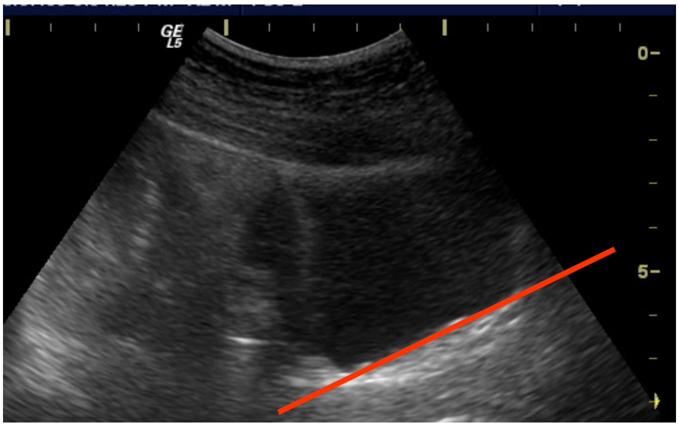



At rest

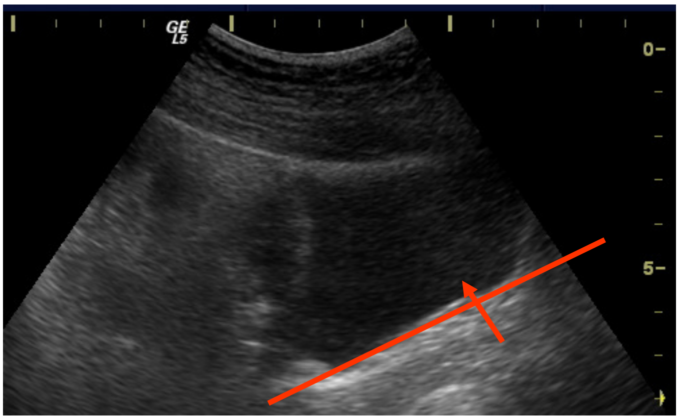



During contraction

**Figure 9.19. The bladder base at rest and during contraction in TC8 (transverse view)**



At rest



During contraction

**Figure 9.20. The bladder base at rest and during contraction in the sagittal view in TC8. The arrow indicates the direction of pelvic floor muscle (PFM) contraction.**

### *TC8* Intervention

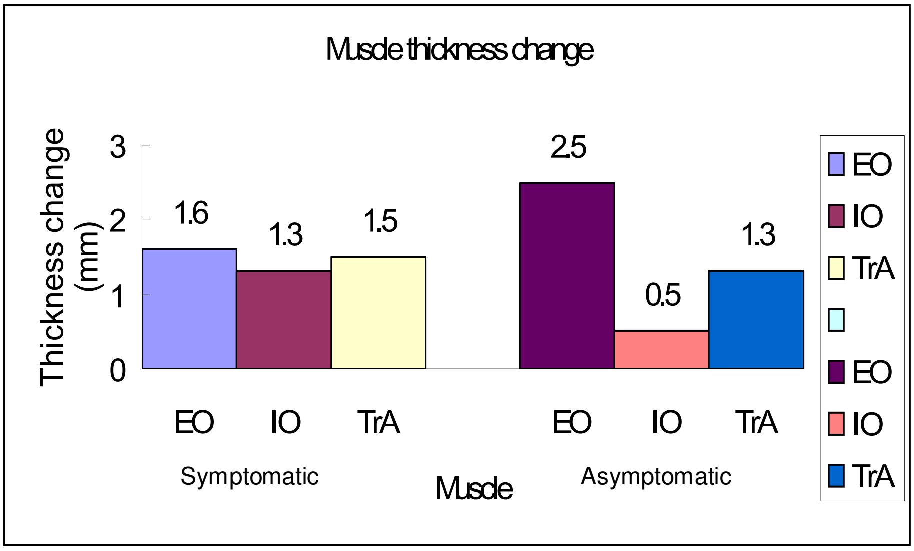
A belt was applied following the protocol for a backward facing pelvis, with more compression force on the left side (see Figure 4.7). The participant was requested to keep a diary of changes in symptoms and how they affected her during daily tasks.

### *TC8* Outcome measurement

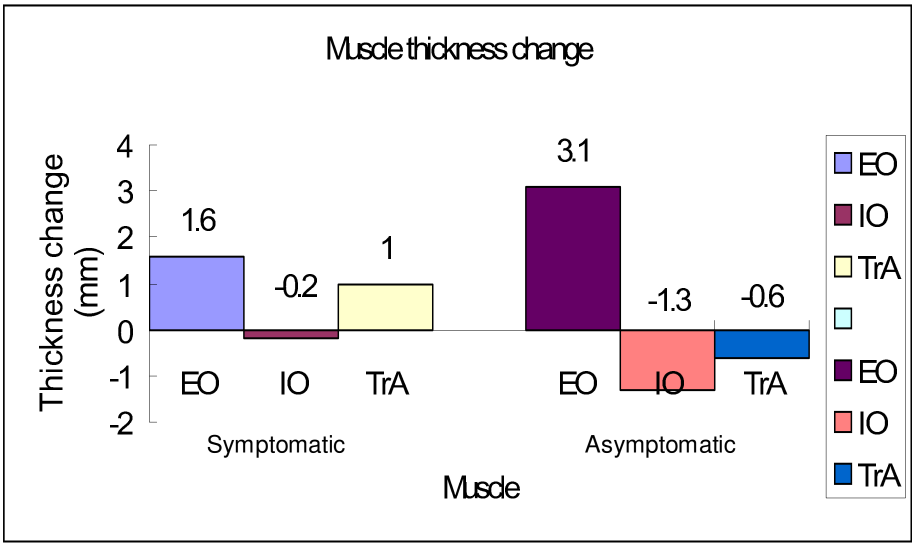
After six weeks of intervention, the pain intensity decreased from 4/10 to 1/10. Pain tolerance also improved in sitting from within 1.5 hours to three hours, and in standing from around one hour to over two hours. Alignments of pelvic positions changed, with even height of the PSISs. As for the other alignment findings, the patient self-reported a more even feeling while standing on her feet. The objective findings of post-intervention from ultrasound and motion analysis are shown in Table 9.8. In this case, muscle thickness on TrA at rest was increased on both sides. After six weeks intervention, less activity of TrA and IO during the functional task were found (See Figure 9.21). The angle changes in lumbar and pelvic positions were not altered (see Table 9.12).

**Table 9.12. Outcome measurements from Case Study 4, Participant TC8**

| **Ultrasound Imaging data – muscle thickness (mm)** | | | | |
|---|---|---|---|---|
| **Baseline measurements** | | **Post-intervention measurements** | | **Healthy reference data** |
| **Side -status** | **Mean ± SD** | **Side -status** | **Mean± SD** | |
| **Sym-Rest** | | Sym-Rest | | |
| **EO** | 5.1 | EO | 4.6 | 4.07±0.97 |
| **IO** | 7.7 | IO | 6 | 5.7±1 |
| **TrA** | 2.4 | TrA | 1.8 | 2.04±0.64 |
| **Sym-ASLR** | | Sym-ASLR | | |
| **EO** | 6.7 | EO | 6.2 | 4.38±1.3 |
| **IO** | 9 | IO | 5.8 | 6.22±1.3 |
| **TrA** | 3.9 | TrA | 2.8 | 2.52±1.07 |
| **Asym-Rest** | | Asym-Rest | | |
| **EO** | 4.2 | EO | 4.2 | 4.07±0.97 |
| **IO** | 6.3 | IO | 7.3 | 5.7±1 |
| **TrA** | 3.3 | TrA | 2.8 | 2.04±0.64 |
| **Asym-ASLR** | | Asym-ASLR | | |
| **EO** | 6.7 | EO | 7.3 | 4.38±1.3 |
| **IO** | 6.8 | IO | 6 | 6.22±1.3 |
| **TrA** | 4.6 | TrA | 2.2 | 2.52±1.07 |
| **Motion analysis** | | | | |
| **Baseline measurements** | | **Post-intervention measurements** | | |
| **Angle -Task** | **Mean** | **Angle –Task** | **Mean** | |
| **Lumbar position** | | | | |
| **Sym-leg stand** | 17.14 | Sym-leg stand | 13.5 | 13.25±7.65 |
| **Aym-leg stand** | 3.83 | Aym-leg stand | 4.3 | |
| **Pelvic position** | | | | |
| **Sym-leg stand** | 4.59 | Sym-leg stand | 5.8 | 13.71±7.03 |
| **Aym-leg stand** | 4 | Aym-leg stand | 4.3 | |




**A. Baseline data**




**B. Post-intervention**

**Figure 9.21. Muscle thickness for each muscle at baseline and post-intervention in TC8**

### *9.6.5. Case study 5: TP19*

**Baseline data**

This patient was a 36 year old housewife with two children. She complained of coccydynia for six months since giving birth. The treatments she experienced were oral medication and physiotherapy based on the modalities such as transcutaneous electrical nerve stimulation (TENS) or hot pack.

***TP19*** **Chief complaint**

The patient reported a dull pain over the apex of the coccyx. The average pain intensity was 6/10, and pain tolerance for sitting was around 1.5 hours and for standing was within one hour. The symptoms worsened during positional changes. She reported a high frequency of voiding and sometimes leaking occurred on the way to the toilet. She could sense and contract her PFMs. The bladder base was observed to be uneven on ultrasound images, and asymmetrical bladder base lifting occurred during PFM contractions.

***TP19*** **Physical examination**

From the physical findings, the impression of this patient was coccydynia with bilateral SIJ dysfunction.

**Table 9.13. Physical findings on examination in PT19**

| Tests | Right (+/-) | Left (+/-) |
|---|---|---|
| **Gillet test** | + | + |
| **ASLR** | + | + |
| **Passive mobility** | | |
| **Innominate anterior rotation** | Hypermobility | Hypomobility |
| **Innominate posterior rotation** | Hypermobility | Hypomobility |
| **Sacrum nutation** | Hypermobility | |
| **Sacrum counternutation** | Hypomobility | |
| **SIJ Inferoposterior glide** | Stiffness | Stiffness |
| **SIJ Superoanterior glide** | Stiffness | Stiffness |
| **Pain provocation test :** | | |
| **Long dorsal lig.** | + | --- |
| **Sacrotuberous lig.** | + | + |
| **Anterior distraction** | --- | --- |
| **Posterior distraction** | --- | --- |

* + indicates positive finding; - indicates negative finding

* Lig. indicates ligament SIJ indicates sacroiliac joint

During palpation, a tender point over the apex of the coccyx and slight oedema were found in the bilateral anal wall. Pain characteristics were dull pain and soreness over the low back. Sharp pain over the coccyx after prolonged standing was reported. As for assessment of posture, the alignment of the lower extremity of this participant demonstrated symmetrical height of the PSISs and a backward facing pelvic outlet. Internal rotation of the hips, internal rotation of the tibia and increased arches of the feet due to the supinated talus were found.

***TP19*** **Intervention**

A belt application appropriate for a backward facing pelvis was used as the intervention (see Figure 4.7). She was requested to keep a diary of changes in symptoms and how they affected her during everyday tasks.

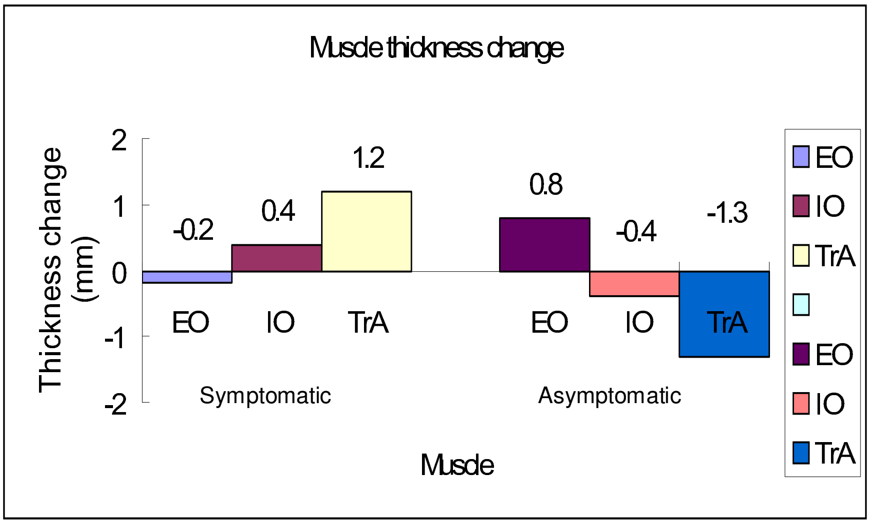
***TP19*** **Outcome measurement**

After six weeks of intervention, the pain intensity reduced from 6/10 to 2/10. Pain tolerance also improved in sitting from within 1.5 hours to four hours, and in standing from within one hour to over two hours. The alignment of pelvic positions was even height of PSIS, the same as at baseline. The objective findings post-intervention from ultrasound and motion analysis are shown in Table 9.9. In this case, muscle thickness of TrA increased on the symptomatic side and decreased on the asymptomatic side. Increased activity of TrA and IO during the functional task was found after intervention (See Figure 9.22). There were no alterations in angle changes in lumbar and pelvic positions during the functional task (see Table 9.14).

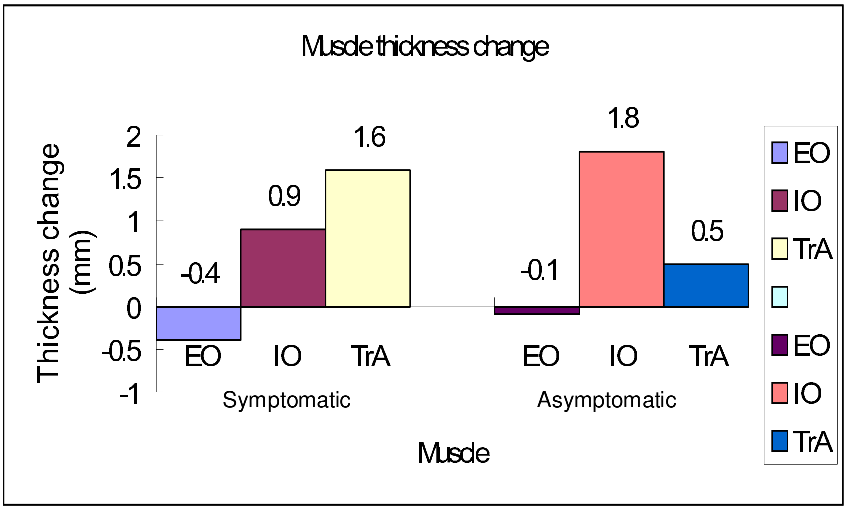
**Table 9.14 Outcome measurement for Case Study 5 Participant TP19**

| **Ultrasound Imaging data – muscle thickness (mm)** | | | | |
|---|---|---|---|---|
| **Baseline measurements** | | **Post-intervention measurements** | | **Healthy reference data** |
| **Side -status** | **Mean ± SD** | **Side -status** | **Mean± SD** | |
| **Sym-Rest** | | Sym-Rest | | |
| **EO** | 4.7 | EO | 4.4 | 4.07±0.97 |
| **IO** | 6.4 | IO | 7.8 | 5.7±1 |
| **TrA** | 2 | TrA | 3.2 | 2.04±0.64 |
| **Sym-ASLR** | | Sym-ASLR | | |
| **EO** | 4.5 | EO | 4 | 4.38±1.3 |
| **IO** | 6.8 | IO | 8.7 | 6.22±1.3 |
| **TrA** | 3.2 | TrA | 4.8 | 2.52±1.07 |
| **Asym-Rest** | | Asym-Rest | | |
| **EO** | 3.7 | EO | 4 | 4.07±0.97 |
| **IO** | 6.7 | IO | 5.8 | 5.7±1 |
| **TrA** | 3.6 | TrA | 3.3 | 2.04±0.64 |
| **Asym-ASLR** | | Asym-ASLR | | |
| **EO** | 4.5 | EO | 3.9 | 4.38±1.3 |
| **IO** | 6.3 | IO | 7.6 | 6.22±1.3 |
| **TrA** | 2.3 | TrA | 3.8 | 2.52±1.07 |

| **Motion analysis** | | | | |
|---|---|---|---|---|
| **Baseline measurements** | | **Post-intervention measurements** | | |
| **Angle -Task** | **Mean** | **Angle -Task** | **Mean** | |
| **Lumbar position** | | | | |
| **Sym-leg stand** | 0.85 | Sym-leg stand | 1.7 | 13.25±7.65 |
| **Aym-leg stand** | 3.42 | Aym-leg stand | 3 | |
| **Pelvic position** | | | | |
| **Sym-leg stand** | 1 | Sym-leg stand | 1.5 | 13.71±7.03 |
| **Aym-leg stand** | 1.9 | Aym-leg stand | 2.3 | |




**A. Baseline data**




**B. Post-intervention**

**Figure 9.22. Muscle thickness change for each muscle at baseline and post-intervention in TP19**

### *9.6.6. Case study 6: TP28*

**Baseline data**

This patient was a 26 year old research assistant, with a two year history of coccydynia and history of trauma 12 years ago. She had not received any treatment.

***TP28*** **Chief complaint**

She reported a dull and cloudy pain over the coccyx and the sacral area. The average pain intensity was 4/10, and pain tolerance for sitting was around 1.5 hours and for standing was less than one hour. The symptoms worsened if she maintained in the same posture, such as in sitting or standing. She did not have problems of incontinence but had difficulty to sense and contract her PFMs.

***TP28*** **Physical examination**

The impression of this patient was coccydynia with bilateral SIJ dysfunction. The right SIJ was restricted more than the left side. The pain provocation test was positive for bilateral sacrotuberous ligaments and for the right long dorsal ligament.

**Table 9.15. Physical examination findings in PT28**

| **Tests** | **Right (+/-)** | **Left (+/-)** |
|---|---|---|
| **Gillet test** | + | + |
| **ASLR** | + | + |
| **Passive mobility** | | |
| **Innominate anterior rotation** | Hypomobility | Hypomobility |
| **Innominate posterior rotation** | Hypomobility | Hypomobility |
| **Sacrum nutation** | Hypermobility | |
| **Sacrum counternutation** | Hypomobility | |
| **SIJ Inferoposterior glide** | Stiffness | Stiffness |
| **SIJ Superoanterior glide** | Stiffness | Stiffness |
| **Pain provocation test:** | | |
| **Long dorsal lig.** | + | --- |
| **Sacrotuberous lig.** | + | + |
| **Anterior distraction** | --- | --- |
| **Posterior distraction** | --- | --- |

* + indicates positive finding; - indicates negative finding

* Lig. indicates ligament SIJ indicates sacroiliac joint

During palpation, a tender point over the apex of the coccyx and slight oedema around the right anal wall were found. The pain characteristics were dull pain and soreness over her lower back. A sharp pain over the coccyx after prolonged standing during work was reported. As for assessment of posture, the alignment of the lower extremities of this participant demonstrated even height of PSISs, but motion of the right PSIS was limited during the dynamic task. Her pelvic outlet was of the forward facing type. The right lower extremity showed an internally rotated hip, internally rotated tibia and supinated talus. An asymmetrical bladder base at rest was found through the ultrasound imaging technique (see Figure 9.23). During PFM contraction, the bladder base showed asymmetrical lifting (left side) in the transverse view and the bladder neck had very limited motion (see Figure 9.24).

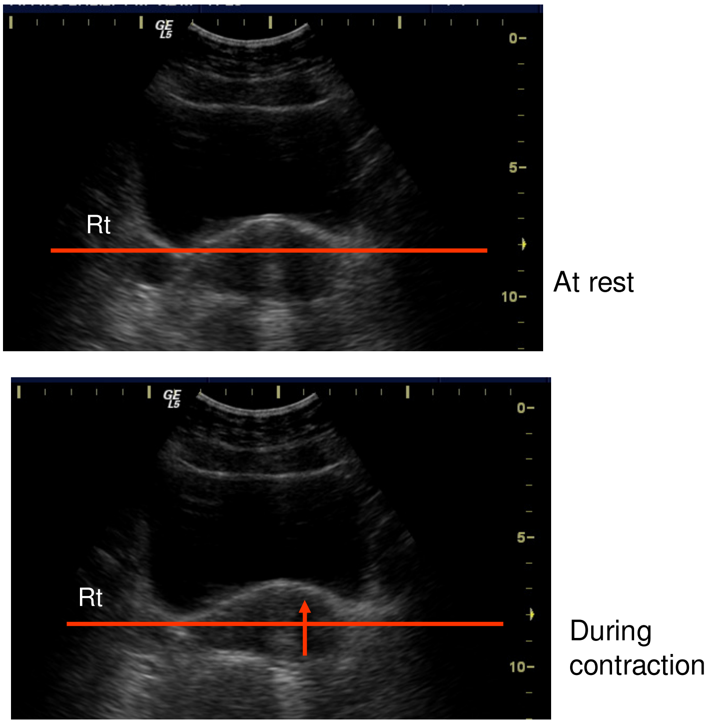



**Figure 9.23. The bladder base at rest and during contraction in TP28 (transversal view). The arrow indicates the direction of pelvic floor muscle (PFM) contraction**

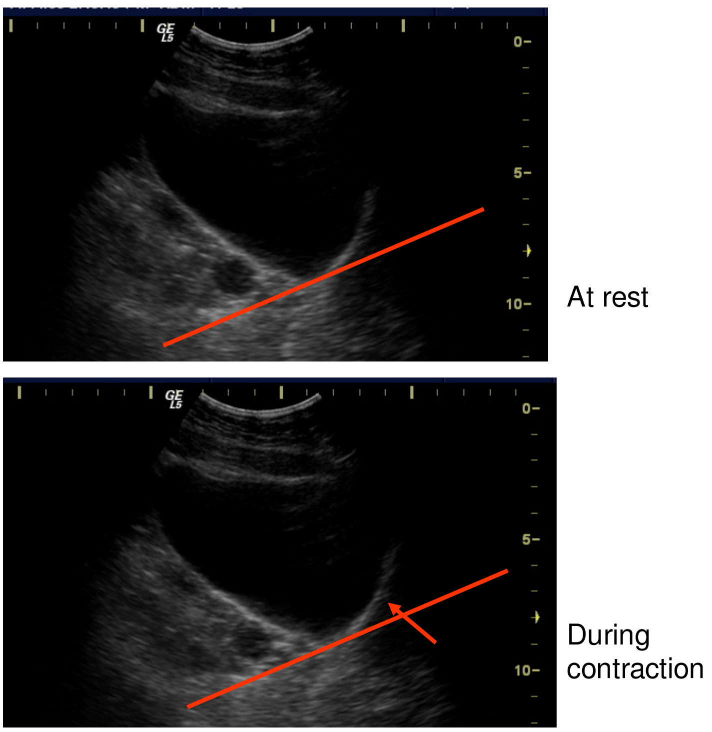



**Figure 9.24. The bladder base at rest and during contraction in the sagittal view in TP28. The arrow indicates the direction of pelvic floor muscle (PFM) contraction.**

### ***TP28*** **Intervention**

A belt was applied for a backward facing pelvic, with more compression force over the right side (see Figure 4.7). The participant was requested to keep diary of symptoms changes and how they affected her daily tasks.

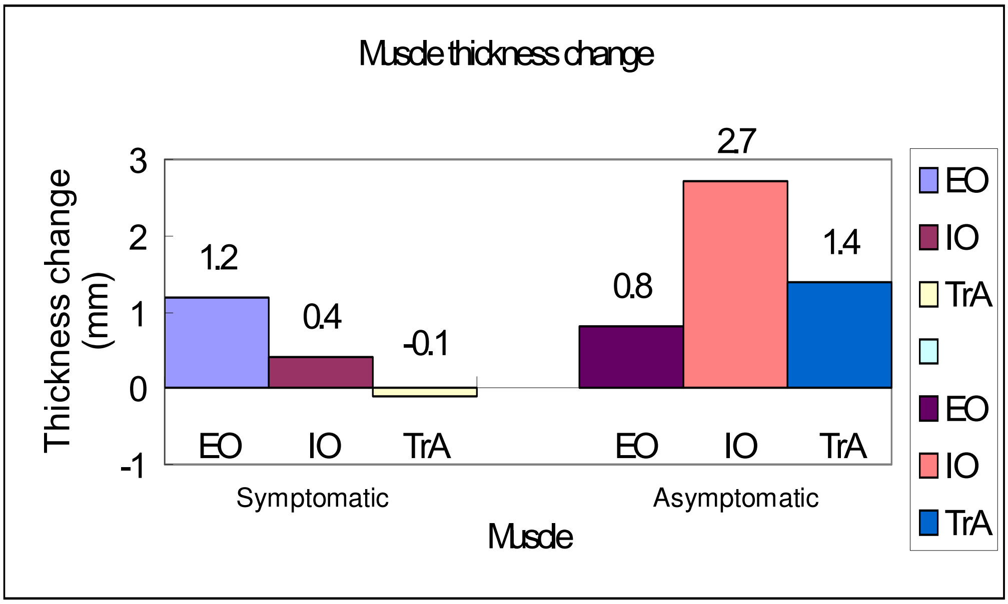
### ***TP28*** **Outcome measurement**

After six weeks of intervention, the pain intensity reduced from 3-4/10 to 1-2/10. Pain tolerance also improved in sitting from 1.5 hours to four hours, and in standing from within one hour to 1.5 hours. The alignment of pelvic positions changed to even height of PSISs, both in static standing and during the functional test. As for the other alignment findings, the patient self-reported a more even feeling while standing on her feet. Post-intervention objective findings from ultrasound and motion analysis are shown in Table 9.10. Muscle thickness of TrA was increased on the symptomatic side. Lower activity of TrA and IO during the functional task was found on both sides (See Figure 9.25). There were no alterations in angle changes in the lumbar and pelvic positions (see Table 9.16).

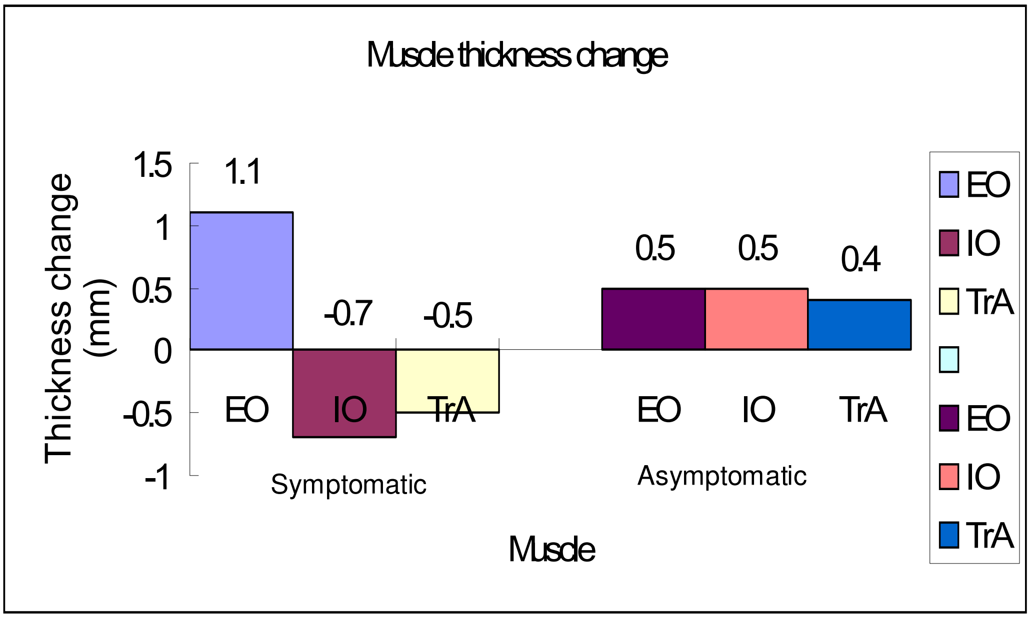
**Table 9.16 Outcome measurement Case Study 6 Participant TP28**

| **Ultrasound Imaging data – muscle thickness (mm)** | | | | |
|---|---|---|---|---|
| **Baseline measurements** | | **Post-intervention measurements** | | **Healthy reference data** |
| **Side -status** | **Mean ± SD** | **Side -status** | **Mean± SD** | |
| **Sym-Rest** | | Sym-Rest | | |
| **EO** | 4.3 | EO | 4.4 | 4.07±0.97 |
| **IO** | 5.9 | IO | 5.8 | 5.7±1 |
| **TrA** | 2 | TrA | 3.1 | 2.04±0.64 |
| **Sym-ASLR** | | Sym-ASLR | | |
| **EO** | 5.5 | EO | 5.5 | 4.38±1.3 |
| **IO** | 6.3 | IO | 5.1 | 6.22±1.3 |
| **TrA** | 1.9 | TrA | 2.6 | 2.52±1.07 |
| **Asym-Rest** | | Asym-Rest | | |
| **EO** | 4.7 | EO | 5 | 4.07±0.97 |
| **IO** | 7.2 | IO | 7.6 | 5.7±1 |
| **TrA** | 2.2 | TrA | 2.2 | 2.04±0.64 |
| **Asym-ASLR** | | Asym-ASLR | | |
| **EO** | 5.5 | EO | 5.5 | 4.38±1.3 |
| **IO** | 9.9 | IO | 8.1 | 6.22±1.3 |
| **TrA** | 3.6 | TrA | 2.6 | 2.52±1.07 |

| **Motion analysis** | | | | |
|---|---|---|---|---|
| **Baseline measurements** | | **Post-intervention measurements** | | |
| **Angle –Task** | **Mean** | **Angle -Task** | **Mean** | |
| **Lumbar position** | | | | |
| **Sym-leg stand** | 2.2 | Sym-leg stand | 4 | 13.25±7.65 |
| **Aym-leg stand** | 3.5 | Aym-leg stand | 4.2 | |
| **Pelvic position** | | | | |
| **Sym-leg stand** | 1.24 | Sym-leg stand | 2.8 | 13.71±7.03 |
| **Aym-leg stand** | 6.1 | Aym-leg stand | 5.4 | |




**A. Baseline data**




**B. Post-intervention**

**Figure 9.25 Muscle thickness change for each muscle at baseline and post-intervention for TP28**

## 9.7 Discussion

### *9.7.1. The changes after the six weeks of pelvic belt intervention*

The subjective findings showed that all patients' symptoms decreased to different degrees. In general, the intensity of pain was decreased and tolerance of pain increased. Comparing the findings from the Oswestry Disability Index, functions improved although the scale did not change very much. Postural changes were observed but were not quantified.

The design of the pelvic belt is based on the Snijider's hypothesis of "force closure". Hu et al (2010) reported less activity of abdominal muscles in people wearing a belt during treadmill walking at an accelerating speed. The present patients with coccydynia were tending to over-activate the abdominal muscles, which may result in the hypertrophy. The function of pelvic belt for these patients may relax the muscles and so relive symptoms. Jansen et al. (2010) used ultrasound imaging to detect the influence of the pelvic belt on the abdominal muscle thickness activity in patients with long-standing groin pain (LSGP). No correlation between thickness changes on abdominal muscles and pelvic belt application was reported. The changes in muscle morphology are unlike muscle activation on EMG, which could respond immediately. As for the present project, the observations were made over time but the individual changes reflected on the ultrasound were variable. The sensitivity of ultrasound imaging to detect change over-time needs to be established.

Regarding the present objective findings, morphology of the abdominal muscles, thickness changes for each muscle during contraction and change in lumbar and pelvic joint angles have been reported. Each patient showed different types and degrees of changes, making these observations inconclusive. Some patients showed an increased thickness of TrA at rest but some showed a decrease. As for the thickness change in each muscle during a functional task, some patients demonstrated increased activity of IO and TrA but some showed decreased activity of these muscles. Although an increase in the ability to thicken the muscle was reported to be relevant to increased muscle activity, many factors may affect the observation and measurements, such as pain duration. In comparison with the data between controls and patients, TrA in patients was thicker than controls (see Chapter 5). The thicker TrA muscle in patients with chronic coccydynia may result from over-activity of muscles due to spasm. As found in Chapter 6, patients found it difficult to relax, so the deep muscles maintained a hyperactive state, which may lead to hypertrophy of the TrA muscles. Patients found it particularly difficult to relax their TrA muscles for the randomised tasks at different contraction levels (see Chapter 6). These findings suggest that the function of TrA could be deficient.

As for biomechanical performance, the angle changes in the lumbar and pelvic joints were similar before and after the intervention. However, all values were smaller than the reference data in healthy age-matched controls (Chapter 7). This indicates that patients stiffened their trunk before carrying out the task, so the angle change was small. The small angle changes may not be responsive enough to reflect the post-intervention changes in symptoms. The duration of intervention could be another consideration. The application of the belt over six weeks may not be long enough to induce neural plasticity to change the strategies to carry out the task.

#### *9.7.2. Physical examination findings in patients*

The symptoms of coccydynia may coexist with other chronic conditions, such as SIJ dysfunction or back pain in the lumbopelvic region. With regards to the physical examination findings, these six patients showed asymmetrical mobility in the pelvic girdle of varying severity. The symptomatic side (or worse side if bilateral) of the six patients showed excessive joint mobility (hypermobility) in the unilateral pelvic girdle. Patients with a longer pain course, such as TP19 and TP28, demonstrated less mobility in the whole pelvic girdle. According to Panjabi's ball-in-bowl theory, the physiological range of joints may be changed once symptoms occur. Patients may use more force to maintain stability over time, reflecting changes in motor control.

When reviewing the physical examination findings for the six 6 patients, the impressions can be simply classified as "coccydynia with unilateral SIJ dysfunction" and "coccydynia with bilateral SIJ dysfunction". Obviously, patients diagnosed with coccydynia have predominantly symptoms related to the coccyx rather than the SIJ. The severity of symptoms may relate to findings from the provocation tests. Generally, the provocation test for the sacrotuberous ligament was reported as positive in coccydynia. Four of the six patients claimed the problem of mild urinary incontinence, and two had lack of awareness of pelvic floor muscle contractions. Interestingly, the bladder base in the transversal view was uneven for each patient, which indicated the possibility of asymmetrical functions of pelvic floor muscles in patients with coccydynia but this needs to be explored further by studying other aspects of the pelvic floor, such as electromyographic activity using indwelling electrodes, as well as transperineal ultrasound imaging, as opposed to the transabdominal technique used in the present study for cultural reasons.

### *9.7.3. Limitations of the study*

Although the six patients reported improvements in their symptoms, the morphological changes in muscles varied individually. Many factors could affect the changes in symptoms, such as their severity and range, and the tasks used to study them. These possible contributors could be due to factors relative to the individual patient or to the experimental protocol.

#### *9.7.3.i Individual factors*

Each patient had a different duration of pain, onset history, coexisting dysfunctions, and may have worn the belt in different way. Although each patient was taught to wear the belt by the investigator, the force they applied using the strap was not quantified and may have affected the outcome. Age and childbirth history may affect joint mobility and possibly worsen the symptoms. Occupation and life style could be another consideration. Patients with a sedentary life style may be more prone to soft tissue strains resulting in cumulative minor trauma. Congenital anatomical features may influence symptoms. None of these factors could be examined in this small series of case studies but warrant further exploration in larger studies.

#### *9.7.3.ii Experimental protocol issue*

The chosen functional task was ‘active straight left leg raise’, but patients’ symptomatic sides could be left or right. As for the variables in the application of pelvic belt, the compression force was subjective and not quantified. Additionally, the ultrasound imaging technique may be not sensitive enough to detect the effects of pelvic belt over 6 weeks even if the symptoms were relieved. It could be due to the length of intervention being not long enough to affect the ability of muscles to produce the changes.

## 9.8. Conclusions

This is a preliminary study to investigate a potential intervention to relieve the symptoms of coccydynia, including pain, continence and postural alignment. The findings from RUSI suggested that patients may use different strategies to carry out a task. Although the symptoms were relieved in patients, there was no conclusive evidence of an effect of the pelvic belt on objective assessments. RUSI may have the limitation to detect morphological changes over time. The correlation between coccydynia and urgent incontinence requires further study.

# Chapter 10: General discussion

The main purpose of the present study was to explore the largely unknown phenomenon of coccydynia in Taiwanese women. In comparison with healthy participants, the findings indicate that altered neuromuscular function and biomechanical changes occur in patients through the examination of rehabilitative ultrasound imaging (RUSI), motion analysis (using the VICON system) and surface electromyography (EMG). The possible contributors to induce or trigger this disorder are suggested according to the observations of patients involved in this study.

## 10.1. Main findings of the present study

The main findings for the three investigative techniques are summarised briefly in this section and then discussed in more depth in subsequent sections of 10.2.

Thicker transverses abdominis muscles (TrA), longer latency of internal obliquus muscles (IO) and less mobility in the lumbopelvic region were demonstrated in women with coccydynia in comparison to the age-matched controls. In the controls, the variations of findings were large and may be due to the influence of age disparity, and are discussed herein. The lower thickness changes of TrA at sub-maximal contraction (20% MVIC) found in patients may indicate reduced awareness and/or activation ability of TrA muscles during the task. As was proposed, changes in neuromuscular function were similar to those that also occur in low back pain, indicating similar mechanisms of dysfunction from the underlying pathology. Also a potential intervention of the pelvic belt was proposed for coccydynia and reductions in symptoms were found, without any changes in the objective investigations. The implications of these findings are discussed below.

### *10.1.1. Ultrasound imaging findings on muscle morphometry (Chapters 5 & 6)*

In this present study, RUSI was found to be a highly reliable for measurement within the same session in healthy participants and in patients with coccydynia, both at rest, and during a unilateral active straight leg raise (ASLR) task, in line with the findings from existing reports (Rankin et al., 2006, Hides et al., 2007, Kiesel et al., 2007, Teyhen et al., 2007, Teyhen et al., 2008, Koppenhaver et al., 2009, Costa et al., 2009b). The reliability of RUSI measurements during contraction was lower than at rest in both groups, but the ICC values were acceptable (>0.7) for clinical and research use. The precision of measurement was demonstrated by the standard error of measurement and the small values indicate good precision, particularly in controls. Bland and Altman plots indicated a larger variation of measurements in patients to support the findings from the other indices of reliability. The reliability of

EO (ICC=0.83) and IO (ICC= 0.75) during a contraction was reported to be less than in the deepest muscle, the TrA (ICC=0.92). This may be due to the location; the superficial muscles might be more prone to being influenced by the technique and cause errors, e.g. by compression of the ultrasound transducer through the subcutaneous soft-tissues.

The reliability of RUSI during the active draw-in maneuver (ADIM) at different contraction levels was high in healthy young participants during all muscle states (ICC> 0.93), but there was a lower ICC between-days at rest in patients (ICC= 0.61~0.64). Reliability of RUSI in ADIM at 20% maximal voluntary effort (MVE) was lower for the symptomatic side (ICC=0.79) than in the asymptomatic side (ICC=0.99). As for the performance of MVE, larger variation on the asymptomatic side (ICC=0.74) was shown than in the symptomatic side (ICC=0.88). The poor reliability at rest could be due to deficient motor control in the ability to relax between different tasks, so participants may need longer intervals to allow them to get back to a resting state compared with healthy participants.

The difference of morphology in muscle thickness between controls and patients was reported to be consistent with previous studies on chronic lower back pain (Critchley and Coutts, 2002), which differs from research regarding acute lower back pain where patients demonstrate smaller muscles (Hides et al., 1994, Norasteh et al., 2007). This is consistent with the fact that the present patients were not acute. A wide age range of healthy participants was studied (20-65 years) and a significant difference was found in muscle characteristics during contraction between the younger cohort (mean age = 25.9 SD=3.26) compared to the in older cohort (mean age =47.06 SD=12.07), but no significant difference was found at rest. This suggests that the alteration of contractile ability with increased age may be detected by RUSI. In the older group, the majority of participants tended to use more force to carry out a task, in comparison with the younger cohort, which may either indicate less control over the contraction or weaker muscles, which have to work harder. As for the awareness of efforts following verbal instruction from the examiner, perhaps age could lead to different results. Possible factors could be lifestyle, poor awareness of muscle contraction and their experience. However, the different levels of contraction of ADIM studied in Chapter 6 were carried out in a young control group, and in the patient group who were older, but were not carried out in older controls.

### *10.1.2. EMG findings (Chapter 8)*

During the trial of one leg standing, the activation of IO demonstrated longer latency in comparison with the controls. These findings are consistent with the existing studies on abdominal muscle function in patients with low back pain (Hodges and Richardson, 1999a, Hodges, 2001). It indicates that coccydynia could be associated with altered recruitment of abdominal muscles. The findings from EMG could not be integrated with the findings from ultrasound imaging due to data collection not being conducted simultaneously but the abnormalities observed for the two modalities in the present study are discussed in the following paragraph. Due to the difficulty in the normalisation of EMG data, only the timing of IO firing was reported. Existing studies used needle EMG to gather data from TrA during a dynamic task, and the findings indicated that the muscle firing of TrA happened prior to the task (Hodges and Richardson, 1997, Hodges et al., 1999) in healthy controls, and a later firing of TrA in patients with low back pain (Hodges and Richardson, 1999a, Hodges, 2001). Their findings supported the feedforward mechanism. The IO is directly attached to the TrA and was assumed to have delayed activation in patients with coccydynia, as stated in the hypothesis in Chapter 2 (Section 2.6.2). A longer latency of IO firing in patients was reported in the present study (latency= 75 ms SD=52 ms). In comparison to other studies which investigated various tasks, IO activation was found to activate prior to the tasks of shoulder abduction and shoulder extension, but was later than the task of shoulder flexion in healthy individuals (Hodges et al., 1997; Hodges et al., 1999). According to Bergmark’s theory (1989), muscle fibres can be sorted into local and global muscles (see Chapter 2, Section 2.2.1). The IO muscle was initially classified as a global muscle due to its muscle fibres not directly attaching to the vertebrae and crossing multiple segments. Due to parts of the muscle bundles originating from the vertebrae, IO muscle was also found to contribute to the local muscle system. This indicates IO is mufti-functional and contributes to different tasks.

Generally, disorders in the lumbopelvic region could lead to aberrant muscle recruitment. The feed-forward mechanism could be attenuated or disappear due to pain inhibition (Hodges and Moseley, 2003, Vleeming et al., 2007). However, compensatory strategies should be considered due to the different responses to the task between individuals. This leads to more issues about the factors which can affect muscle recruitment and also raise the possibility of re-gaining the function of the feed-forward mechanism. The data from the back muscles contained too many artefacts in the signals to enable them to be used in the present study. For many patients, even if low back pain symptoms have been relieved, muscle morphology was still reported to be altered (Hides et al., 1996). The influence could be on muscle recruitment or functional performance. For a specified task, even if the general performance is the same, the elements used for the task could be different in patients.

### *10.1.3. Motion capture system findings (Chapter 7)*

Patients demonstrated higher variation in the one leg standing task than healthy participants. Although the angle changes during one leg standing on the symptomatic side showed a trend for greater changes than when standing on the asymptomatic side, the statistics did not show significant difference between sides. The angle changes in patients were very small, so the VICON system had difficulty discerning the angle changes. However, the VICON could provide an indication of the tendency of angle changes in both patients and in controls and the findings indicate less angle change in patients in comparison with controls. These findings go against the earlier hypothesis that patients would have more unstable lumbar activity and use more lumbar motions to compensate for this reduced equilibrium during tasks. In this study, patients tend to exhibit a rigid body, in order to conduct the one leg standing task. A forthcoming question is whether or not the difficulty of tasks affects the strategy for completing the task.

The tactic of using different speeds to accomplish the task could be manifest. Patients tended to carry out the task at a slower speed, in comparison to controls. Higher speeds could result in larger motion changes in order to help maintain the balance, whereas slower speeds could lead to smaller angle changes. In the healthy groups, senior participants were observed to perform the task in a slower way than younger participants. These findings support Panjabi's ball-on-bowl theory (see Chapter 2, Section 2.2.4) that an injury or a dysfunction causes abnormal motion, with changes in the neutral zone and range of motion. The smaller angle difference changes in the lumbopelvic regions in patients with coccydynia may be due to the reaction of the spinal stabilisation system decreasing the neutral zone through muscular actions, or perhaps adaptive stiffening of the spinal column which occurs over time.

### *10.1.4. Clinical/ Statistical significance of studies*

In the present study, three techniques were applied to investigate coccydynia objectively. These measurements found group differences between healthy controls and patients in the present study, but whether these measurements could be used to predict prognosis is unknown.  Clinical significance and statistical significance are not always equally relevant. The statistics could over-estimate or under-estimate the findings from instruments ,which may not respond to the clinical performance. An example is seen in the case studies of the pelvic belt intervention in Chapter 9.

The six patients in the case studies showed improvement in symptoms, as well as in their daily functions. However, the techniques of RUSI and VICON did not show changes. Due to signal problems, EMG data were not used for analysis in the case studies. RUSI was found to provide evidence of muscle morphology alteration between healthy controls and patients. After 6 weeks of intervention with the pelvic belt, muscle thickness of TrA was not changed but patients reported marked symptom relief. The length of the intervention may not have been long enough to cause changes in muscle thickness or contractibility. Thickness measurement on the abdominal muscles is a linear dimension between muscle borders. The absolute value of muscle thickness and difference in muscle thickness may be too small to show clinically significant changes. Therefore, it is still a challenge to apply RUSI over-time as an outcome measurement, due to the inadequate sensitivity to detect the changes in muscle thickness.

The findings from the VICON motion analysis system demonstrated similar difficulty in detecting change over-time as with RUSI. The changes in angle difference either did not exist or were small, so did not reflect the changes in symptoms. Again, the length of intervention may be not long enough to result in a change in angle difference. The motion VICON capture system is very precise, so it is unlikely that changes occurred within the six week period. Generally, clinical findings showed that the symptoms and function ability were subjectively improved but the objective findings did not reflect these changes.

## 10.2. Discussion on the condition of Coccydynia

### *10.2.1. Characteristics of coccydynia group studied*

Although only 19 patients were involved in this study, 14 of the 19 patients took part in both trials of RUSI and motion analysis, and 17 took part in reliability studies. Based on the history taking, coccydynia can be classified as three basic types: trauma history, postpartum and idiopathic. The majority of patients demonstrated anatomical scoliosis or functional scoliosis (10 of 17 participants). The definition of anatomical scoliosis herein is that it can be diagnosed by X-ray findings and that functional scoliosis shows no X-ray findings but shows asymmetrical muscle imbalance in the lower back.

Traumatic and postpartum coccydynia occur within three months after the injury/birth as defined in Chapter 2 (Section 2. 1.1). In general, the symptoms typically originate from the coccyx and are sometimes combined with a unilateral tender point, depending on the causes that contribute to this dysfunction. In this study, six patients belonged to the type co-existing with unilateral pain, and they also complained of mild incontinence and the feeling of an un-emptied bladder. These six patients had no awareness of their pelvic floor muscle (PFM) contractions, and four of the six patients could not sense contraction of these muscles during the ultrasound examination of the bladder, both in transverse and sagittal views. In Chapter 2 (Section 2.2.2), the roles of intra abdominal pressure (IAP) and the PFMs were described, in relation to controlling the function of the lumbopelvic region. If a disorder occurs in this region the function of the PFMs can be affected.

The number of patients with Idiopathic coccydynia was less than the traumatic type (see Table 10.1.). The types of coccydynia were determined following the definition in Section 2.1.1. All these patients demonstrated asymmetry in muscle contours, such as uneven gluteal folds, but no significant differences were found in the ultrasound examination.

**Table 10.1. The number of patients in different classification of coccydynia**

| Classification | Numbers |
|---|---|
| Traumatic and postpartum types | 15 |
| Idiopathic type | 4 |

Ten of the 19 patients had structural (n=7) and functional (n=3) scoliosis. Scoliosis can be classified into structural and functional type, and also the severity of scoliosis should be considered as a possible influence on the results in clinical studies. Due to the small sample size in the present study, scoliosis could not be concluded to be associated with coccydynia. The more precise definition of scoliosis and its severity e.g. thoracic or lumbar type with or without torsion should be considered in the sub-classification, and then the correlation of muscle morphology and the symptoms can be assessed. It could be explored in a future study but will not be discussed more deeply herein.

Hormonal changes in pregnancy can lead to laxity of ligaments (Sapsford et al., 1998, Ryder and Alexander, 2000). Postpartum patients should also record whether Postpartum Pelvic Girdle Pain (PPPGP) occurs or not. Two of the patients had undergone natural delivery within one year and complained of coccyx pain since that time. Their symptoms did not relieve after childbirth but no dislocation or subluxation was presented on X-ray. It could be due to the limitation of the X-ray technique not being taken in a sitting position, so slight subluxation may not be obvious in static standing (Maigne and Tamalet, 1996). On observation by the author, over half of the patients preferred to use chest breathing rather than abdominal breathing, and two patients had no awareness of natural breathing (2:2 chest and abdominal). This indicates an interesting phenomenon that patients with reduced abdominal breathing patterns may have weakness or insufficient function in the lumbopelvic region.

Clinical findings indicate that the majority of patients have co-existing unilateral or bilateral sacroiliac (SI) dysfunction. Three patients complained of the presence of 'clicking' hip in particular on the side of SI dysfunction that was defined as the symptomatic side. According to the alignment hypothesis mentioned in Chapter 2 (Section 2.4), the arch of the foot is decreased once excessive anterior pelvic tilting is observed. The position of the pelvis has influence on the alignment of the femoral shaft and also is affected by the mal-alignment of the lower extremities. These co-existing symptoms and factors which may affect coccydynia are illustrated in Figure 10.1, based on the patients' reports.

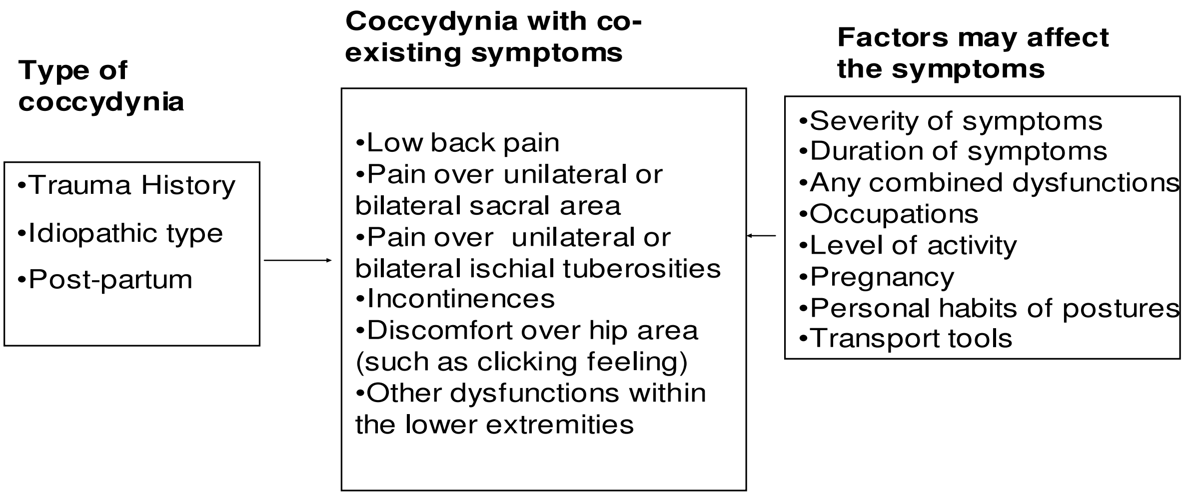



**Figure 10.1. The co-existing symptoms and factors affecting coccydynia**

### *10.2.2. The time course of pain in patients with coccydynia*

Clinical findings indicate that coccydynia has a progressive symptom change, so patients with different pain time courses may have different changes in their torso. In the traumatic group, most patients complained of coccydynia with one side more severely symptomatic than the other. Symptoms occurred in and around the coccyx, and then the discomfort went up to the sacral areas or down to the buttocks (ischial tuberosities). If the symptoms existed over 6 months, patients would complain of lower back pain and some patients may complain of pain radiating to the lower extremities (see Figure 10.2).

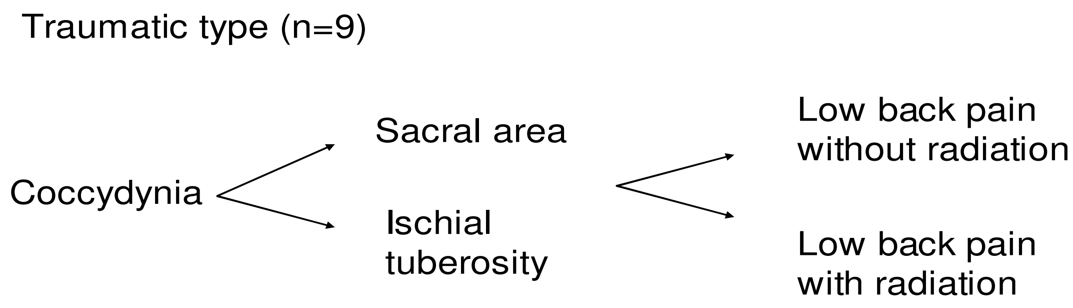



**Figure 10.2. The progression of pain in traumatic coccydynia**

Pain inducing factors, in general, were prolonged sitting or standing. The influence of coccydynia on the function of the pelvic floor muscles is still questioned. The gold standard of pelvic floor muscle assessment is an intrusive method of digital palpation. In the early stage of this study, transabdominal ultrasound was used to gather information on pelvic floor muscles via observing bladder shape. The bladder shape could be affected by many factors, and could be used as a criterion for diagnosis. However, transabdominal ultrasound could offer visual observation for PFM contraction via the motion of the bladder neck in the sagittal view and the bladder base in the transversal view. It could provide objective information about the accuracy of PFM contraction, so was reported in a limited number of cases for reference (Chapter 9 case studies).

The co-activation of the abdominal muscles and PFMs is an import element to develop initra-abdominal pressure (IAP) and is also thought to contribute to spinal stability (Hemborg et al., 1985).Recently, a relationship between activation of the abdominal and pelvic floor muscles during voluntary exercise was reported to support the hypothesis of the IAP mechanism (Sapsford and Hodges, 2001, Sapsford et al., 2001, Neumann and Gill, 2002, Thompson et al., 2005 ). In the studies of Sapsford et al (2001), they used fine-wire EMG to collect data from TrA, IO, EO and rectus abdominis (RA). Participants were requested to carry out maximal contractions of the PFMs in three different lumbar positions (flexion, extension and neutral) in a crook-lying position with hips flexed to 60 degrees. In their preliminary experiment, the findings showed increased activity of all abdominal muscles during a maximal contraction of the PFMs. In their additional pilot experiment (Sapsford and Hodges, 2001), they recorded EMG activity of the PFMs with surface electrodes inserted into the anus and vagina. These recordings were corroborated by measurements of anal and vaginal pressures. They found isometric contractions of the abdominal muscles also resulted in increased muscle activity the of pubococcygeus muscles (PFMs). Their findings indicate that abdominal muscles and

PFMs work in synergy and cannot be isolated. They also found that participants had more difficulty performing a maximal PFMs contraction with a flexed spine, which was inferred to be caused by a decreased feeling of lift of the pubococcygeus.

Because the sample size in this study by Sapsford and Hodges (2001) was small (n=7), their findings may not be representative. However, their findings may be relevant to coccydynia due to the PFMs being attached to the coccyx. In this present study, many patients with coccydynia were found to have a more flexed spine. Some of the patients had difficulty in sensing their PFMs contracting or reported having urinary incontinence. Although this preliminary study of coccydynia did not cover this aspect of dysfunction, it could be further investigated in future studies.

(Smith et al., 2009) carried out several cross-sectional studies in 2943 younger (18 to 23 years old), 2298 midele-aged (45 to 50 years old) and 2258 older (70 to 75 years old) women from the Australian Longitudinal Study on Women's Health to investigate the contributors to low back pain. The postal survey was used to collect self-report data on physical and mental well-being, health behaviours, diagnosis and social factors. They concluded that a woman with incontinence or allergy (such as respiratory disorders of hay fever or sinusitis) has a greater risk of developing back pain in the next few years. In their early report from the younger and middle-aged cohorts in 2008, they suggested that pregnancy may lead to earlier occurrence of back pain but did not affect the long-term prevalence. They also found a stronger association between back pain and incontinence during pregnancy (Smith et al., 2008 ). Therefore, incontinence and respiratory disorders may be correlated with the incidence of back pain. In this present study, some patients with coccydynia reported incontinence and some showed abnormal breathing patterns i.e. were unable to do abdominal breathing. Because trunk muscles and pelvic floor muscles contribute to continence and lumbopelvic control, it is reasonable to infer correlations among these factors. The findings from Smith et al. (2008, 2009) indicate the possible contributors to back pain, and as this present study showed, these factors may also affect coccydynia.

The duration of pain in the lumbopelvic region could affect function of the PFMs. Considering the biomechanical factors, the shortened or elongated PFMs could lead to an excessive flexed or extended coccyx, and further affect the function of the PFMs. To further contemplate the biomechanical issues, the participants' pelvic and lumbar positions should be examined. In patients with a flatter back (less lordosis), the pelvis tends to be tilted backwards; but if there is more lumbar lordosis, more forward pelvic tilting is reported.

### *10.2.3. Neuromuscular and functional performance in patients with coccydynia*

Considerable disagreement regarding the potential mechanisms in low back pain exist (Hodges and Moseley, 2003) and the situation may be similar for coccydynia (see Chapter 2, Section 2.3.4). The altered neuromuscular functions, such as a longer latency of local muscles (TrA) from EMG were reported in patients with chronic low back pain (Hodges and Richardson, 1999a, Hodges, 2001). Hodges et al (1997, 1999, 2001) reported that the muscle recruitment of deep abdominal muscles (TrA) was not affected by the direction of arm motions in healthy controls, but were delayed or disappeared in patients with low back pain. The onset of IO during the arm movements in normal participants was reported to be prior to the limb motion in shoulder abduction and extension, but be later in shoulder flexion. This may be due to the anatomic orientation features of the IO muscle bundles, as these arise partly from the local muscles and partly from the deep muscles, which may affect muscle recruitment in different tasks (see Chapter 2, Section 2.2.1.) The longer response time of muscles was found in patients than in normal controls. The findings in the present study demonstrated similar differences, with longer latency of IO reported during one-leg standing in patients with coccydynia than in healthy controls. Pain was found to attenuate motor control and affect postural adjustment. However, the potential mechanisms of pain are diverse and still unanswered.

Recently, growing evidence from ultrasound imaging studies reported altered structure and function of the deep trunk muscles (e.g. TrA and multifidus) in patients with low back pain. Patients with chronic low back pain showed thicker TrA than in controls (Critchley and Coutts, 2002), and patients with pain in the acute stage demonstrated a thinner muscle thickness (Norasteh et al., 2007). The findings indicate that muscle wasting and delayed muscle activation of deep muscle were observed in the acute stage but no significant difference for the muscle morphology between the two groups of patients and controls were reported (Norasteh et al., 2007). In this present study, chronic coccydynia is defined as pain duration longer than three months. The range of pain duration in the present patients was between three months and over ten years, so all patients fell into the chronic coccydynia category. In the present study, patients with coccydynia were hypothesised to have similar alterations in the neuromuscular performance of ultrasound imaging and EMG to those with low back pain. Patients with coccydynia showed thicker TrA muscles and longer latency of IO than the controls. The findings of thicker TrA thickness are consistent with the patients with chronic low back pain (Critchley and Coutts, 2002). The morphological changes of hypertrophy in TrA muscles may be due to over-activity of deep muscles.

The reliability of RUSI measurements in TrA muscles at rest was lower in patients than in healthy participants during the session of different efforts of ADIM (see Chapter 6). This indicates that the muscle behaviours were less consistent and more variable during the repeated efforts in comparison with controls. Therefore, patients may have difficulty in task changes and in relaxation of the deep muscles, which may lead to hypertrophy of TrA muscles. As for sub-maximal contraction of the abdominal muscles, the consistent performance was good (ICC>0.7). Additionally, lower thickness changes were found in patients than in controls, and the thickness changes and percentage of thickness changes also showed significant differences between groups. In consideration of the correlation between muscle thickness changes and muscle recruitment during a specific task, it might be interpreted as lower muscle recruitment of TrA in patients. However, the experimental protocol of ultrasound did not incorporate simultaneous electromyography (EMG), This limitation could be improved in future studies.

As for the physiological findings of muscle firing, the later firing of IO was found during one leg standing in both groups. Longer latency of IO muscles was reported in patients than in controls, and was consistent with the findings of longer latency in TrA in low back pain (Hodges and Richardson, 1999a, Hodges, 2001) and sacroiliac joint pain (Hungerford et al., 2003). The IO muscle is localised in the more superficial area than the TrA muscle, so muscle firing is later than the point of starting the task. In consideration of biomechanical performance, less changes in lumbopelvic angle were found in patients than in controls, indicating that patients used the strategy of adaptive stiffening of the spine to carry out the task, in keeping with Panjabi's theory stated in Chapter 2 (Section 2.2.4.)

### 10.3. Discussion of the technology of RUSI

RUSI can be used as a research and rehabilitation technique clinically, because the reliability of its measurement of muscle thickness is regarded as acceptable (Rankin et al., 2006, Hides et al., 2007, Kiesel et al., 2007, Teyhen et al., 2007, Teyhen et al., 2008, Teyhen et al., 2009). In most RUSI studies, the reliability of thickness measurements of the abdominal muscles (Teyhen et al., 2007, Koppenhaver et al., 2009, Costa et al., 2009b), and the lumbar multifidus (Kiesel et al., 2007, Koppenhaver et al., 2009) in healthy controls is high, and has good precision (TrA standard error of measurement <1.2 mm and lumbar multifidus <3.7 mm). A lower reliability of RUSI has been reported in lower back patients (ICC>0.7) but the technique is still valid enough to apply clinically (Koppenhaver et al., 2009). Hebert et al (2009) did a systematic review of RUSI for the quantitative assessment of the abdominal and lumbar muscles, and reported only limited numbers of studies being of superior quality(Hebert et al., 2009). Therefore, the methodology of techniques needs to be improved, if RUSI measurements are to be used as legitimate measures of evaluating functional deficits and morphological changes in muscles.

### *10.3.1. RUSI in healthy participants*

Most researchers investigated the reliability of RUSI in small populations and under limited conditions, most commonly only at rest or during a single testing task. The findings could not be generalised or extrapolated to another situation, and a specific population. In this present study, the targeted group is Taiwanese women with coccydynia, so the reliability of RUSI measurements in healthy Taiwanese women and women with coccydynia needed to be established, due to the majority of prior studies being focussed upon Western society, with mixed genders and patients with lower back pain. Some RUSI studies were conducted in Taiwan to investigate the reliability of imaging cervical multifidus, and abdominal and thigh muscles (Lee et al., 2007, Lin et al., 2009, Jhu et al., 2010). The sample sizes were small, with mixed genders and narrow age ranges, so could not be used as a reference for this study. The TrA muscle is located in the deepest layer of the abdominal muscles and cannot be investigated directly, so RUSI offers a simple and non-invasive way to assess this muscle. Generally speaking, reliability of RUSI in TrA thickness measurements at rest in different postures is good (Bunce et al., 2002, Bunce et al., 2004). Bunce et al. (2002) reported ultrasound to be reliable for assessing muscle thickness changes in TrA between supine lying, standing and walking.

Ainscough-Potts et al (2006) investigated the thickness of the right TrA and IO in 30 healthy controls, with mixed genders adopting four positions of supine lying, and relaxed sitting in three different poses (on a chair, on a gym ball and on gym ball lifting the left foot off the floor). The influence of exhalation has been standardised by a system of only taking measurements at the end of inhalation and exhalation. Gym ball exercise is frequently applied clinically to facilitate deep muscle contractions of the abdominal and pelvic floor muscles, but little research was carried out to support the intervention. Both muscles were found to be thicker at the end of exhalation rather than at the end of inhalation in the four experimental positions, and the findings are in line with findings of (De Troyer et al., 1990) in TrA and (Misuri et al., 1997) in both muscles.

A slightly greater muscle thickness of the TrA and IO was found for sitting on the gym ball, in comparison with sitting on a chair, but a significant difference in thickness in both muscles was recorded whilst the subjects sat on the gym ball with the left foot off the floor. This indicates that muscle activities of the TrA and IO increased, and supports the intervention of gym balls. Generally, a tendency is clearly observed that muscle thickness increases as stability of posture decreases. During the supine lying task, the TrA thickness was 3.98±0.91 mm at inspiration, and 4.23±0.99 mm at exhalation, and the IO thickness was 9.05±2.95 mm at inhalation and 9.62±3.1 mm at exhalation. In comparison with the data collected in the present study, a larger muscle size in IO (5.7± 1 mm) was found by Ainscough-Potts et al (2006), and a similar TrA thickness (4.07 ±0.97 mm) was reported. These studies support RUSI to be a reliable and reproducible technique to investigate muscle morphology under the different conditions.

### *10.3.2. RUSI in patients with coccydynia*

Norasteh et al. (2007) showed good reliability (ICC=0.72-0.99) of ultrasound imaging, both in controls, and in groups with acute lower back pain (ALBP). The experimental protocol was to measure the bilateral sides of the lateral abdominal wall, in three different positions: supine, sitting and standing, and both at the point of inhalation and exhalation. The degree of muscle thickness during the three different positions was calculated. This demonstrated no significant morphological changes in muscles between groups.

Another study of patients was by Critchley at al (2002), which investigated patients with chronic lower back pain during four-point kneeling. They found thickness of TrA at rest in controls to be 5.1±1.2 mm, and in patients to be 5.8± 1.7 mm. The TrA during lower abdominal hollowing was reported to be 7.7±2.4 mm in controls, and 6.7± 1.6 mm in patients. No significant difference was demonstrated between the two groups in the thickness of TrA at rest, and change of thickness in the TrA was significantly less in patients, which is consistent with the findings of the present study. Additionally, a trend towards a greater increase of thickness in the IO was more apparent in the patients with lower back pain than in controls; but this was not sufficient to attain statistical significance. In this present study, significant differences were found in the TrA and the IO during contraction, and could support the hypothesis that coccydynia could lead to morphological changes in abdominal muscles, and different contraction strategies may be observed due to a defect in motor control.

Koppenhaver et al. (2009) investigated intra-examiner and inter-examiner reliability of RUSI in the thickness measurements of the TrA and lumbar multifidus muscles, both at rest and during a contraction of ASLR, maximal-ADIM and a contra-lateral arm lifting manoeuvre in patients with lower back pain. Their findings demonstrated good reliability (ICC>0.74) and good precision (the TrA standard error of measurement being ≤0.5 mm, and the lumbar multifidus standard error of measurement being ≤ 1.1mm). A low between-days figure was reported (ICC= 0.87) in comparison with the other studies (Teyhen et al., 2005). The decreased reliability could be a consequence of the instruction from the examiner, levels of participant motivation and their varying ability to perform the task. This is because the degree of TrA thickness changes depends upon the effort with which the TrA is voluntarily contracted; this could be affected by the instruction of the examiner. In the present study of level contraction (Chapter 6), the analogy of an elevator in a 10-storey building to aid repeatable force generation was used to standardise the activation of the TrA to 20% MVE and MVEIC. Greater reliability was found in healthy participants (ICC>0.9) than in patients (ICC>0.7) but the healthy group was younger, so it is not known whether age influenced the results. The lower reliability of the two levels of contractions in patients could be due to a deficiency of motor control skills, due to their pathological dysfunction and/or age.

### *10.3.3. Different efforts of recruitment of TrA muscles*

The most frequent method used by clinicians to activate the TrA is to apply the manoeuvre of abdominal hollowing, and Richardson and Jull (1995) advocated four-point kneeling as the easiest way to activate the TrA. However, all the above tasks in the previous section are only based on recommendations in the literature and not on evidence to support them as the most viable or optimum means of activating the TrA. RUSI provides an objective method for investigating whether the TrA becomes active during these tasks.

Whether the changes in muscle thickness could be used as an indirect measurement of muscle recruitment is a foremost question in the technique of ultrasound imaging. McMeeken et al. (2004) compared needle EMG recordings from TrA contractions with real time ultrasound imaging of muscle thickness at different levels of activity, and reported a good correlation at all levels between the two technologies. However, Hodges et al (2003) used surface EMG and fine wire EMG recording, and compared the response with RUSI in the abdominal muscles, and found a good correlation between TrA and IO but only at sub-maximal contraction levels up to 30% maximal. Although the issues of limited sample size of the investigated population exist, these findings support the idea that changes in muscle thickness are indicative of relative muscle activity, at least for low contraction levels. However, (Brown and McGill, 2010) showed no definitive relationship between muscle activation and thickness increase in EO and IO during the abdominal bracing and hollow manoeuvres; consequently they theorised that ultrasound imaging alone may not be a valid measure of muscle activation. However, EO and IO have different behaviours to TrA during these manoeuvres. The composite laminate-like structure of the abdominal wall (see

Figure 10.3.) and the orientation of force transmissions could be the reasons for this interpretation of the results. The issues concerning the validity of ultrasound imaging in comparison with EMG are still unanswered.

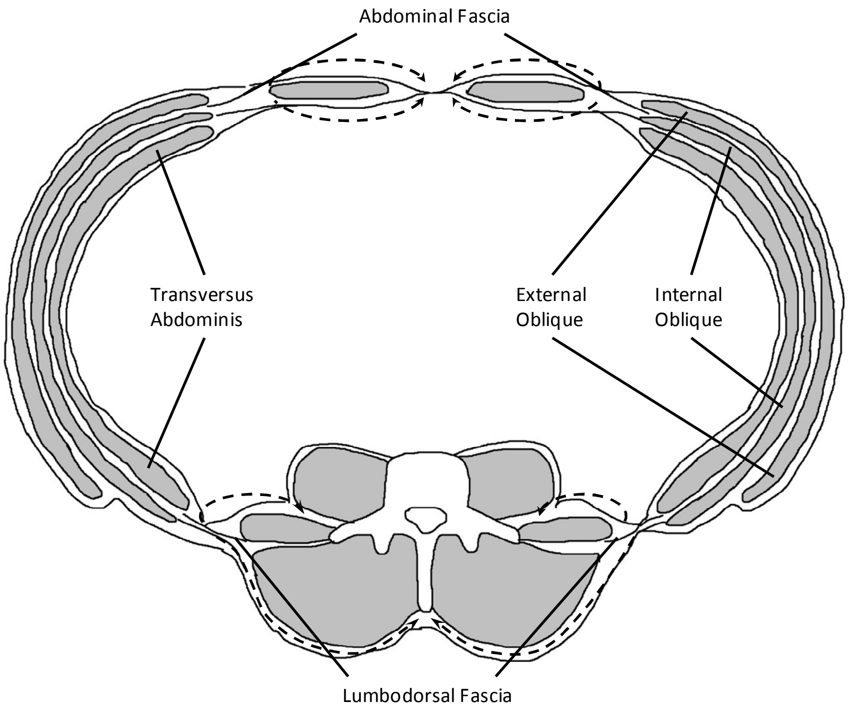



**Figure: 10.3. The structure of the three layers of the lateral abdominal wall.**

Clinicians attempt to use verbal instruction to ask people co-contract their abdominal muscles whilst performing functional tasks, but many physiotherapists have noticed difficulty in eliciting such deep muscle contractions via only verbal instructions. During the initial experimental protocol of ultrasound imaging in the present study, each participant was requested to carry out an ASLR whilst "slightly" drawing in her abdomen. The volume of effort sufficient for TrA to protect the spine when executing the functional task is unknown, and whether participants carry out the same effort under the same verbal instruction is unexplored as well. Therefore, for further standardisation of the experimental protocol, an additional study for different levels of contraction in TrA thickness was carried out (Chapter 6). Due to the sub-maximal contraction of the TrA being reported as having a good correlation with EMG, a 20% MVE of the draw-in manoeuvre was targeted in the present study. The reproducibility of RUSI at all levels of contraction was good in controls, but was poor at rest in patients. During the 20% MVE task in patients, the reliability was good (ICC>0.93), and the findings indicated that sub-maximal effort under the verbal instruction using the elevator analogy of 10-floors is highly reliable and reproducible. The poor reliability of the TrA at rest and the moderate reliability at MVE, indicates that patients may have difficulty relaxing the deep muscles, and cannot fully exert themselves to achieve a task, perhaps due to pain inhibition, reflex inhibition or fear of pain. Furthermore, it was observed patients could not change immediately from rest into a contraction. These factors could lead to poor reliability.

Age could be another factor which affects muscle contraction effort during the same task. A limitation of the study on the level of contraction was that only younger participants were recruited for comparison with patients and the same protocol was not carried out with the senior Taiwanese women. In Chapter 5, the influence of age on muscle thickness and relative thickness changes between the two age groups are discussed in Section 5.2.5, indicating that age may affect the awareness or ability of effort during muscle contractions, or that weakness may require greater effort and level of contraction.

### *10.3.4. Other possible factors to affect the recruitment of muscles*

There are many factors that affect muscle morphology and behaviours in different groups during different tasks. Several possible factors are discussed herein to clarify the variations in the technique of RUSI. In the previous paragraph, age was considered to be a factor which has influence upon muscle recruitment during a task. The effort required of muscles to achieve a task could vary according to increasing age (see Chapters 5 and 6). Whether the function of the TrA muscles deteriorates with age is not clear and this question warrants further study in order to provide stronger evidence.

The influence of BMI was reported to be relevant to coccydynia (Maigne et al., 2000a). However, the correlations among BMI, muscle morphology and the recruitment patterns are unknown. In the present study, there was no difference amongst the three BMI groups, but bias could exist due to the study involving a small, possibly unrepresentative number of low and high BMI participants. It indicates a tendency for less muscle recruitment of TrA muscles in Low and High BMI groups, in comparison with Normal BMI groups.

Gender is another factor to affect the morphology of muscles. The majority of studies did not only focus on a single gender, like the present study, but a difference in muscle thickness between men and women does exist. The average TrA muscle thickness in men is larger than in women (Bunce et al., 2002, Rankin et al., 2006, Springer et al., 2006), and also the cross-sectional area (CSA) of lumbar multifidus (Stokes et al., 2005).

The precision of RUSI measurement in both respiratory states is good but less variability occurred at the end of exhalation than at the end of inspiration (De Troyer et al., 1990, Misuri et al., 1997, Ainscough-Potts et al., 2006). However, there is no information about the different muscle recruitment patterns (TrA thickness) in relation to different breathing patterns in controls, and it is unknown what length of time an altered breathing pattern is needed to result in muscular changes in TrA or even whether it would have much effect at all. Breathing patterns could be affected by many factors such as age, gender, and lifestyle, and may result in alterations of abdominal muscle recruitments and morphological changes.

Breathing pattern disorders, such as patients with chronic hypoxemia, were found to be relevant to the biomechanical changes in muscle behaviours (Jammes et al., 1997). One element of spinal stability is intra-abdominal pressure (IAP) which was discussed in Chapter 2. Hodges et al. (2001, 2005) found that IAP could co-operate with the recruitments of abdominal and back muscles to augment the stability of spine. Although limited numbers of participants were included in these studies, the activity of the diaphragm was indicated as a contributor to spinal stability (Hodges and Gandevia, 2000a, Hodges and Gandevia, 2000b, Hodges et al., 2001a, Hodges et al., 2005). The patients with sacroiliac pain were reported to show impaired recruitment of the diaphragm and pelvic floor muscles (O'Sullivan et al., 2002). These findings indicate the possibility of breathing pattern disorders in patients with coccydynia, since some were observed in the present patients. However, consideration of the influence of breathing patterns on muscle behaviour was not included in the present study.

The duration of pain may affect the morphological changes in muscles. Norasteh et al. (2007) reported similar muscle thickness during resting, in both patients with acute lower back pain (4.36±1mm) and in controls (4.36 ± 1.03 mm). Critchley at al (2002) reported larger resting muscle thickness in patients with chronic lower back pain (5.8± 1.7 mm) in comparison to controls (5.1±1.2) but larger muscle thickness during contraction in controls (7.7 ±2.4) than in patients (6.7±1.6).

Population bias could also be present. The existing studies in controls predominantly originate from Australia, the USA and the UK. Some studies involved participants who were young and accustomed to a higher activity level than the general population (Urquhart and Hodges, 2005, Urquhart et al., 2005b, Urquhart et al., 2005a, Ainscough-Potts et al., 2006, McCook et al., 2007). Eastern studies were relatively few and involved participants who were young, from both genders and in a small number (Jhu et al., 2010). For example, the number of participants in the studies by Ainscough-Potts et al (2006) was 30 with a mean age of 27.7 (SD=8.6), recruiting from physiotherapy students and staff from King's College London. The

Urquhart et al (2005) samples were n=7 with mean age 30 years (SD=4), and n=30 with mean age 22.3 years old (SD=1.5). Jhu et al. (2010) studied 18 participants (mean age 22.6± 2.5), consisting of 14 men and 4 women. The activity level of participants was not recorded, so no information about how the activity level might have influenced muscle recruitment during the task was given. Stokes et al. (2005) and Rankin et al. (2006) provided normal reference ranges for multifidus and abdominal muscles in the Western society. Racial differences may exist due to different body size (BMI), body types and habitual activities. In the present study, the wide range of participants were derived from the whole community in a city in Taiwan, so the life style could be considered more representative of the general female population in that country than those that participated in the research in western countries, who were mainly university students and staff.

#### *10.3.5. RUSI as an outcome measurement*

As stated in Chapter 3, RUSI has been shown to be a valid method against MRI for measuring muscle thickness of the abdominal muscles, multifidus and pelvic floor muscle at rest. As for dynamic tasks, the muscles have been observed to increase in thickness on RUSI images during dynamic tasks. However, the correlation between the changes in muscle thickness and muscle efforts is still questionable.

Hodges et al (2003) and McMeeken et al (2004) compared ultrasound and EMG measures of abdominal muscles and found high correlations (ICC= 0.84-0.9) for IO and TrA muscles under the specific tasks of abdominal muscles contraction at low force levels . For EO, there was no correlation between ultrasound and EMG (McMeeken et al., 2004). However, a good relationship (ICC=0.63-0.94) was reported for EO during the task of isometric trunk twist, but showed poor correlation (ICC=0.16-0.86) during the abdominal hollow (John and Beith, 2007). Brown and McGill (2010) also showed conflicting results with no correlation between EMG and ultrasound imaging in five healthy males during a series of abdominal muscle contractions targeted as 50% of activation level (bracing, hollowing, flexor moment and extensor moment). These conflicting findings indicate a complex relationship between muscle activation and change in muscle thickness in different muscles and during different tasks. The activation patterns of abdominal muscles for different tasks could be varied. Critchley and Coutts (2002) and Ainscough-Potts et al (2006) used the percentage of the thickness of the individual's muscle in lying as a way of standardising the results to evaluate the relative muscle activity. The change in muscle thickness and the percentage change in muscle thickness were also a way to indicate the ability of muscle to contract. The percentage change in muscle thickness is a way to normalise data. However, the above studies, which combined RUSI and

EMG were carried out in small numbers of participants, so whether these results could represent the population is uncertain. Also the recruitment of participants were mainly in the School of Physiotherapy in Universities, so the participants may be highly engaged in regular exercise and have greater awareness of muscles at different levels of contraction than the general population.

Recently, several studies used RUSI to provide an objective assessment of interventions. For example, (Brenner et al., 2007) compared the percentage changes in thickness of multifidus at L4-L5 and L5-S1 at pre-manipulation, immediately post-manipulation and 1 day after manipulation to assess the short-term effect of spinal manipulation. They found that the ability of multifidus contractions was improved during the tests, and may provide evidence to support the influence of spinal manipulation. Although this is only a case report and cannot be taken as strong evidence, RUSI can provide a convenient way to investigate the change in deep muscles clinically.

#### *10.3.6. Possible factors affecting the reliability of ultrasound imaging*

The experience of the investigator may influence the quality of scans obtained and measurements made. The present studies showed that a young physiotherapist could learn the RUSI technique to achieve sufficient reliability of muscle thickness measurement if they followed the same protocol. The error of measurement can be decreased by repeated practice. The participants' positions are also possible factors. A study by Bunce et al. (2004) compared the TrA in three different postures (supine, sitting and standing). They found no significant difference in the deepest muscles, but they did not mention whether position affected the superficial muscle layers of IO or EO. Coldron et al (2004) compared the multifidus in the two positions of side-lying and prone at rest. The thickness of multifidus in the two positions showed no significant difference. It means that RUSI is a highly reliable technique to investigate the deepest muscles at rest but did examine reliability for a dynamic task.

In the present pilot work, greater measurement errors found during contractions may have been caused by movement of the transducer over the skin surface or movement of the muscles beneath the skin relative to the transducer. Therefore, the superficial abdominal muscles (i.e. IO and EO) are assumed to show higher measurement errors rather than the TrA. The superficial muscles can also be distorted by compression from the transducer. However, the results from the present study showed that the ICCs for TrA were slightly less than EO and IO, and similar to the findings from Critchley and Coutts (2002).The possible explanation might be that the degree of contraction may not be identical between efforts, as this is difficult to standardise for the abdominal muscles. It indicates that people may have different contraction patterns of muscles when carrying out the same task, so how to further standardise the protocol to reduce the possible errors is necessary. This issue was examined in more detail in Chapter 6.

#### *10.3.7. Strategies for muscle recruitment during tasks in healthy participants and patients*

In patient groups, three strategies were observed in real-time ultrasound imaging to activate the abdominal muscles during the ASLR task: (1) TrA contraction only (2) TrA and IO co-contraction (3) EO and IO co-contraction without TrA thickness changes. In the majority of controls, co-contraction of TrA and IO was mostly observed and isolated contraction of TrA can be difficult. Some patients showed very thin TrA (see Figure 10.4) or using IO or EO or together to compensate the function of TrA. However, the findings from the present study demonstrated thicker TrA muscles in the patient group than in controls at rest. Patients with coccydynia may have insufficient or dysfunction of respiration due to poor function of abdominal muscles. However, there are no studies to date to support these suggestions.

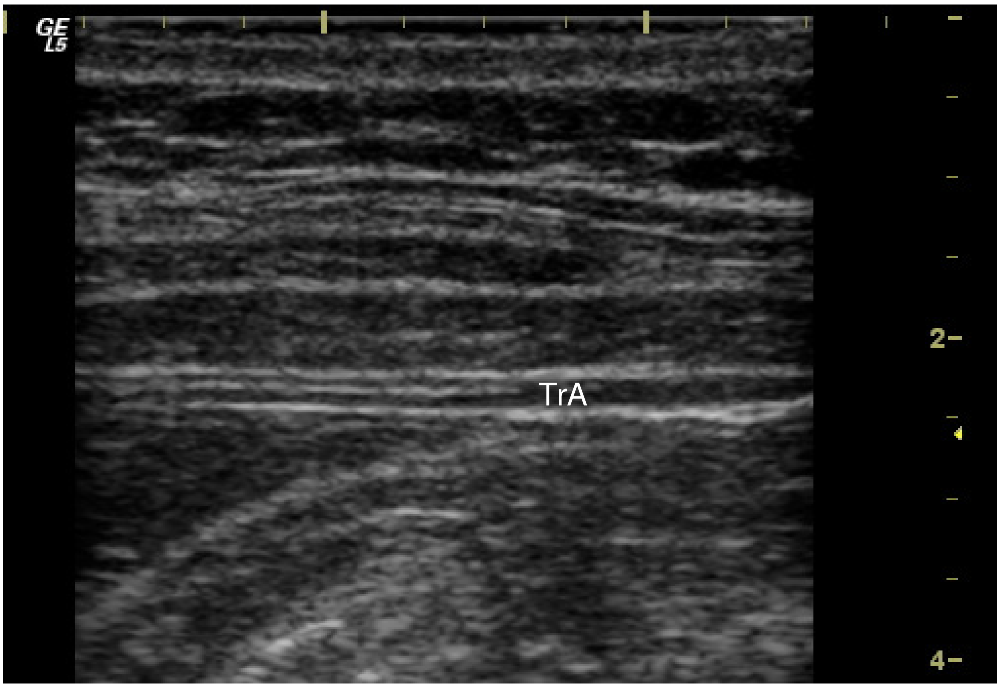



**Figure 10.4. Ultrasound scan of the abdominal muscles in a patient rest. The TrA muscle was thin in this patient**

Kiesel et al (2007a) reported high ICC values of lumbar multifidus during the task of contra-lateral arm lifting. In the present study, a contra-lateral leg lift was used to activate lumbar and sacral multifidus because this task is commonly applied in the clinic and can provide more information for therapeutic exercise. High ICCs were reported for lumbar and sacral multifidus in both muscle states, consistent with the existing studies (Kiesel et al., 2007). The investigated muscle contraction strategies were categorised: (1) contraction was prior to the task (2) contraction was later than the leg rise (3) no thickness changes during the task. Only 2 of the 16 controls showed no change in thickness during the task but all patients showed little or no contraction in the same task.

### *10.3.8. Other possible factors: scoliosis, BMI and age*

In the patients, significant differences were reported in IO and TrA on the asymptomatic side during contractions between the scoliosis and no-scoliosis groups. Due to the small sample size, the different types of scoliosis were not considered. The findings indicate that patients with coccydynia and coexisting scoliosis may have influence on the strategy of muscle activity, in particular in the deeper muscles.

Significant differences in thickness change and percentage thickness change were found between the young and old healthy participant groups. It raises the possibility of altered motor control and / or muscle efficiency with increasing age. It is known that muscle strength decreases with age (Doherty et al., 1993, Booth et al., 1994, Bemben, 1998, Clark and Taylor, 2011). However, RUSI is restricted to offering thickness changes that may not be as sensitive as cross-sectional area measurements, and cannot provide information about muscle properties, such as nerve conduction speed, muscle firing or force of contraction. The application of EMG combined with RUSI could provide more objective assessment. BMI is a factor that may be correlated with the prevalence of coccydynia but there is no published evidence of this. In the present study, no difference among three BMI groups (high, normal and low) was found, which may be due to the small sample size.

Previous studies of abdominal muscle size reported that muscle size did not significantly alter with age (Rankin et al., 2005). (Fulton et al., 2009) reported older adults without respiratory or musculoskeletal pathologies showed the similar patterns of TrA thickness during a gradual upper limb exercise test to the young asymptotic participants in their previous report in 2008 (McEvoy et al., 2008). The TrA muscle was found to be continuously and increasingly active, but not act uniformly during the whole trial. They did not discuss muscle thickness during contractions or thickness changes in different age cohort groups. Their findings indicate that the more complicated task recruited more TrA muscle fibres, which reflected on the muscle morphology.

In this present study, muscle thickness of TrA was generally larger at maximal voluntary effort (MVE) during the active drawing-in maneuver than 20% of MVE. TrA thickness during contraction was significantly greater in the healthy older Taiwanese women than in the younger cohort. The possible explanation for these findings could be age which affects the motor control on the recruitment of muscle fibres. Although similar patterns of TrA thickness during the gradual tasks reported by Fulton et al. (2009) in older and younger groups (McEvoy et al., 2008), it did not necessarily mean that similar motor control of muscle recruitment occurred throughout the trails in the two age cohorts. Another possible explanation is that the older participants had greater body weight or weaker muscles, which would require recruitment of more muscle fibres to carry out the tasks.

### 10.4. Discussion of the technologies of motion analysis and EMG

#### *10.4.1. Motion capture system*

The lumbar spine and pelvis work together to maintain balance and so could be viewed as a couple, working in tandem motion. In general, the greater the lumbar lordosis the greater the backward pelvic tilt, and vice versa. Therefore, the changes in angle in the lumbar spine and pelvis were the data chosen to measure in the present study. As for the reproducibility of motion analysis in both the angles in the two groups, an acceptable reliability for between-trials (ICC>0.7) was reported, but a poor ICC was shown for between-days, which is consistent with other studies using motion analysis during different functional tasks such as running (Schache et al., 2002b, Schache et al., 2002a).

The high variation in between-day finding could be due to individual differences, such as excessive lumbar lordosis, the placement of markers, and the unavoidable soft tissue motions in particular in participants with high BMI. In young healthy participants, the average lumbar angle change was 16.1 ° (SD=7.65°) and the average pelvic angle change was 17.17° (SD= 6.37°). In older controls, the average changes in lumbar angle was 12.89° (SD=7.66°) and pelvic angle was 11.07° (SD=9.13°). In comparison with the healthy groups, smaller angle changes were reported in patients, both during symptomatic-leg standing, lumbar 5.05° ±SD 5.25° and pelvic angle 4.23°±SD 3.49°, and asymptomatic-leg standing, lumbar 4.89°±SD4.2° and pelvic angle 5.49°±SD 3.3° (see Chapter 7). This indicates that patients tend to stiffen their trunk to carry out the task. In actuality, motion analysis can only offer an indication of the *tendency* of motion: the findings cannot be regarded as categorical, due to the limitation of unverified validity.

### *10.4.2. EMG*

During the one leg standing task in healthy controls, activation of IO onset (53 ms SD=47ms) occurred later than hip flexion. In the patient group, a significantly longer latency of IO onset was found (75ms SD=52 ms). The reliability of EMG between-trials was acceptable (ICC> 0.65), but was not good for between-days which is generally accepted as a limitation of EMG (DiFabio, 1987, Roy et al., 1989, Thompson and Biedermann, 1993, Roy and Oddsson, 1998, Hogrel, 2005). The high variation between days may be affected by the electrode placements, individual differences and environments. In people with more subcutaneous fatty tissue, the difficult of surface electrodes to detect the signal is increased. The contact between skin surface and the electrodes also needs to be considered, due to skin motion during the task. The severity of symptoms is also another consideration. Due to the difficulty in data normalisation, only timing of muscle activation was used for analysis in the present study.

## 10.5. The theory of mal-alignment in the lumbopelvic region

At the end of Chapter 2, the mal-alignment theory based on the observation was mentioned. Whether the alignment theory matched the findings is discussed herein.

### *10.5.1. Dysfunction in lumbopelvic region may lead to muscle imbalance*

All patients demonstrated more severe symptoms one side than the other or showed asymmetrical muscle profiles, such as the gluteal lines, so it was thought that this could indicate a difference between sides in the deepest muscles. In this study, however, the symmetry of bilateral abdominal muscles was assessed, and no significant differences were found to support the hypothesis. A trend toward larger thickness on the symptomatic side was found than on the asymptomatic side, as observed in the present study. However, no significant difference between sides was reported. In patients with sacroiliac joint dysfunction (SIJ dysfunction), the determination of muscle imbalance is also limited in a quantitative way. Due to the diagnosis of SIJ dysfunction being based on the soft tissue diagnosis, the difference may not relate to orthopaedic deformity, so could not be accepted by the majority of orthopaedists. In the author’s experience, orthopaedic surgeons do not accept this type of soft tissue diagnosis. The RUSI could provide the technique to assess muscle morphology, so could provide the objective evidence of imbalance rather than observation only. However, the sensitivity of ultrasound imaging for differentiating muscle imbalance is not clear so far. The author is considering the correlation between muscle morphology and pelvic positions, but the objective assessment for pelvic positions should be developed first.

### 10.6. Information from case studies

Although previous reports suggested that a pelvic belt will increase the force of pelvic floor muscles, studies on the effectiveness of the pelvic belt in clinical trials are few (Hu et al., 2010, Jansen et al., 2010, Damen et al., 2002). Coccydynia was assumed to present with higher tension of PFMs, so the alignment of the pelvis could be altered and the stability may be disturbed. As the background information on the pelvic belt stated in Chapter 9 (Section 9.1), the additional compression forces for the pelvis can increase the stability of the SIJ and induce activation of TrA muscles. Due to different types of pelvic outlet, the applied pelvic belt in this study includes a main belt and two additional belts, which allow patients to apply pressure in different ways, as stated in Section 9.2. After a six-week intervention, patients reported relief of symptoms and improvements in function and quality of life. However, muscle morphology and angle changes in the lumbar and pelvic joints did not show changes. The individual difference in muscle behaviours was diverse and could be due to different symptoms. The reasons for these differences may be different compensative strategies or the short intervention period.

The pelvic belt is a type of spinal orthosis and believed to maintain and further stabilise the pelvic position. Woodard et al (2005) summarised the complications of spinal bracing in three general categories: skin and soft-tissue injuries, ineffective stabilisation, and a variety of combined complications such as post-operation complications. Predisposing factors that affect the compliance of pelvic belt application should include these three categories. Pressure is defined as force per unit area and is the major cause of ulcers occurring over bony prominences. Patients were required to wear the belt with “sufficient” force to stabilise their pelvic position. The degree of applied force is very subjective. Excessive force may result in excessive pressure on the skin, which may cause ischemia leading to pain, breakdown, and/or frank ulceration. Insufficient force may lead to ineffective stabilisation (Woodard et al., 2005). In this present study, patients were taught to wear the belt over their inner clothing to avoid direct skin contact, which may result in skin allergy or friction over the prominent bones. However, three of six patients commented that sweating may affect their will to engage to this intervention if the study was carried out in summer. These possible complications did not occur in this study, but need to be considered in future studies and clinical practice. The regular checking of skin condition must be involved in clinical practice once the intervention of the pelvic belt is applied.

## 10.7. Discussion on Limitations of the Study

The limitations of the study could be divided into equipment and the individual differences between patients.

### *10.7.1. RUSI*

The limitation of holding the ultrasound transducer manually would have potentially involved changes in its angle relative to the muscle, but obviously not sufficiently enough to produce poor reliability on repeated testing. Despite the greater degree of error in measuring scans obtained during muscle contraction than at rest, the findings showed that ultrasound imaging has sufficient reproducibility for examining the lateral abdominal muscles during the ASLR test. However, the results for inter-recti distance (IRD) were not all reliable enough for routine use.

A limitation in the present protocol was to carrying out the unilateral left leg raise on one side only, so we could not determine whether the abdominal muscles of dominant and non-dominant sides display different muscle activation strategies. Also, the correlation between the pelvic positions and morphological changes on abdominal muscles is also not clear. During the study, we found that many asymptomatic people showed asymmetry of pelvic positions or the pelvis is not in the neutral position. The muscle characteristics could change progressively following the duration of asymmetric body alignment or pain could inhibit the function of muscles. However, the whole picture of the correlations between these different factors cannot be obtained from this preliminary study.

The RUSI technique has been shown in several studies to be a highly valid (Hodges et al., 2003, Richardson et al., 2004b, McMeeken et al., 2004, Hides et al., 2006, Kiesel et al., 2007) and reliable (Hides et al., 1992, Coldron et al., 2003, Teyhen et al., 2005, Rankin et al., 2006, Van et al., 2006b, Coldron et al., 2007, Teyhen et al., 2007, Whittaker, 2007, Stokes et al., 2007, Costa et al., 2009b, Costa et al., 2009a) technique to use clinically, and showed differences between normal and abnormal groups. However, the sensitivity of the technique is still questioned, as to whether this is good enough to enable RUSI to be used as a valid outcome measure over time. Whether the intervention with the pelvic belt was long enough to produce detectable changes in muscle characteristics is unknown. In the present study, ultrasound data were not collected simultaneously with EMG due to the limitation of facilities and resources. Simultaneous recordings of RUSI and EMG would allow the relationships between muscle morphology and motor control to be examined more thoroughly.

### *10.7.2. Motion capture system (VICON)*

Low between-days reliability of this technique was found which is consistent with existing studies using similar motion capture systems (Kadaba et al., 1989, Kadaba et al., 1990, Steinwender et al., 2000). The lower ICCs were reported in patients than in controls.

The possible factors that could affect the accuracy of changes in angle include:
(1) The skills of the investigator to reposition the skin markers on different days
(2) The influence of skin motion
(3) Higher BMI
(4) The oscillation of wands (Schache et al., 2002b)
(5) The severity of symptoms
(6) Individual lumbar curvature
(7) The influence of participants' clothes
(8) Different movement strategies.

Also, the individual lumbar curvature or a very large lordosis may make the lumbar markers invisible, in particular during data collection in patients. The main purpose of the motion analysis technique applied in this study was to detect the difference in angle changes during the task. However, the angle changes were very small and could not provide conclusive findings. The chosen task may not really represent the response of muscles in the lumbo-pelvic region or the performance, so other tasks could be explored in further studies.

### *10.7.3. EMG*

As for EMG data, some of the data in Taiwan was found to be too noisy to be used for the investigations of neuromuscular performance, in particular of the back muscles. Once the participants carried out the tasks, the electrodes over bilateral EO muscles and back muscles were displaced by the skin motions and could not detect the signals properly. The EO muscles were difficult to be detected in participants with a high BMI due to the layer of fat restricting the signal, although EO muscles are more superficial than others. The data collection of multifidus was affected by the lumbar curvature. During the functional tasks, the degree of angle changes in the lumbar area can affect the attachment of electrodes and lead to poor signals. Therefore, the data from these muscles were not used and only the data from IO muscles were analysed. Due to missing data, the between-days reliability in the patient group could not be carried out. Problems within the technique could not be reported due to limited facilities, but could be solved by using different equipment in the future.

For the issues about the application of EMG on multifidus and abdominal muscles, the types of electrodes should be considered. In the main study, only re-useable electrodes were available. However, the re-useable electrodes were affected by the skin motions during the task. Disposable electrodes and a linear electrode for the back muscles could be a way to solve this problem. Otherwise, needle EMG for detecting the deep muscle could be considered in the future. Due to the limitation of facilities, ultrasound cannot be captured simultaneously with EMG but this could be used in the future.

#### *10.7.4. Individual difference in participants*

The age ranges of controls and patients were different for the reliability studies due to the limitation of recruitment of participants for the pilot study in Southampton, which involved young female Taiwanese students who stayed only one year. However, the age range for recruitment of patients was wider (aged 20 - 65 years) than the controls (aged 20 - 35 years). The level of muscle contraction during the same tasks may be altered in different age groups, and it could affect the stability of the technique. Older controls were therefore then recruited in Taiwan for the main study.

Muscle morphology and motor control will be influenced by the pain course, which varied in the patients, with some only being symptomatic for three months and others for as long as over 10 years. The heterogeneity of the group in terms of duration of symptoms, as well as the small numbers, do not make conclusions regarding motor control ability in the patient group possible but the present findings provide directions for further studies. Although standardising the instructions to patients to achieve low force TrA contractions appears to produce reliable contractions, further research is needed to compare the reliability of methods of instruction to obtain low levels of effort.

In Chapter 6, the patient group was not age-matched with the control group in this particular study, due to the restricted availability of participants at the time of the study. The control group was recruited from Taiwanese students in Southampton. Despite the age range for inclusion in the study being wide enough to match that typical of patients with coccydynia, the student participants were relatively young. When it came to recruiting patients with coccydynia in Taichung, Taiwan, they were generally older than the previously studied controls. At that stage, it was assumed that age would not have a major influence on TrA thickness, given the evidence from previous studies in the Western literature (Rankin et al, 2005). The older controls in Taiwan who only performed 20% MVE for the purposes of addressing a research question outside of the main present study, also showed larger muscles than the younger controls but these results were not known at the time of this study. The findings need to be examined in an age-matched control group.

The majority of patients with coccydynia showed one side to be more affected than the other but most studies only explore one side (such as dominant or non-dominant side). Many patients demonstrated some co-existing dysfunction such as sacroiliac joint dysfunction (SI dysfunction), clicking hip and the diagrams of pain were not consistent in all patients. However, the sample size was not large enough to look at sub-groups for comparison. The evaluation of pelvic outlet was not detailed enough to be sub-classified for further comparison within individuals and groups. The evaluations should be more specific and more quantitative. The pain course may affect muscle activation patterns, muscle performance or muscle morphology. However, again, the sample size was too small to sub-classify participants. As for the case studies, although patients reported improvement in symptoms, the objective assessments were unchanged. Also, this study was not designed with any placebo or intervention controls and therefore cannot really estimate the effectiveness.

As mentioned above, the pilot study in Southampton only included young participants, so cannot represent the whole Taiwanese female population across ages. As for the reliability study, the participants were requested to come twice within one week for both RUSI and motion analysis. Some healthy participants did not come to the 2nd session due to the long duration of trials. The reliability study on patients was in the same situation. Some patients denied attending the 2nd trial due to the boredom of repeated trails or varied symptoms limiting their will to attend within 10 days. Some patients preferred to accept treatments rather than wasting their time on the trails. Patients who were willing to be in reliability study were enthusiastic about the project due to suffering from the problem for many years. In the present study, the acceptance of RUSI appeared to be greater than the other two techniques (motion analysis and EMG).

#### *10.7.5. Unanswered questions*

There are several unanswered questions that have arisen from the present study:

1. Correlations between coccydynia and the physical factors studied could not be established due to the limitation of sample size.
2. The muscle activation patterns and compensatory strategies for muscle activation are not yet clear.
3. The effects of level and duration of pain intensity on muscle morphology are still

unknown. Few studies focus on this aspect, even in low back pain.

4. The influence of vibration on the ligaments and surrounding soft tissues around the coccyx is unknown. One of the most common modes of transport in Taiwan is the motor scooter but the influences of frequency and intensity of vibration on the human body from the scooter are unknown. Doppler ultrasound may be useful for detecting the changes on the soft tissues and may be worthwhile to use in a future study.
5. An epidemiology study will be needed to clarify this gap between clinical findings and the true population
6. Although the role of pelvic floor muscles is discussed in the maintenance of spinal stability, it was not evaluated in the present study. The objective assessments for the function of pelvic floor muscles and pelvic outlet need to be developed in the future. Although the position of the coccyx is hypothesised to be relevant to the function of PFMs, a quantitative method is still lacking.

**10.8. Contributions of the present study to knowledge**

The contribution of the present study to knowledge includes providing information on:

10.8.1. Normal reference data of muscle morphology in Taiwanese women

10.8.2. Changes in muscle thickness on RUSI during the active straight leg raise appear to be influenced by age, as changes were greater in the older than younger healthy participants. This difference in contractile ability may be due to muscle weakness or altered motor control with age. Alternatively, the difference could be explained by greater BMI in the older participants, which may require stronger contractions to achieve the task.

10.8.3. Symptoms of pain in coccydynia have been shown to be associated with changes in muscle morphology, motor control and biomechanical changes in the lumbopelvic region, providing objective evidence of similarity with the changes documented in the literature for patients with low back pain.

10.8.4. RUSI was shown to be an appropriate technique to investigate difference in abdominal muscle morphology between patients with coccydynia and healthy controls

10.8.5. Reliability of inter-recti distance measurement on RUSI at rest and during contractions in patients with coccydynia and healthy participants

10.8.6. Use of the pelvic belt was found to be a potentially effective intervention for reducing symptoms in coccydynia

## Chapter 11: Conclusions and future plan

This study provides a model for future investigators who examine a musculoskeletal disorder in the lumbopelvic region, and supplies information concerning altered motor control. However, unanswered questions remain and the subject requires further exploration in the future.

### 11.1 Conclusions

In our findings, the reliability of RUSI, both at rest and during an active straight leg raise (ASLR), was established in the pilot work in Southampton (ICC>0.7). Poor reliability was evident in patients in the study in Taiwan; in particular involving the TrA muscle at rest, suggesting that inconsistent morphological performance exists, perhaps due to pain inhibition. In the healthy groups, older participants demonstrated greater thickness changes whilst performing the ASLR, in comparison with younger participants. The findings indicate that age could have impacted on muscle recruitment of TrA. In the results of the level of contraction study, 20% maximal effort was found to be the most stable task, in comparison with maximal effort. This could provide a way of standardising the influence of abdominal muscle contractions following oral instruction in clinical practice.

From the motion analysis findings on the angle changes of lumbar and pelvic positions during the one leg standing task, the angle changes were lower in patients than in controls. It could be concluded that most of the patients with coccydynia demonstrated rigid strategies to perform the task. Several strategies employed to help maintain balance during one leg standing have been observed. If the degree of the lumbar angle decreases, the mobility of pelvis is increased. There were some significant physiological findings in the abdominal muscles in this study. Delayed internal oblique (IO) firing during one leg standing was found in patients and senior participants, in comparison with the younger healthy participants. It has therefore been demonstrated that patients with coccyx pain display alteration in motor control in the lumbo-pelvic region, similar to other dysfunctions, such as low back pain. Due to the small subject population, we cannot answer all our questions but we may deduce from our findings that coccyx pain is associated with biomechanical and neuromuscular dysfunction and that this research warrants further study.

Considering the deficiency of spinal stability in patients with coccydynia, the application of a pelvic belt was regarded as a means to provide an external support in the lumbopelvic region. In the six case studies, the three investigative techniques (rehabilitative ultrasound imaging, RUSI; motion analysis and electromyography) and pain assessment were used to evaluate the changes between pre- intervention and post- intervention following 6-weeks of pelvic belt application. As for subjective assessment, the symptoms of pain and discomfort were relieved but not cured, and tolerance during sitting and standing were increased. However, the three objective assessments did not demonstrate any differences. This could be due to the sensitivity of the applied technique being insufficiently receptive to detect the finer changes, or due to relatively short time period of the study, which may have been insufficient for changes to occur.

In conclusion, patients with coccydynia definitely demonstrated alterations of neuromuscular and biomechanical function, whether on RUSI, EMG or motion analysis. However, the chosen tasks cannot guarantee the same changes to be present in different tasks.

## 11.2 Future studies

### *11.2.1. Ultrasound and EMG application*

Ultrasound and EMG could be used to detect the muscle thickness and muscle firing of abdominal muscles simultaneously during a task, and could provide more meaningful information during dynamic functions. EMG could be used as a tool for providing visual or audio feedback, and RUSI could provide visual feedback, in order to give participants a hint of the desired efforts, and could be applied in a training protocol for exercise interventions.

In the study of level of contraction, the drawing-in manoeuvre was used as a task. The reproducibility of 20% maximal effort in healthy young participants was better than in patients. According to the percentage of thickness changes, patients tended to show less change in comparison with the healthy participants. However, the age disparity between the two groups could have influenced the muscle recruitment pattern. The limitation of this part of the experiment was the absence of older controls. In future studies, EMG could be integrated into the protocol to provide more information on muscle activation and a more direct comparison is needed between age-matched groups.

Although the differences in muscles morphometry at rest and during the functional task of ASLR in patients with coccydynia and healthy controls were found, the physiological findings from EMG are limited due to the use of surface electrodes. The activation patterns of muscles in the lumbopelvic region cannot be said conclusively to demonstrate the same changes as other dysfunctions, such as low back pain. A more detailed experimental protocol using indwelling electrodes is needed to be carried out to provide an overview of this dysfunction in different age groups.

The majority of existing studies about RUSI are from Western society and populations of mixed genders, so cannot be used as a reference for Asian studies. In particular, the studies relevant to the validity of EMG and RUSI are mainly from healthy young students in Australia with high physical activity levels, so the results of muscle recruitment could display more muscle thickness changes than a general population with less physical activity. Whether the RUSI technique has enough sensitivity to be used as an outcome measure has yet to be proven.

Due to the restriction of equipment, reusable electrodes were applied in this study. During dynamic functional tasks, the contact surface may undergo movement and affect the results. Taking financial considerations into account, disposable electrodes were the best option available. The equipment could be improved and advanced to provide stronger evidence for future practice changes.

### *11.2.2 Further studies on Coccydynia: Epidemiology, progression of symptoms and possible intervention skills*

#### *11.2.2.i Epidemiology*

Although coccydynia is, as Chapter 1 stated, a common dysfunction in women, the understanding of this dysfunction is still limited and can only provide a small piece of the whole picture. Possible factors contributing to this dysfunction and the correlation with other disorders need to be explored in the future. Scoliosis could be a contributor to sacroiliac dysfunction but the relationship with coccydynia is unknown. Another possible causative factor is vibration from modes of transport. Vibration has been proven to lead to lumbar degeneration or herniation and it could impact the coccyx as well, due to the direct contact with a surface. Different frequencies of vibration could be harmful to body organs, and could affect the ligaments and muscles which provide stabilisation for the torso. Therefore, the prevalence of coccydynia in Taiwan could be directly related to the country's most popular means of daily transportation, the motor scooter. An increasing number of scooters could contribute to the pervasiveness lower back disorders. An epidemiological study of coccydynia in Taiwanese women is projected to gain more information regarding the exact rate of occurrence of this condition.

*11.2.2.ii Progression of symptoms*

Coccydynia is diagnosed as pain in and around the coccyx but how the symptoms change over time is unknown. It is impossible to only focus on coccydynia, without taking into account the neuromuscular changes in the entire lumbopelvic region. Coccydynia is a type of low back pain but could demonstrate different muscle activation strategies at different stages in the symptom progression. Actually, in our study patients with coccydynia reported a succession of symptoms that differed between subjects and symptoms seemed to be very variable and unpredictable due to various contributing factors. Some people had problems coexisting with unilateral sacroiliac joint (SIJ) dysfunction and some did not. Generally, patients tended to present one side with severe symptoms or more changes on one side than the other, which was evident from the appearance of the gluteal muscles, i.e. level of the gluteal fold.

If patients only have central coccyx pain in the initial stage, why do they still demonstrate an asymmetrical line of the gluteal muscles? Perhaps the dominant and non-dominant sides could explain this. In the course of our observations, we noticed that the progression of symptoms tended to start from the coccyx and then extend to SI pain or the sacral area. Patients with symptoms over a period of years often reported the existence of diffuse pain in the lower back pain. This sort of sequence could be the most predominant type of pain progression. The impact of pain duration on muscle morphology and physiological performance is still unknown due to the wide range of pain courses in the present study. Postpartum women were considered to be a high risk population, and their symptoms were highly correlated with hypermobility of the coccyx. However, information on idiopathic patients is limited. In future, an observational study of coccydynia according to different pain courses could be planned, and these would be studied to obtain further information on the mechanisms involved in the development of coccydynia.

*11.2.2.iii Possible intervention: pelvic belt*

The pelvic belt is intended to provide an external compression force to increase the stability of the pelvis and was found to relieve the symptoms of pain in the coccyx. In the case studies (Chapter 9), all patients showed reduced severity of pain, higher tolerance of sitting and standing, and a slight decrease in pain on functional activity. However, whether the improvements were purely from the pelvic belt or from another intervention is not known. The patients may have continued to accept other medications, physiotherapy or Traditional Chinese Medicine to relieve their pain whilst they were wearing the belt. A more controlled study is needed in order to further assess the effectiveness of the pelvic belt and establish precisely what the period of intervention should be. Additionally, we need to further investigate how the pelvic belt works in a different direction to the compression force on muscles in the lumbopelvic region. Due to these considerations, perhaps a pelvic belt could be used more as an assistive tool during exercise interventions, rather than simply wearing one for a prolonged period and then reviewing the effects. It is very difficult to maintain pelvic positions after manipulation, so the application of a pelvic belt immediately post-manipulation is helpful for patients, as it better enables them to sense the contraction of muscles (biceps femoris/ gluteal maximus) ,which can provide dynamic stability resulting from the recruitment of all muscles and ligaments in order to steady the weakened area. This clinical observation needs to be demonstrated by evidence from a suitably designed study.

### *11.2.3. More quantitative evaluation of pelvic position*

In this PhD study, a challenge was faced involving the validity and reliability of pelvic position determination. Following the alignment theory, the pelvic position could be linked to altered alignment of the lower extremities and vice versa. The observation of alignment is a very clinical and highly reliant upon the investigator's experience. Discerning how to improve or prove the accuracy of assessment of pelvic positions, both at rest and during dynamic tasks, could allow clinicians to provide more relevant information in clinical practice and studies.

### *11.2.4. Function of pelvic floor muscles in coccydynia*

A proportion of the patients demonstrated symptoms of incontinence: both urgent and stress related. This raises questions as to whether the intervention of the pelvic floor muscles could help to improve such symptoms. Another issue concerns how to make the outcome measurement as a reliable and valid as possible. RUSI seems to be a potential method with which we might provide a non-invasive means to indirectly observe the function of pelvic floor muscles through the bladder shape; however the validity of RUSI regarding bladder shape and pelvic floor muscles is unconfirmed. The bladder is an organ consisting entirely of soft tissues, so a bony landmark is not available as a reference point in trans-abdominal ultrasound imaging. The way in which we approached the assessment relied upon inspecting whether or not PFMs contract correctly. How to improve the assessment of function of the pelvic floor muscles in a more reliable way is always a challenge.

This study presented a dysfunction model in the lumbopelvic region and a similar protocol could be applied to other disorders. The lumbopelvic region is always a weak point in women and could lead to many dysfunctions. Women's health physiotherapy is a very specifically field and needs to be distinguished from general orthopaedic problems.

### 11.3. Possible implications for clinical practice

- Physical examination of coccydynia should include the low back, sacroiliac joint and bladder function. The assessment of posture and gait is necessary to provide the information about compensative strategies being used by an individual.
- The alignment of the pelvic belt is difficult to manage. The pelvic belt is potentially useful as an assistive intervention tool in the lumbopelvic region to enhance or extend the effectiveness of manual therapy.

### 11.4. Implications for future research

- In future studies, ultrasound imaging and EMG could be use synchronously to examine neuromuscular function under specific conditions.
- Controlled studies with and without the pelvic belt need to further explore the function of the pelvic belt in lumbopelvic region dysfunction.
- The relationship between coccydynia and incontinence needs to be explored in future studies.
- The non-invasive technique of ultrasound imaging needs to be developed and is a potentially useful biofeedback tool for lumbopelvic muscle training.
- An epidemiological study of coccydynia in Taiwanese women is projected to gain more information regarding the causes and rates of occurrence of this disorder.

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## Appendix 13.1. Full approval from the Ethics Committee

**13.1.1 Full approval from the Ethics Committee in University of Southampton**

**13.1.2. The approval for the additional pilot study in Taiwan from the Ethics Committee in University of Southampton**

**13.1.3 The full approval for the pilot study in Taiwan from Institution Review Board from the China Medical University Hospital, Taichung, Taiwan**

**13.1.4. The approval for the amended inter-rater reliability analysis**

**13.1.5. The approval for another pilot study of different level contraction of abdominal muscles in Southampton**

**13.1.6. The report for the enhanced peer review from University of Southampton for the main study in Taiwan**

**13.1.7. The full approval for the main study from Institution Review Board from the China Medical University Hospital, Taichung, Taiwan**

### 13.1.1 Full approval from the Ethics Committee in University of Southampton

University of Southampton

**School of Health Professions and Rehabilitation Sciences**

Dr Paula Kersten, Head of School

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18 January 2008

San-Pei Chen
School of Health Professions and Rehabilitation Sciences
University of Southampton

Dear San-Pei

**Submission No: PO7/12-01**
**Title: Pilot study of normal lumbo-pelvic muscles**

I am pleased to confirm **full approval** for your study has now been given. The approval has been granted by the School of Health Professions and Rehabilitation Sciences Ethics Committee.

You are required to complete a University Insurance and Research Governance Research Governance Application Form (IRGA) in order to receive insurance clearance before you begin data collection. The blank form can be found via www.blackboard.ac.uk and the MSc H&R Dissertation; MSc Physiotherapy (Pre-reg) Critical Enquiry; or Health Doctorates-Research Governance courses respectively.

You need to submit the following documentation in a plastic wallet to Dr Martina Prude in the Research Governance Office (RGO, University of Southampton, Highfield Campus, Bldg. 37, Southampton SO17 1BJ):

- Completed IRGA Research Governance form (**signed by both student and supervisor**)
- Copy of your research protocol/School Ethics Form (final and approved version)
- Copy of participant information sheet
- Copy of SoHPRS Risk Assessment form, **signed by yourself and supervisor** (original should be with Zena Galbraith)
- Copy of your information sheet and consent form
- Copy of this SoHPRS Ethical approval letter

Your project will be registered at the RGO, and then automatically transferred to the Finance Department for insurance cover. **You can not commence data collection until you have received a letter stating that you have received insurance clearance.**

**Please note that you have ethics approval only for the project described in your submission. If you want to change any aspect of your project (e.g., recruitment or data collection) you must discuss this with your supervisor and you will need to request permission from the Ethics Committee and RGO.**

Yours sincerely

Dr Jo Adams
Acting Chair, SHPRS Ethics Committee

Occupational Therapy Physiotherapy Podiatry
in a research led interdisciplinary environment

### 13.1.2. The approval for the additional pilot study in Taiwan from the Ethics Committee in University of Southampton

UNIVERSITY OF
Southampton
School of Health Professions
and Rehabilitation Sciences

San-Pei Chen
School of Health Professions & Rehabilitation sciences
University of Southampton

8th February 2008

Dear San-Pei

Ethics Submission No: *P07/12-01*
Title: Pilot Study of normal lumbo-pelvic muscles

Thank you for your letter dated 7th February 2008 requesting amendment to your previously fully approved study.

The School of Health Professions and Rehabilitation Sciences Ethics Committee has approved your amendment regarding:

- To carry out a pilot study in Taiwan

Please note that you will have to apply for insurance separately.

Yours sincerely

Maggie Donovan-Hall
Chair, SoHPRS Ethics Committee

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Tel: +44 (0)23 8059 2142 Fax: +44 (0)23 8059 5301 www.sohp.soton.ac.uk

**13.1.3 The full approval for the pilot study in Taiwan from Institution Review Board from the China Medical University Hospital, Taichung, Taiwan**

中國醫藥大學附設醫院
CHINA MEDICAL UNIVERSITY HOSPITAL
台灣省台中市北區育德路 2 號
No.2 Yuh Der Road Taichung Taiwan R.O.C.
TEL:(04)22052121

**The Institutional Review Board**
**China Medical University Hospital, Taichung, Taiwan**

Tel: 886-4-22052121 ext: 4132 Fax: 886-4-2207-1478

Date：Apr. 15, 2008

To：Li-Wei Chou , Attending Physician of Rehabilitation,
China Medical University Hospital

From：Martin M-T Fuh MD,DMSci.
Chairman, Institutional Review Board

Subject：Pilot study of normal subjects to examine the reliability of applied techniques on lumbopelvic muscle function.

The Institutional Review Board has recommended the approval of the protocol number: DMR97-IRB-042; Informed Consent Form Version Date: Feb. 15, 2008, date Apr. 15, 2008, for the protocol identified above, for a period of 12 months, and has determined that human subjects will be at risk.

Approval of your research project is, therefore, granted until Apr. 14, 2009. You are reminded that a change in protocol in this project requires its resubmission to the Board. By the end of this period you may be asked to inform the Board on the status of your project. If this has not been completed, you may request renewed approval at that time.

Also, the principal investigator must report to the Chairman of the Institutional Review Board promptly, and in writing, any unanticipated problems involving risks to the subjects of others, such as adverse reactions to biological drugs, radio-isotopes or to medical devices.

CHINA MEDICAL UNIVERSITY HOSPITAL
The Institutional Review Board
NO.2 YUH-DER ROAD, TAICHUNG, TAIWAN, R.O.C.

Martin M-T Fuh MD,DMSci.
Chairman, Institutional Review Board
China Medical University Hospital

### 13.1.4. The approval for the amended inter-rater reliability analysis

UNIVERSITY OF Southampton
School of Health Sciences

San-Pei Chen
School of Health Sciences

25th November 2008

Dear San-Pei

**Ethics Submission No: P07/12-01**
**Title: Pilot study of normal lumbo-pelvic muscles**

Thank you for your letter dated 10th November 2008 requesting amendment to your previously fully approved study.

The School of Health Professions and Rehabilitation Sciences Ethics Committee has approved your amendment regarding the inclusion of second research (Martin Warner) to measure some of the data in order to carry inter-rater reliability analysis of the EMG signals. Please contact the insurance office to inform them of this amendment.

Yours sincerely

Maggie Donovan-Hall
Deputy Chair, School of Health Sciences Ethics Committee

Direct tel: +44 (0)23 8059 8880
Direct fax: +44 (0)23 8059 4792
email: mh699@soton.ac.uk

SoHPRS Ethics Decision Feedback version 01 Feb 2008

### 13.1.5. The approval for another pilot study of different level contraction of abdominal

UNIVERSITY OF Southampton
School of Health Sciences

E09/Jan 2009/ v1.0

San-Pei Chen
School of Health Sciences
Building 45
University of Southampton
Highfield
Southampton
SO18 1HG

19th January 2009

Dear San-Pei

**Ethics Submission No:P07/12-01**
**Title: Pilot study of normal lumbo-pelvic muscles**

Thank you for your letter requesting amendment to your previously fully approved study.

The School of Health Professions and Rehabilitation Sciences Ethics Committee has approved your amendment regarding:

- The inclusion of imagining 10 floors of a lift/elevator scale (this is an approach used in clinical practice which aims to standardize the present protocol).
- In order to test the reliability of achieving different levels of contraction at rest, 30%, 50% and 100% of maximum voluntary contraction, these new tests will be included in the current pilot tests.
- The recruitment of 20 new participants recruited in the same procedures as stated in the original ethics protocol.
- The use of the new participant information sheet.

Please contact the insurance office to ensure that they are aware of the changes.
Yours sincerely

Dr Maggie Donovan-Hall
Vice Chair, SoHS Ethics Committee

t: +44 (0)23 8059 8880
e: mh699@soton.ac.uk
f: +44 (0)23 8059 4792

Building 45
School of Health Sciences, University of Southampton, Highfield Campus, Southampton SO17 1BJ United Kingdom
Tel: +44 (0)23 8059 7979 Fax: +44 (0)23 8059 7900 www.southampton.ac.uk/healthsciences

### 13.1.6. The report for the enhanced peer review from University of Southampton for the main study in Taiwan

UNIVERSITY OF
Southampton
School of Health Sciences

1st May 2009

To whom it may concern:

**San-Pei Chen: Coccydynia in Taiwanese women**

The above study has been successfully peer reviewed by the School of Health Sciences, University of Southampton.

Yours sincerely

Susan Rogers
Head of Research and Enterprise Services
Direct tel: +44 (0)23 80597942
email: ssr@soton.ac.uk

UNIVERSITY OF SOUTHAMPTON · SCHOOL OF HEALTH SCIENCES

Please reply to:
**Building 67**
School of Health Sciences, University of Southampton, Boldrewood Campus, Southampton SO16 7PX United Kingdom
Tel: +44 (0)23 8059 8843 Fax: +44 (0)23 8059 8909 www.southampton.ac.uk/healthsciences

**13.1.7. The full approval for the main study from Institution Review Board from the China Medical University Hospital, Taichung, Taiwan**

中國醫藥大學附設醫院
CHINA MEDICAL UNIVERSITY HOSPITAL
台灣省台中市北區育德路 2 號
No.2 Yuh Der Road Taichung Taiwan R.O.C.
TEL:(04)22052121

# The Institutional Review Board
## China Medical University Hospital, Taichung, Taiwan

Tel: 886-4-22052121 ext: 1925 Fax: 886-4-2207-1478

**Expedited Approval** Date：Jul. 20, 2009

To：Li-Wei Chou , Attending Physician of Rehabilitation,
China Medical University Hospital

From：Martin M-T Fuh MD,DMSci.
Chairman, Institutional Review Board

The Institutional Review Board has recommended the approval of the following documents:

**Protocol Title**：Coccydynia in Taiwanese women：biomechanical and physiological study.

**CMUH IRB No.**：DMR98-IRB-137.

**Informed Consent Form**：Version Date: Jul. 01, 2009

Approval of your research project is, therefore, granted from Jul. 16, 2009 to Jul. 15, 2010, and has determined that human subjects will be at risk.

According to Taiwan government's regulations and ICH-GCP guidelines, by the end of this period you may be asked to inform the Board on the status of your project. If this has not been completed, you may request to send status of progress report two months before the final date for renewed approval.

You are reminded that a change in protocol in this project requires its resubmission to the Board. Also, the principal investigator must report to the Chairman of the Institutional Review Board promptly, and in writing, any unanticipated problems involving risks to the subjects of others, such as adverse reactions to biological drugs, radio-isotopes or to medical devices.

CHINA MEDICAL UNIVERSITY HOSPITAL
The Institutional Review Board
NO.2, YUH-DER ROAD, TAICHUNG, TAIWAN, R.O.C.

Martin M-T Fuh MD,DMSci.
Chairman, Institutional Review Board
China Medical University Hospital

## Appendix 13.2. Information sheets and consent forms

### 13.2.1. The information sheet for the pilot study in Southampton

**University of Southampton**
**School of Health Professions and Rehabilitation Sciences**

**PARTICIPANTS INFORMATION SHEET**

Title of Project: The reliability study of measurement techniques on healthy subjects

Dear fellow students:
You are being invited to take part in a research study. Before you decide it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part.
Thank you for reading this.

The aim of this study is to find out more information about coccydynia, also named as tailbone pain in Taiwanese women. At this stage, I need to examine the reliability of the required measurement techniques on ***healthy subjects***. What I need to do is to carry out three examinations: Rehabilitation ultrasound imaging (RUSI), surface electromyography (sEMG) and Motion analysis. All three examinations are non-invasive and won't cause any injuries. Please bring your comfortable clothing such as vests and shorts to attend this trial. You will be asked to just wear your underclothing. The whole process of the experiment will take for two hours with two separate sessions on the different days in the laboratory in Building 45 in the University of Southampton. The data will be anonymously recorded in the school compute and will only be used in this study.

You will be asked not drink alcohol 24 hours before the study and not do rigorous exercises 48 hours before the study to avoid any possible influences on the results. It is up to you to decide whether or not to take part. If you do decide to take part you will be given this information sheet to keep and be asked to sign a consent form. You will be free to withdraw at any time without giving a reason. A decision to withdraw at any time, or a decision not to take part, will not affect you in any way. The findings we get from this study will help us to examine the reliability of these three measurement techniques and can be used as the groundwork for the future clinical studies on patients. ***Should you wish to complain then the usual university complains mechanism will be open to you.*** During the study, if you have any problems or are unhappy with the procedures, please let me know or contact one of my supervisors (see below).

.

If you still have questions, please contact me without hesitation.

Ethic number: PO7/12-01

**SAN-PEI, CHEN**
MPhil/PhD student
School of Health Professions & Rehabilitation Science
University of Southampton
Office: 024727*25275
Mobile: 0777 158 2164
E-mail: sc3w07@soton.ac.uk

**Supervisors**
**Professor Maria Stokes**
E-mail: m.stokes@soton.ac.uk
**Dr. Paul Chappell**
E-mail: phc@ecs.soton.ac.uk
**Professor Robert Alan**
E-mail: ra@soton.ac.uk

### 13.2.2. The consent form for the pilot study in Southampton

**University of Southampton**
**School of Health Professions and Rehabilitation Sciences**

**PARTICIPANT CONSENT FORM**

Title of Project: The reliability study of measurement techniques on healthy subjects

I ______________________________________________ (full name in block capitals) have read the information sheet and agree to take part in this study. The investigator has explained to my satisfaction the purpose of the experiment and the possible risks involved. I understand that I am free to withdraw my consent and discontinue participation at any time without penalty or loss of benefits to myself. I understand that the data collected as part of this study will be treated confidentially, and that published results of this project will maintain my anonymity. In signing this consent form, I am not giving up my rights. A copy of this form has been offered to me.

I have reviewed and understand the Information for Research Participants Information Sheet and have asked any questions I may have to the researcher taking my consent:

**I give consent to participate in the above study: (please initial the box)**

☐ **YES**

☐ **NO**

I do not have: **(please initial the box)**

**1. Any history of neurological, neuromuscular, rheumatologic, dermatological or system diseases:**

☐ **YES**

☐ **NO**

**2. Any previous spinal surgery or previous spinal or pelvic fractures.**

☐ **YES**

**3. Current back pain.**

☐ **NO**

☐ **YES**

**4. Current pregnancy.**

☐ **NO**

☐ **YES**

☐ **NO**

**5. Any history of back pain or back injury.**

☐ **YES**

☐ **NO**

Signature ____________________
Date ________________________
Name of Researcher taking consent:
__________________________________________________

### 13.2.3. Questionnaire for back pain history

**Back pain history**

**(1) Activity Level**

1.1 Would you engage in regular exercise? If yes, Please answer the following questions.

___

1.2 What kinds of exercise you choose?

___

1.3 How frequency you do per week?

___

1.4 How long you do exercise per session?

___

**(2) Back pain history**

2.1 Do you have any history of back pain or back injury? If yes, please answer the following questions.

___

2.2 When did you suffer from back pain?

___

2.3 How long did it last for?

___

2.4 Did the history of back pain restrict function or caused you to have time off work?

___

2.5 Did you receive any treatments for the back problem?_

___

2.6 Did the back pain be recurrent within the recent one year?

**13.2.4. The information sheet and the consent form for the main study in Taiwan (Chinese version)**

<table>
<tr><td colspan="2">中國醫藥大學附設醫院受試者同意書</td></tr>
<tr><td colspan="2">試驗主題：台灣女性尾骨疼痛致病機轉之觀察型研究</td></tr>
<tr><td>執行單位：中國醫藥大學附設醫院復健部</td><td>電話：04-22052121 轉 2381</td></tr>
<tr><td>試驗主持人：周立偉（簽名　　　　）</td><td>職稱：醫師（助理教授）</td></tr>
<tr><td>協同主持人：張文正<br>吳鴻文<br>Maria Stokes</td><td>職稱：教授<br>助理教授<br>Professor</td></tr>
<tr><td>研究人員：陳珊貝</td><td>職稱：英國南安普頓大學博士生</td></tr>
<tr><td>緊急聯絡人：周立偉</td><td>二十四小時緊急聯絡電話:0966-202207</td></tr>
<tr><td colspan="2">受試者姓名：　　　　　　　　　病歷號碼：<br>性別：　　　　　　　　　　　　出生日期：<br>身分證字號：<br>聯絡電話：<br>通訊地址：</td></tr>
<tr><td colspan="2">法定代理人/有同意權人姓名：<br>與受試者關係：<br>性別：　　　　　　　　　　　　出生日期：<br>身分證字號：<br>連絡電話：<br>通訊地址：</td></tr>
<tr><td colspan="2">(一)試驗簡介：<br><br>本研究為『台灣女性尾骨疼痛致病機轉』之研究，目的為觀察尾骨疼痛之致病肌轉。實驗設計與流程源自於研究者目前所就讀的英國南安普頓大學。<br>研究者會以肌肉骨骼超音波測量您的腹部肌肉與背部肌肉的大小厚度，並由膀胱位置判斷骨盆底肌肉的張力。觀察並了解在日常生活中，由椅子上站起來並水平步行，直接連結腹橫肌的腹內斜肌、與背部肌肉動作形態。此外並觀察在單腳站立的測試中，這些肌肉的動作表現。該動作常用於臨床測試薦髂關節問題，以觀察薦骨與髂骨的相對動作。同時藉由動作分析，觀察日常生活中，坐到站並水平步行與兩邊單腳站立(one-leg standing)的動作。藉以得知腰部與骨盆區薦骨與髂骨的相對動作和腰椎活動度，在動力學與運動學中的關係。</td></tr>
</table>

# 中國醫藥大學附設醫院受試者同意書

(二) 試驗目的：

我們敬邀您參加一項在台灣有 47 位女性參加的 **關於腰部骨盆區的肌肉表現與動作評估**的研究計劃。本計畫是為了想要瞭解正常女性與患有尾骨疼痛患者，其腰椎骨盆區肌肉的型態特色與該區的關節活動情形，做為日後『女性尾骨疼痛』治療評估的參考。同時測試用於觀察的三種儀器，超音波、表面肌電圖與動作分析的可信度。本研究的評估工具皆為非侵入性的方式，並不會造成您任何傷害或不適。我們期待您的加入。

(三) 試驗之主要納入與排除條件：

**如果您是正常受測者:**

(1) 納入條件:沒有神經科、神經骨骼、風濕、皮膚、脊椎手術、脊椎變形與脊椎或骨盆區骨折病史、背痛病史和現有背痛、精神方面的問題、懷孕者，可納入該研究。雖曾有背痛病史，但超過一年以上未復發，且疼痛並未嚴重到造成日常生活功能受限或必須暫時離開工作者，可納入該研究。

(2) 排除條件: 有上述問題者或無法了解或完成整各實驗流程者，皆排除於該研究外。

**如果您是尾骨疼痛的患者:**

(1) 納入條件：

1.1 在尾骨周圍有疼痛，且並沒有明顯的下背痛或轉移痛。

1.2 疼痛表現局限於髂尾關節或是尾骨的活動分段區。

1.3 疼痛表現會在久坐或是會因為動作轉換時（在坐到站時）加劇。

1.4 疼痛症狀有持續或斷續超過兩各月

1.5 並沒有現行的抗憂鬱治療

1.6 了解為何參與該研究

(2) 排除條件：沒有神經科、神經骨骼、風濕、皮膚、脊椎手術、脊椎變形與脊椎或骨盆區骨折病史、背痛病史和現有背痛、精神方面的問題、懷孕者，可納入該研究。

(四) 試驗方法及相關檢驗：

在這項研究中, 需要使用到三種測量技術:腹部背部的肌肉超音波檢查、表面肌電圖和動作分析。這三種技術都是非侵入性的檢查，並不會造成任何傷害。請你帶著輕鬆的衣服，像是汗衫和短褲來參加這個測試。超音波研究方面約一小時，動作分析研究約兩各小時。分成兩個階段且在不同天進行。研究地點分別在中國醫藥大學附設醫院復健部的檢查室以及中國醫藥大學的運動力學實驗室進行。

在中國醫藥大學附設醫院復健部檢查室的實驗中，我們會先請您在進行測試前一小時，排空膀胱內尿液並在測試前喝下五百西西的開水。檢查時，會請您以兩個姿勢接受檢查:平躺與俯臥。在平躺情況下，我們會以超音波檢查測試您靜態與收縮狀態下膀胱的位置。之後，會請您排空尿液，再回來照排空後的靜態與收縮狀態下的膀胱位置。接下來會指導您如何作縮小腹的動作，要求您做出腹部最大收縮與兩分力收縮。經過適當練習後，會檢查您在休息、腹部最大收縮與兩分力收縮，三種不同狀態下，腹部外側肌肉的厚度變化。在適度休息後，會測量在靜態與收縮狀態下腹部外側肌肉與連結兩邊腹直肌的筋脈寬。接著會請您更換到俯臥姿勢，同樣以超音波檢查測試您靜態與收縮狀態下腰椎第四第五節多裂肌，與腰椎第五節薦椎第一節的多裂肌。每個部位均重複兩次。

# 中國醫藥大學附設醫院受試者同意書

在中國醫藥大學的運動力學實驗室的實驗中，我們會在您兩邊腹內斜肌、背部肌肉的運動點上貼上紀錄電極，以擷取您活動中肌肉的收縮狀態。同時會在您的身上貼上反光球，以便我們收集您靜止站立與靜止坐著的資料。實驗過程中，我們會請您做下列幾個動作：坐到站並水平行走（請您坐在沒有靠背的椅子，以不扶手把或椅面的方式站起來並以正常步行速度，在十公尺長的步道上行走）；右腳單腳站立同時左腳彎曲到腰的高度，維持五秒鐘再慢慢放下；左腳單腳站立同時右腳彎曲到腰的高度，維持五秒鐘再慢慢放下。

（五）可能產生之副作用、發生率及處理方法：

該研究過程並不會對身體造成傷害，可能發生的問題像是皮膚對表面電極貼片過敏貼片過敏或是患者出現疼痛情形，若發生該情形會立即中止測試給予治療。

（六）其他替代療法及說明：

本研究為檢驗測試工具並非治療，故無其他替代療法。

（七）試驗預期效益：

本研究所得到的發現，將會幫助我們了解尾骨疼痛之致病肌轉，並建立復健超音波之信度研究，可用於日後臨床研究的基礎。

（八）試驗進行中受試者之禁忌、限制與應配合之事項：

您在參與本實驗後，日常生活並不需要做任何改變，您可以從事您原先每日的正常作息活動，包括上班，運動，做家事等，同時，目前您所接受的任何藥物等治療也不需要中斷。請您在參與該研究前二十四小時內不要喝酒，四十八小時內不要參與劇烈的運動，以免對研究結果造成任何可能的影響。當您有任何不適的情況發生時，請告訴您的試驗主持醫師，醫師將給予您最妥善的治療及照顧。一旦您有任何緊急狀況或其他不尋常的身體狀況發生，請立即與您的醫師或護理工作人員聯繫。（0966-202207）

（九）機密性：

您在簽署本受試者同意書後，即同意您的原始醫療紀錄可直接受試驗主持醫師、人體試驗委員會及主管機關檢閱，以確保臨床試驗過程與數據符合相關法律及法規要求，同時您的實驗數據資料將會被帶至英國南安普頓大學實驗室分析，但是您的身分紀錄會受到嚴格的保密，且在相關法律及法規要求下將不公開。如果發表試驗結果，您的身分仍將保密，我們承諾絕不違反您身分之機密性。

（十）損害補償與保險：

1. 如依本研究所訂臨床試驗計畫，因發生不良反應造成損害，由本院負補償責任。但本受試者同意書上所記載之可預期不良反應，不予補償。
2. 如依本研究所訂臨床試驗計畫，因而發生不良反應或損害，本醫院願意提供專業醫療照顧及醫療諮詢。您不必負擔治療不良反應或損害之必要醫療費用。
3. 除前二項補償及醫療照顧外，本研究不提供其他形式之補償。若您不願意接受這樣的風險，請勿參加試驗。
4. 您不會因為簽署本同意書，而喪失在法律上的任何權利。

# 中國醫藥大學附設醫院受試者同意書

## （十一）受試者權利：

1. 試驗過程中，與您的健康或是疾病有關，可能影響您繼續接受臨床試驗意願的任何重大發現，都將即時提供給您。
2. 如果您在試驗過程中對試驗工作性質產生疑問，對身為患者之權利有意見或懷疑因參與研究而受害時，可與本院之人體試驗委員會聯絡請求諮詢，其電話號碼為：04-22062121轉4132。
3. 為進行試驗工作，您必須接受周立偉醫師的照顧。如果您現在或於試驗期間有任何問題或狀況，請不必客氣，可與在中國醫藥大學附設醫院復健部的周立偉醫師聯絡（24小時聯繫電話：0966-202207）。
4. 本同意書一式2份，醫師已將同意書副本交給您，並已完整說明本研究之性質與目的。醫師已回答您有關藥品與研究的問題。

## （十二）試驗之退出與中止：

您可自由決定是否參加本試驗；試驗過程中也可隨時撤銷同意，退出試驗，不需任何理由，且不會引起任何不愉快或影響其日後醫師對您的醫療照顧。試驗主持人或贊助廠商亦可能於必要時中止該試驗之進行。

## （十三）簽名：

主要主持人、或協同主持人已詳細解釋有關本研究計畫中上述研究方法的性質與目的，及可能產生的危險與利益。

1. 試驗主持人/協同主持人簽名：＿＿＿＿＿＿日期：□□□□年□□月□□日
2. 受試者已詳細瞭解上述研究方法及其所可能產生的危險與利益，有關本試驗計畫的疑問，業經試驗主持人詳細予以解釋。

   本人同意接受為臨床試驗計畫的自願受試者。

   受試者簽名：＿＿＿＿＿＿日期：□□□□年□□月□□日

   法定代理人簽名：＿＿＿＿＿＿日期：□□□□年□□月□□日

   有同意權人簽名：＿＿＿＿＿＿日期：□□□□年□□月□□日
3. 見證人姓名：（　　　　　　　　）

   與受試者關係:

   見證人簽名：＿＿＿＿＿＿日期：□□□□年□□月□□日

   身分證字號：□□□□□□□□□□ 聯絡電話：□□□□□□□□□□

   通訊地址：

### 13.2.5. Modified Version of the Oswestry Disability Questionnaire

**To be completed by patient**

Please answer every question by placing a mark on the line that best describes your current condition today.

**Pain Intensity**

______The pain is mild and comes and goes.
______The pain is mild and does not vary much.
______The pain is moderate and comes and goes.
______The pain is moderate and does not vary much.
______The pain is severe and comes and goes.
______The pain is severe and does not vary much.

**Personal Care (Washing, Dressing, etc.)**

______I do not have to change the way I wash and dress myself to avoid pain.
______I do not normally change the way I wash or dress myself even though it causes some pain.
______Washing and dressing increases my pain, but I can do it without changing my way of doing it.
______Washing and dressing increases my pain, and I find it necessary to change the way I do it.
______Because of my pain I am partially unable to wash and dress without help.
______Because of my pain I am completely unable to wash or dress without help.

**Lifting**

______I can lift heavy weights without increased pain.
______I can lift heavy weights but it causes increased pain
______Pain prevents me from lifting heavy weights off of the floor, but I can manage if they are conveniently positioned (ex. on a table, etc.).
______Pain prevents me from lifting heavy weights off of the floor, but I can manage light to medium weights if they are conveniently positioned.
______I can lift only very light weights.
______I can not lift or carry anything at all.

**Walking**

______I have no pain when walking.
______I have pain when walking, but I can still walk my required normal distances.
______Pain prevents me from walking long distances.
______Pain prevents me from walking intermediate distances.
______Pain prevents me from walking even short distances.

**Standing**

______I can stand as long as I want without increased pain.

______I can stand as long as I want but my pain increases with time.

______Pain prevents me from standing more than 1 hour.

______Pain prevents me from standing more than 1/2 hour.

______Pain prevents me from standing more than 10 minutes.

______I avoid standing because it increases my pain right away.

**Sleeping**

______I get no pain when I am in bed.

______I get pain in bed, but it does not prevent me from sleeping well.

______Because of my pain, my sleep is only 3/4 of my normal amount.

______Because of my pain, my sleep is only 1/2 of my normal amount.

______Because of my pain, my sleep is only 1/4 of my normal amount.

______Pain prevents me from sleeping at all.

**Social Life**

______My social life is normal and does not increase my pain.

______My social life is normal, but it increases my level of pain.

______Pain prevents me from participating in more energetic activities (ex. sports, dancing, etc.)

______Pain prevents me from going out very often.

______Pain has restricted my social life to my home.

______I have hardly any social life because of my pain.

**Traveling**

______I get no increased pain when traveling.

______I get some pain while traveling, but none of my usual forms of travel make it any worse.

______I get increased pain while traveling, but it does not cause me to seek alternative forms of travel.

______I get increased pain while traveling which causes me to seek alternative forms of travel.

______My pain restricts all forms of travel except that which is done while I am lying down.

______My pain restricts all forms of travel.

**Employment/Homemaking**

______My normal job/homemaking activities do not cause pain.

______My normal job/homemaking activities increase my pain, but I can still perform all that is required of me.

______I can perform most of my job/homemaking duties, but pain prevents me from performing more physically stressful activities (ex. lifting, vacuuming)

_____Pain prevents me from doing anything but light duties.

_____Pain prevents me from doing even light duties.

_____Pain prevents me from performing any job or homemaking chores.

13.2.6. Poster for participants' recruitment in Southampton (English & Chinese Version)

School of Health Professions
and Rehabilitation Sciences

A study on the working patterns of tummy and back muscles

## Taiwanese Ladies, We need your help!!

### Purpose of this study

This study will help us learn more about how the muscles work in normal daily life. Then the information can be used for patients with back pain.

### What the study involves:

This study will take two sessions on different days and will involve three techniques: (1) Ultrasound Imaging (2) Motion Analysis (3) electromyography (record electronic activity of the muscles). None of these procedures are painful or harmful to you.

This picture is **Ultrasound** which we will use to look at your muscles working.

If you are interested in taking part or would like further details. Please contact

***San-Pei Chen***

E-mail: sc3w07@soton.ac.uk; sanpeichen@hotmail.com

Phone: 02380594791 internal 29376 Ethics No. PO7/12-01

School of Health Professions
and Rehabilitation Sciences

腹部與背部肌肉在日常動作中的測量

台灣女性朋友，我們需要妳的幫忙

**研究目的：**

這各研究幫助我們知道腹部與背部肌肉在日常生活中如何運作。該研究的相關訊息日後可運用於下背痛的患者。

**研究包含：**

該研究主要分為兩個階段,並分為二天進行。每次約 60 分鐘，包含三種技術：(1) 超音波檢查 (2) 動作分析 (3) 肌電圖 (紀錄肌肉的變化)。三各測試流程都不會造成受測者的疼痛或任何傷害。

這張相片用來觀察肌肉活動情形的**超音波**。

如果你想參與該研究或是想知道更多訊息，請聯絡

陳珊貝
信箱: sc3w07@soton.ac.uk; sanpeichen@hotmail.com
電話: 02380594791 分機 29376

審核編號：PO7/12-01.

13.2.7. Poster for participants' recruitment in Taiwan (Chinese version)

中國醫藥大學 China Medical University　中國醫藥大學附設醫院 China Medical University Hospital　UNIVERSITY OF Southampton School of Health Sciences

腹部與背部肌肉在日常動作中的測量

## 女性朋友，我們需要妳的幫忙

**研究目的：**

這各研究幫助我們知道腹部與背部肌肉在日常生活中如何運作。該研究的相關訊息日後可運用於下背痛的患者。

**研究包含：**

該研究主要分為兩個階段,並分為二天進行。每次約 60 分鐘，包含三種技術：(1) 超音波檢查 (2) 動作分析 (3) 肌電圖 (紀錄肌肉的變化)。三各測試流程都不會造成受測者的疼痛或任何傷害。

這張相片用來觀察肌肉活動情形的**超音波**。

如果你想參與該研究或是想知道更多訊息，請聯絡
陳珊貝
信箱: sanpeichen@hotmail.com
電話: 04-22052121　分機 29376

## Appendix 13.3. The additional data in CH5

**1. Descriptive findings of the bilateral muscle thickness from transversus abdominis (TrA) muscle, external obliquus (EO) muscles and internal obliquus (IO), in states of rest and contraction during an active straight leg raise (ASLR). The measurement of inter-rectus distances (IRD) is also listed here.**

| Side-Status | Controls (N=16) | | Side-Status | Patients (N= 17) | |
|---|---|---|---|---|---|
| **Dom-Rest** | **Mean (mm)** | **SD (mm)** | **Sym-Rest** | **Mean (mm)** | **SD (mm)** |
| TrA | 2.1 | 0.7 | TrA | 2.29 | 0.4 |
| IO | 4.27 | 0.89 | IO | 6.5 | 1 |
| EO | 4.3 | 0.89 | EO | 4.39 | 1.13 |
| **Non-dom-Rest** | | | **Asym-Rest** | | |
| TrA | 2.13 | 0.63 | TrA | 2.49 | 0.65 |
| IO | 4.32 | 0.84 | IO | 6.56 | 1.4 |
| EO | 4.32 | 0.84 | EO | 4.35 | 1.17 |
| **Dom-ASLR** | | | **Sym-ASLR** | | |
| TrA | 2.09* | 0.65 | TrA | 3.28* | 1 |
| IO | 4.27 | 1.44 | IO | 7.4 | 1.2 |
| EO | 4.72 | 0.44 | EO | 4.9 | 1.14 |
| **Non-dom-ASLR** | | | **Asym-ASLR** | | |
| TrA | 2.22 | 0.56 | TrA | 3.28 | 0.91 |
| IO | 4.21 | 0.86 | IO | 7.7 | 1.94 |
| EO | 4.27 | 0.87 | EO | 5.08 | 1.47 |
| Rest-IRD | 13.21 | 5.08 | Rest-IRD | 23.64 | 10.26 |
| Contracted-IRD | 20.04 | 7.39 | Contracted-IRD | 19.83 | 8.19 |

*indicates significant difference.

2. Bland-Altman Plots for Between-scans and between-days in controls

- **Results of the Bland and Altman analyses in the bilateral abdominal muscles: mean difference ($\bar{d}$) and the 95% limits of agreement**

| **Between-scans measurement** | | | | | | |
|---|---|---|---|---|---|---|
| | **TrA** | | **EO** | | **IO** | |
| | $\bar{d}$ (cm) | 95% CI for | $\bar{d}$ (cm) | 95% CI for $\bar{d}$ | $\bar{d}$ (cm) | 95% CI for $\bar{d}$ |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | $\bar{d}$ | | | | |
| **1st /Rt /Rest** | 0 | 0.11 →-0.1 | -0.03 | 0.06 → -0.11 | 0 | 0.11 → -0.01 |
| **1st /Rt/ ASLR** | 0 | 0.11→-0.13 | -0.01 | 0.15 → -0.16 | 0.02 | 0.1 →-0.06 |
| **1st/Lt/Rest** | 0.03 | 0.15→-0.09 | -0.01 | 0.09 → -0.11 | 0.04 | 0.18→ -0.1 |
| **1st/Lt/ASLR** | 0 | -0.1→0.1 | 0 | 0.06→ -0.06 | 0.01 | 0.11→-0.09 |
| **2nd /Rt /Rest** | 0.01 | 0.08→-0.07 | 0.02 | 0.12→ -0.08 | 0.02 | 0.11 →-0.06 |
| **2nd /Rt/ ASLR** | -0.01 | 0.07→-0.08 | 0 | 0.14 → -0.13 | -0.02 | 0.1 → -0.14 |
| **2nd /Lt/Rest** | 0.01 | 0.08→-0.06 | 0 | 0.07 →-0.06 | -0.03 | 0.13→ -0.19 |
| **2nd /Lt/ASLR** | -0.01 | 0.07 → -0.1 | 0 | 0.06 →-0.06 | -0.02 | 0.15 → -0.18 |
| **Between-days measurement** | | | | | | |
| | **TrA** | | **EO** | | **IO** | |
| | $\bar{d}$ (cm) | 95% CI for $\bar{d}$ | $\bar{d}$ (cm) | 95% CI for $\bar{d}$ | $\bar{d}$ (cm) | 95% CI for $\bar{d}$ |
| **Rt/ Rest** | 0 | -0.09 →0.09 | 0.01 | 0.16→ -0.14 | 0.04 | 0.2 → -0.13 |
| **Rt/ASLR** | 0 | -0.1→ 0.1 | 0.02 | 0.26→-0.21 | 0 | 0.22→-0.22 |
| **Lt/Rest** | -0.02 | -0.14→ 0.1 | 0.02 | 0.16→ -0.12 | 0 | 0.11 → -0.12 |
| **Lt/ASLR** | -0.01 | -0.17→ 0.15 | 0 | 0.15 →-0.15 | 0.01 | 0.22 → -0.2 |

- **Results of the Bland and Altman analyses in inter-rectus distance (IRD), lumbar multifidus (LM) and sacral multifidus (SF): mean difference ($\bar{d}$) and the 95% limits of agreement**

| | **IRD** | | **LM** | | **SM** | |
|---|---|---|---|---|---|---|
| | $\bar{d}$ (cm) | 95% CI for $\bar{d}$ | $\bar{d}$ (cm) | 95% CI for $\bar{d}$ | $\bar{d}$ (cm) | 95% CI for $\bar{d}$ |
| **Rest 1st** | 0.01 | 0.15 → -0.13 | -0.04 | 0.19 →-0.28 | 0.07 | 0.32→ -0.17 |
| **Contraction 1st** | 0.03 | 0.24→-0.18 | 0.05 | 0.55 → -0.46 | -0.06 | 0.38 →-0.5 |
| **Rest 2nd** | 0.01 | 0.15 → -0.13 | -0.32 | -0.1 →-0.54 | 0.07 | 0.32→ -0.17 |
| **Contraction 2nd** | 0.03 | 0.24 → -0.18 | -0.01 | 0.27 → -0.28 | 0.02 | 0.21 → -0.18 |
| **Between-days measurement** | | | | | | |
| | **IRD** | | **LM** | | **SM** | |
| | $\bar{d}$ (cm) | 95% CI for $\bar{d}$ | $\bar{d}$ (cm) | 95% CI for $\bar{d}$ | $\bar{d}$ (cm) | 95% CI for $\bar{d}$ |
| **Rest** | -0.15 | 0.56 → -0.87 | -0.07 | 0.48 → -0.63 | 0.09 | 0.36→ -0.18 |
| **Contraction** | 1.17 | 2.66→ -0.31 | 0.02 | 0.65→ -0.62 | 0.06 | 0.5 → -0.37 |

$\bar{d}$ is the mean difference between measurements of muscle thickness; 95% CI is the confidence intervals for the mean difference; 1st and 2nd = mean of scans on the first and second days respectively

## 3. Bland-Altman Plots for Between-scans and between-days in patients

- **Results of the Bland and Altman analyses in the bilateral abdominal muscles: mean** difference ( $\bar{d}$ ) and the 95% limits of agreement

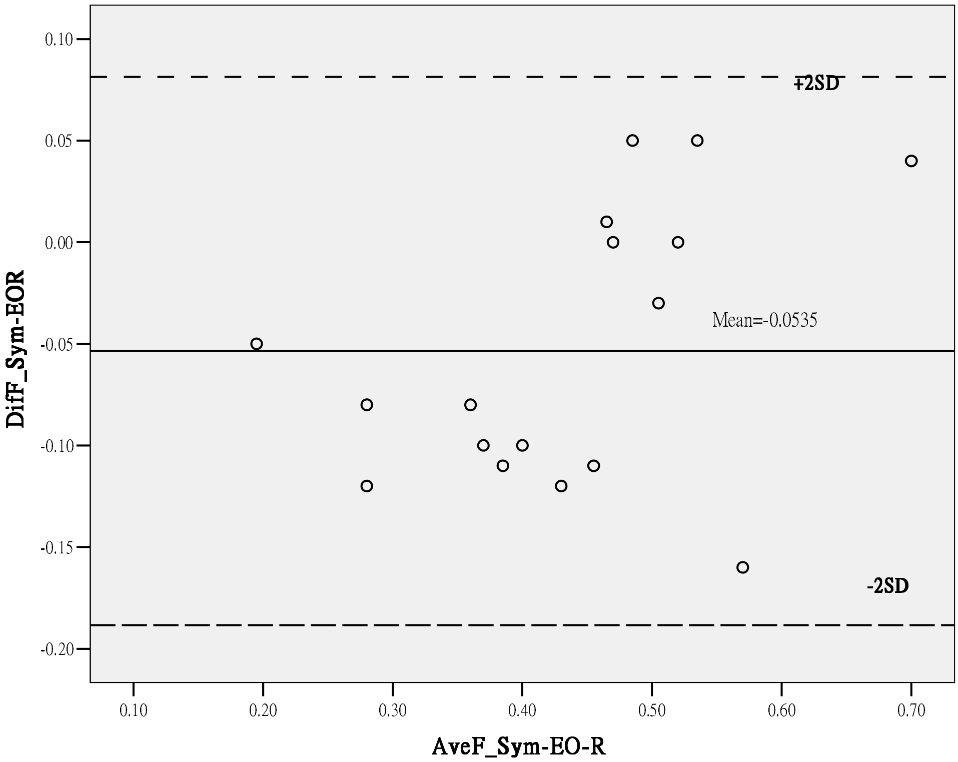
| **Between-scans measurement** | | | | | | |
|---|---|---|---|---|---|---|
| | **TrA** | | **EO** | | **IO** | |
| | $\bar{d}$ (cm) | 95% CI for $\bar{d}$ | $\bar{d}$ (cm) | 95% CI for $\bar{d}$ | $\bar{d}$ (cm) | 95% CI for $\bar{d}$ |
| **1st /Sym /Rest** | 0.00 | 0.06→-0.05 | -0.05 | 0.08 →-0.19 | 0.03 | 0.13 →-0.08 |
| **1st /Sym/ ASLR** | 0.04 | 0.17→-0.09 | 0.02 | 0.21→-0.17 | -0.01 | 0.18 →-0.2 |
| **1st/Asy/Rest** | 0 | 0.1→-0.01 | -0.04 | 0.08 → -0.16 | 0.01 | 0.1→-0.08 |
| **1st/Asy/ASLR** | 0.02 | 0.19 →-0.14 | 0.01 | 0.14→ -0.12 | 0.03 | 0.19→-0.14 |
| **2nd /Sym /Rest** | -0.01 | 0.05→-0.06 | 0.01 | 0.06→-0.05 | 0.01 | 0.06→-0.04 |
| **2nd /Sym/ ASLR** | 0.01 | 0.09→-0.07 | 0.05 | 0.22→-0.12 | -0.01 | 0.17→-0.19 |
| **2nd /Asy/Rest** | 0.01 | 0.06→-0.04 | 0 | 0.08→-0.07 | 0 | 0.06→-0.06 |
| **2nd /Asy/ASLR** | 0.01 | 0.14→ -0.11 | -0.02 | 0.13→-0.17 | 0.02 | 0.16→-0.11 |
| **Between-days measurement** | | | | | | |
| | **TrA** | | **EO** | | **IO** | |
| | $\bar{d}$ (cm) | 95% CI for $\bar{d}$ | $\bar{d}$ (cm) | 95% CI for $\bar{d}$ | $\bar{d}$ (cm) | 95% CI for $\bar{d}$ |
| **Sym/ Rest** | -0.01 | 0.13 →-0.14 | -0.01 | 0.16→-0.17 | 0.06 | 0.3 →-0.18 |
| **Sym/ASLR** | 0.02 | 0.23→-0.2 | 0.02 | 0.16→-0.12 | -0.02 | 0.24→-0.27 |
| **Asy/Rest** | 0.01 | 0.16→-0.15 | -0.03 | 0.11→ 0.2 | 0.05 | 0.3 →-0.21 |
| **Asy/ASLR** | -0.02 | 0.15→-0.18 | -0.1 | 0.36→-0.38 | 0.03 | 0.31 →-0.25 |

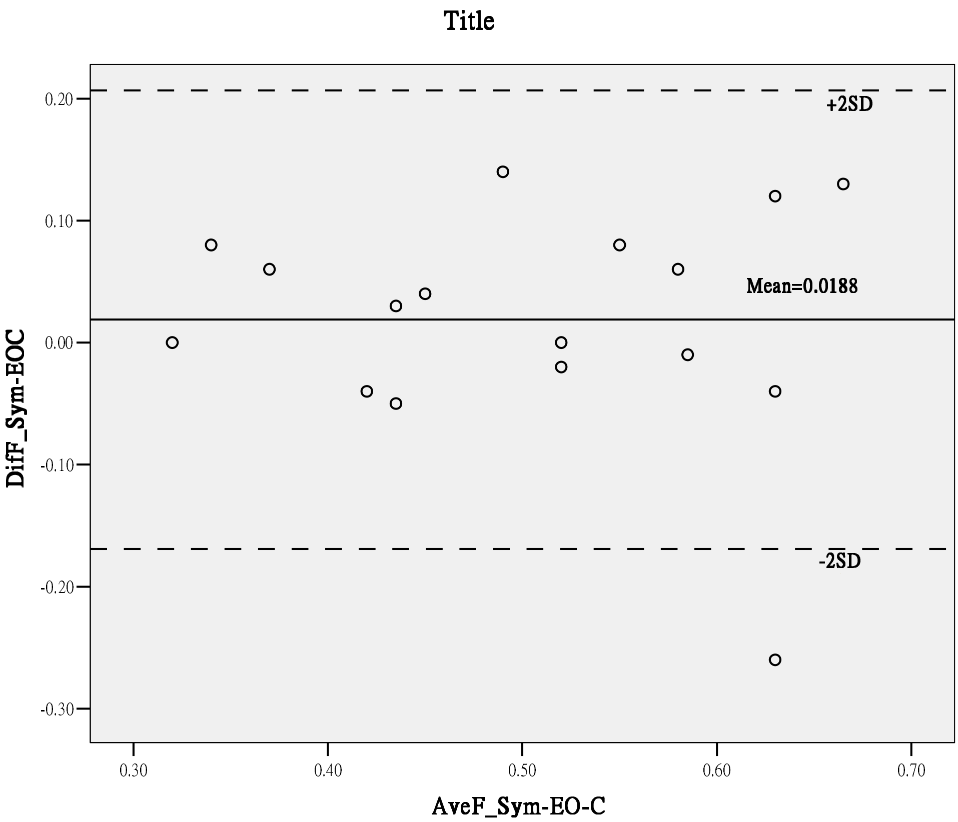
- **Results of the Bland and Altman analyses in inter-rectus distance (IRD), lumbar multifidus (LM) and sacral multifidus (SF): mean difference ( $\bar{d}$ ) and the 95% limits of agreement**

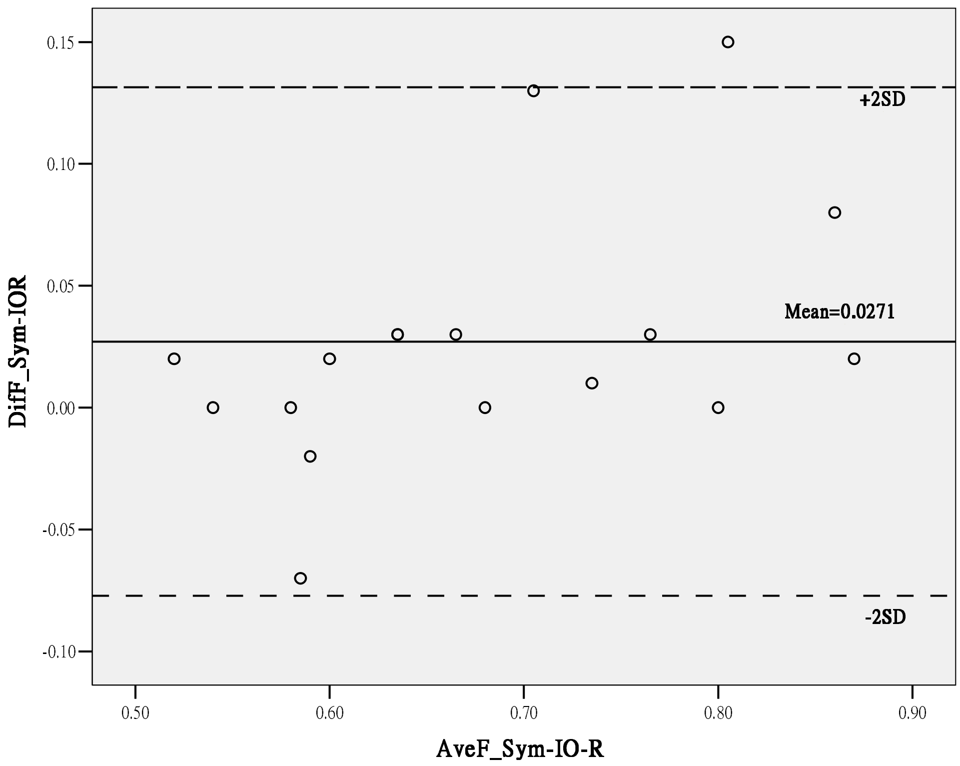
| | **IRD** | | **LM** | | **SM** | |
|---|---|---|---|---|---|---|
| | $\bar{d}$ (cm) | 95% CI for $\bar{d}$ | $\bar{d}$ (cm) | 95% CI for $\bar{d}$ | $\bar{d}$ (cm) | 95% CI for $\bar{d}$ |
| **Rest 1st** | -0.01 | 0.17 →-0.3 | | | | |
| **Contraction 1st** | -0.03 | 0.38→-0.44 | | | | |
| **Rest 2nd** | -0.74 | 0.36 →-0.51 | | | | |
| **Contraction 2nd** | -0.39 | 0.25 →-1.04 | | | | |
| **Between-days measurement** | | | | | | |
| | **IRD** | | **LM** | | **SM** | |
| | $\bar{d}$ (cm) | 95% CI for $\bar{d}$ | $\bar{d}$ (cm) | 95% CI for $\bar{d}$ | $\bar{d}$ (cm) | 95% CI for $\bar{d}$ |
| **Rest** | 0.2 | 2.56 →-2.16 | | | | |
| **Contraction** | 0.5 | 1.97→-0.95 | | | | |

$\bar{d}$ is the mean difference between measurements of muscle thickness; 95% CI is the confidence intervals for the mean difference; 1st and 2nd = mean of scans on the first and second days respectively

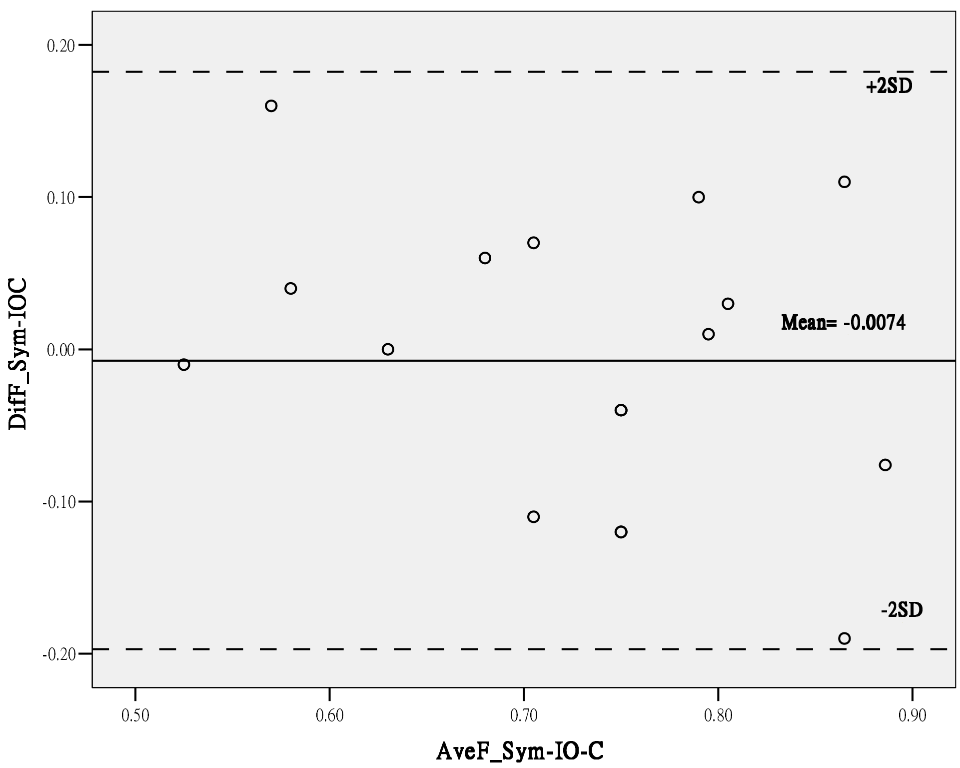
- **Between-scans plotting**



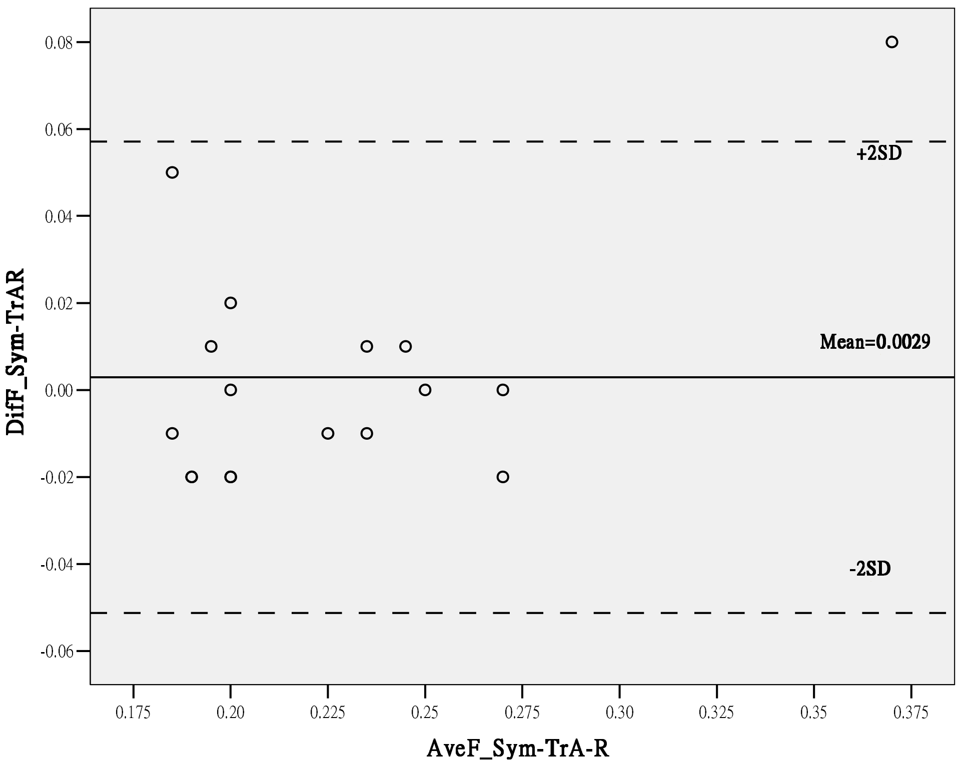





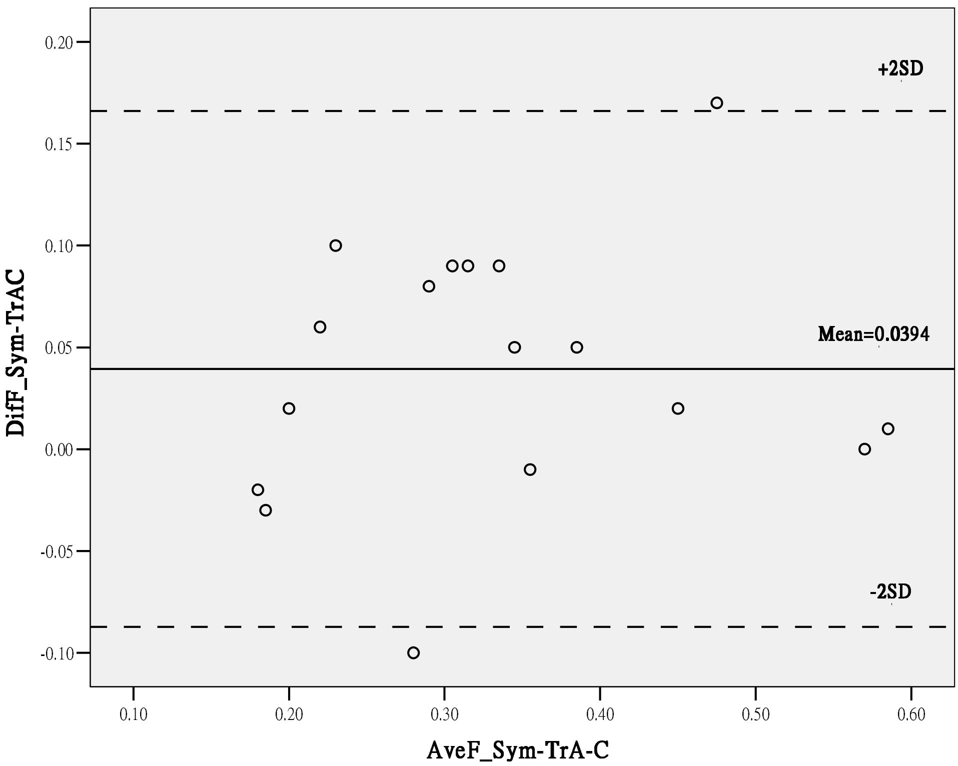
0.15
0.10
0.05
0.00
-0.05
-0.10
+2SD
Mean=0.0271
-2SD
DifF_Sym-IOR
0.50
0.60
0.70
0.80
0.90
AveF_Sym-IO-R

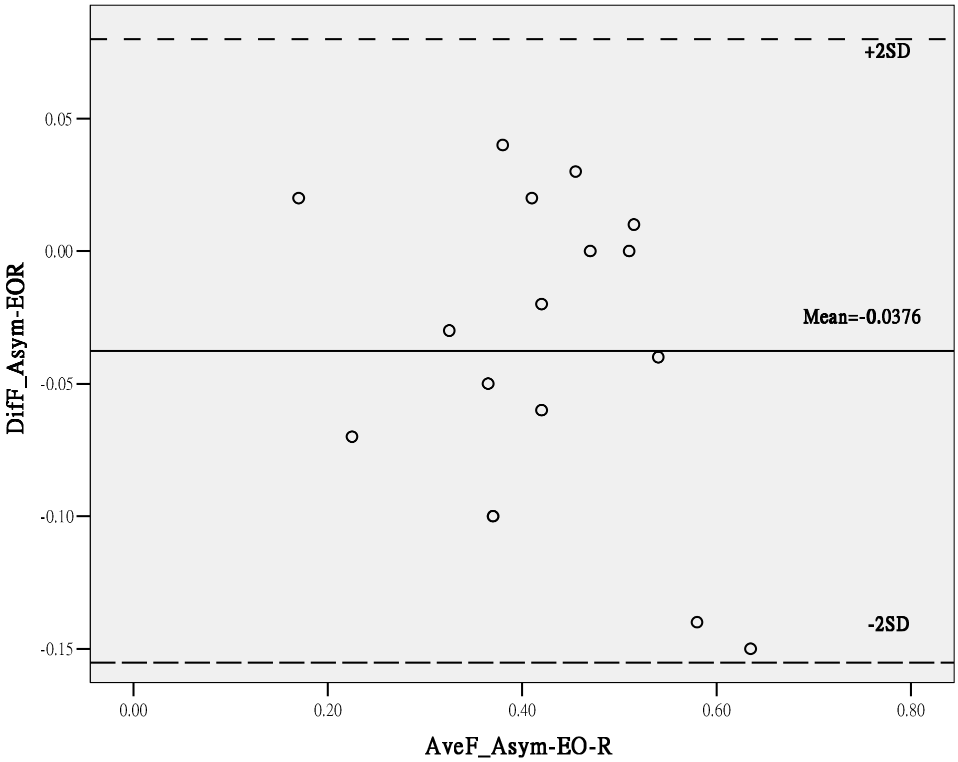
0.20
0.10
0.00
-0.10
-0.20
+2SD
Mean= -0.0074
-2SD
DifF_Sym-IOC
0.50
0.60
0.70
0.80
0.90
AveF_Sym-IO-C

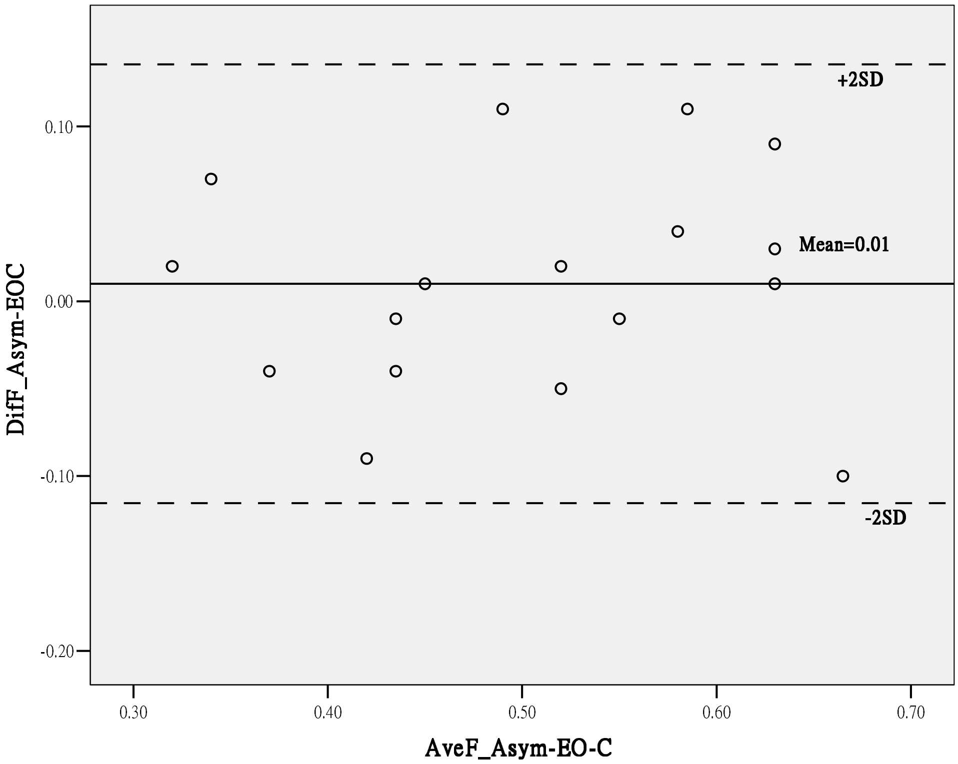


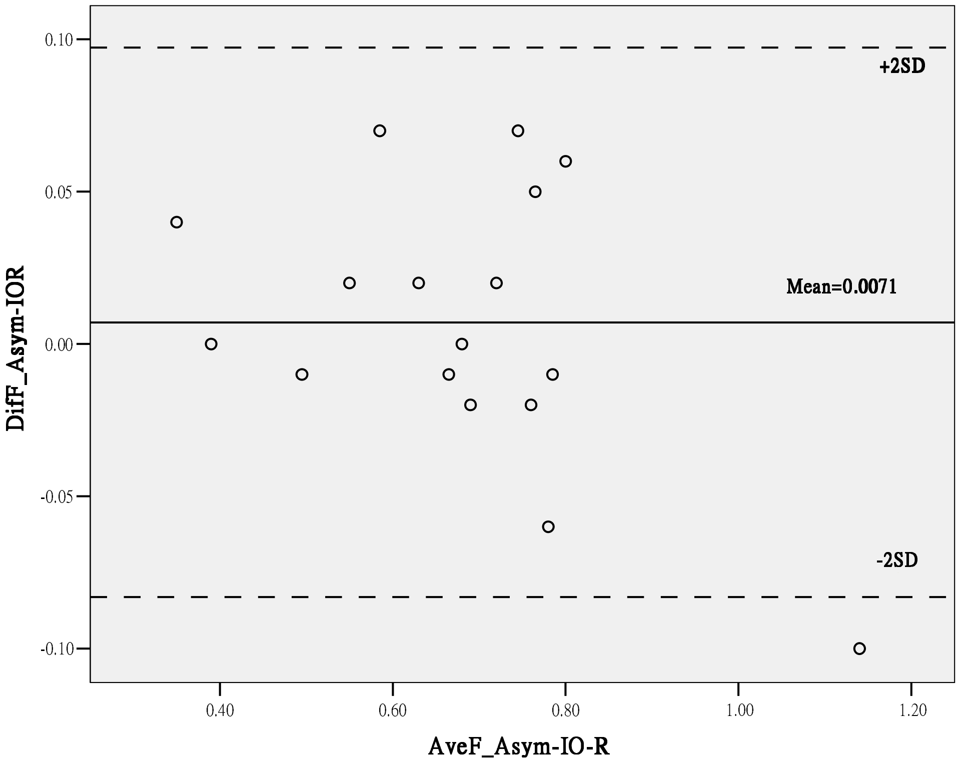
0.08
0.06
0.04
0.02
0.00
-0.02
-0.04
-0.06
DifF_Sym-TrAR
+2SD
Mean=0.0029
-2SD
0.175
0.20
0.225
0.25
0.275
0.30
0.325
0.35
0.375
AveF_Sym-TrA-R

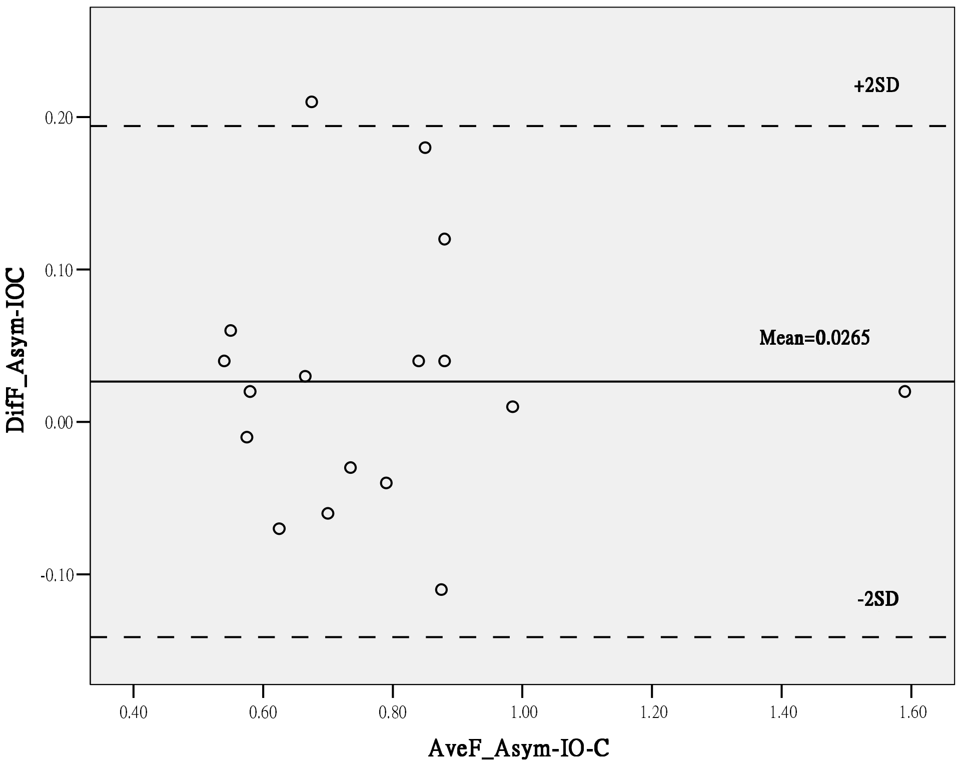
0.20
0.15
0.10
0.05
0.00
-0.05
-0.10
DifF_Sym-TrAC
+2SD
Mean=0.0394
-2SD
0.10
0.20
0.30
0.40
0.50
0.60
AveF_Sym-TrA-C


+2SD
0.05
0.00
Mean=-0.0376
-0.05
-0.10
-2SD
-0.15
DifF_Asym-EOR
0.00
0.20
0.40
0.60
0.80
AveF_Asym-EO-R

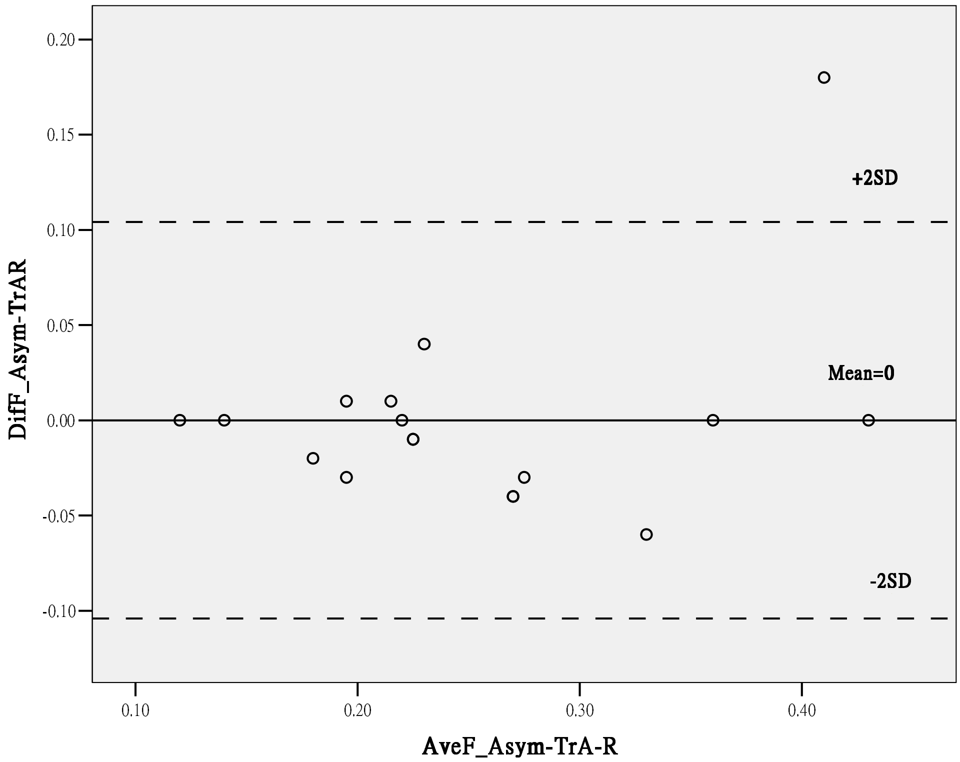

+2SD
0.10
Mean=0.01
0.00
-0.10
-2SD
-0.20
DifF_Asym-EOC
0.30
0.40
0.50
0.60
0.70
AveF_Asym-EO-C

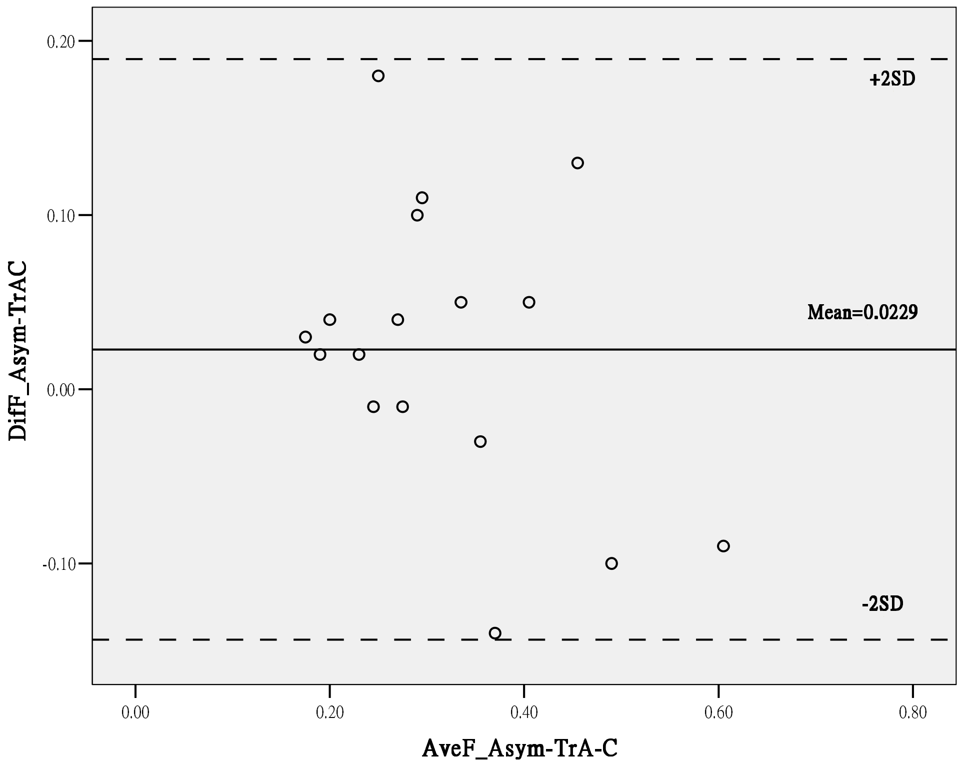


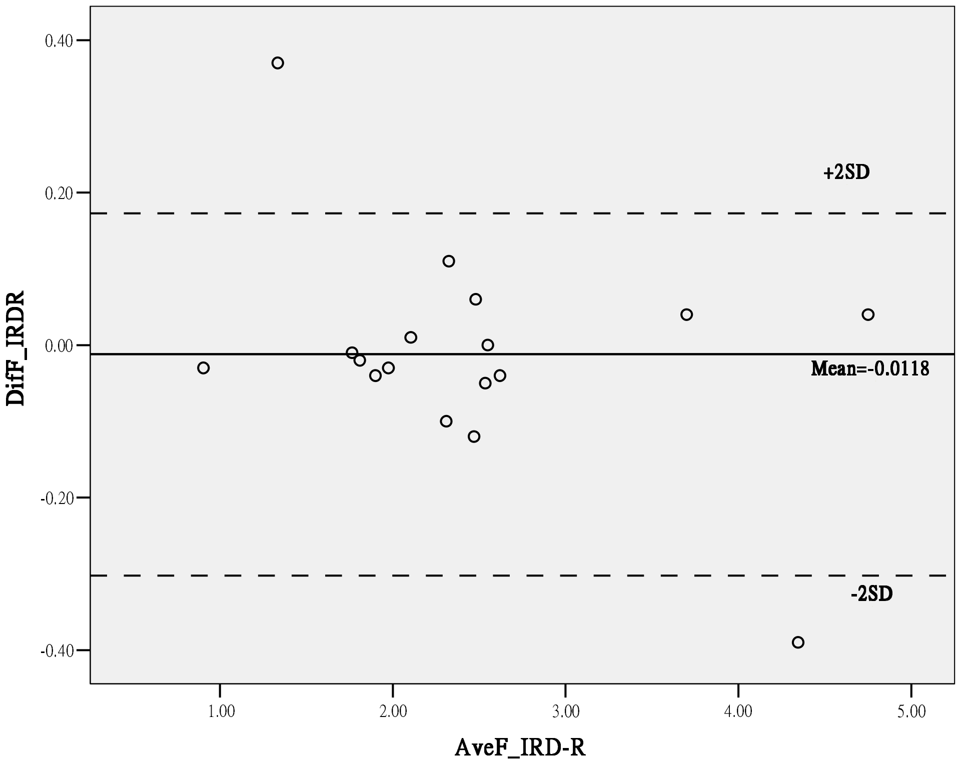
+2SD
Mean=0.0071
-2SD
0.10
0.05
0.00
-0.05
-0.10
0.40
0.60
0.80
1.00
1.20
DifF_Asym-IOR
AveF_Asym-IO-R

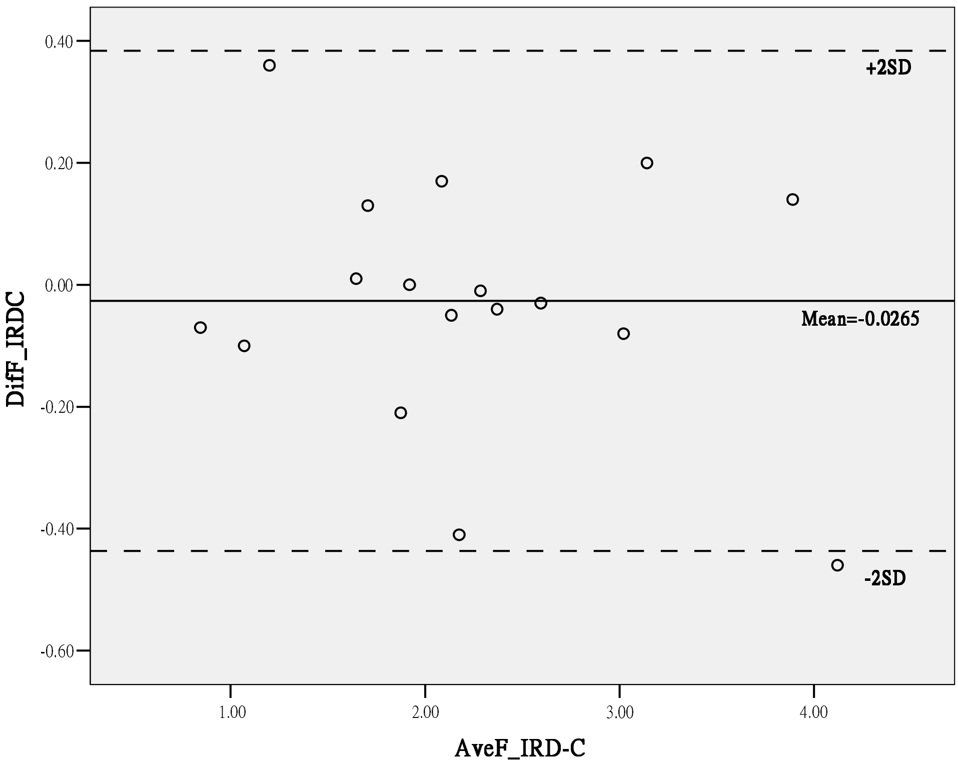



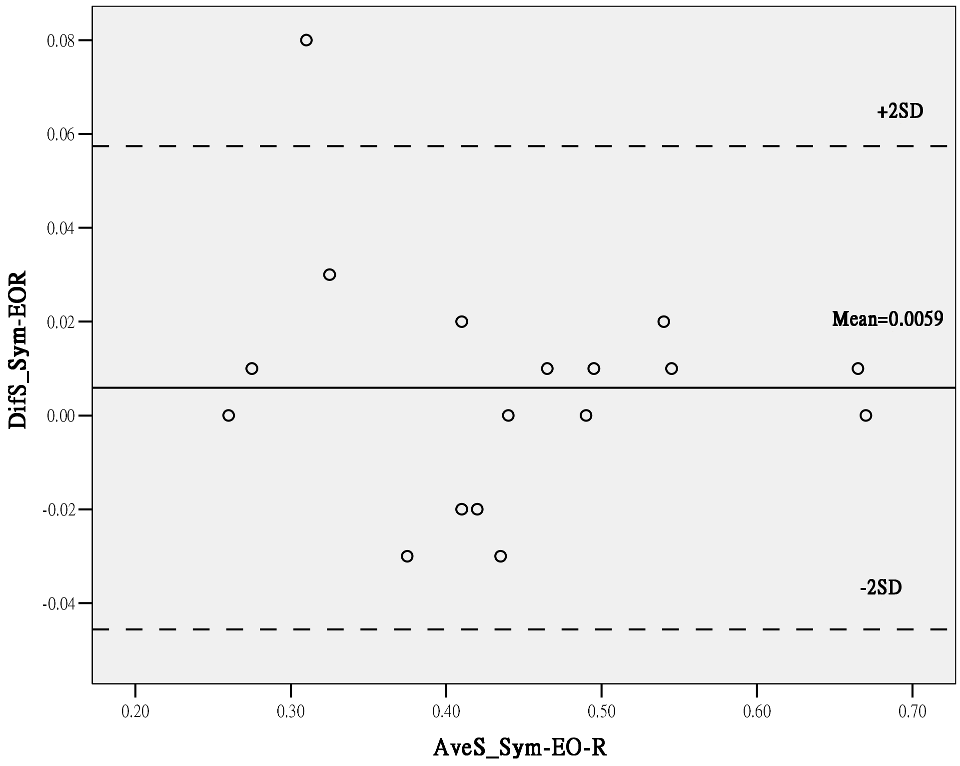
+2SD
Mean=0.0265
-2SD
0.20
0.10
0.00
-0.10
0.40
0.60
0.80
1.00
1.20
1.40
1.60
DifF_Asym-IOC
AveF_Asym-IO-C

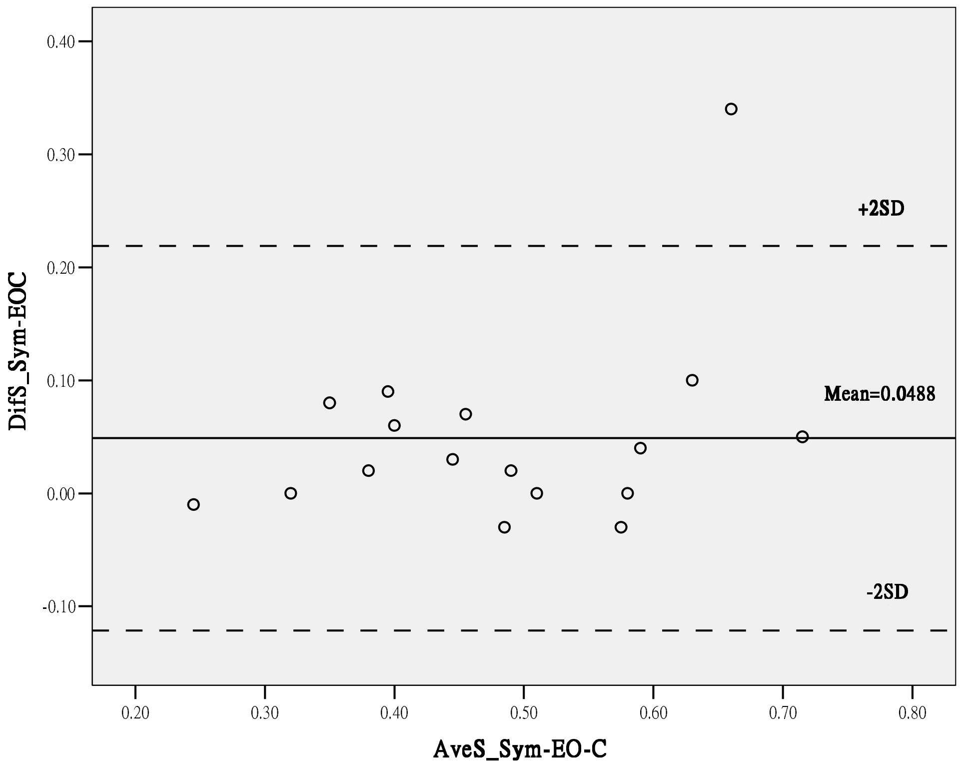

0.20
0.15
0.10
0.05
0.00
-0.05
-0.10
DifF_Asym-TrAR
+2SD
Mean=0
-2SD
0.10
0.20
0.30
0.40
AveF_Asym-TrA-R

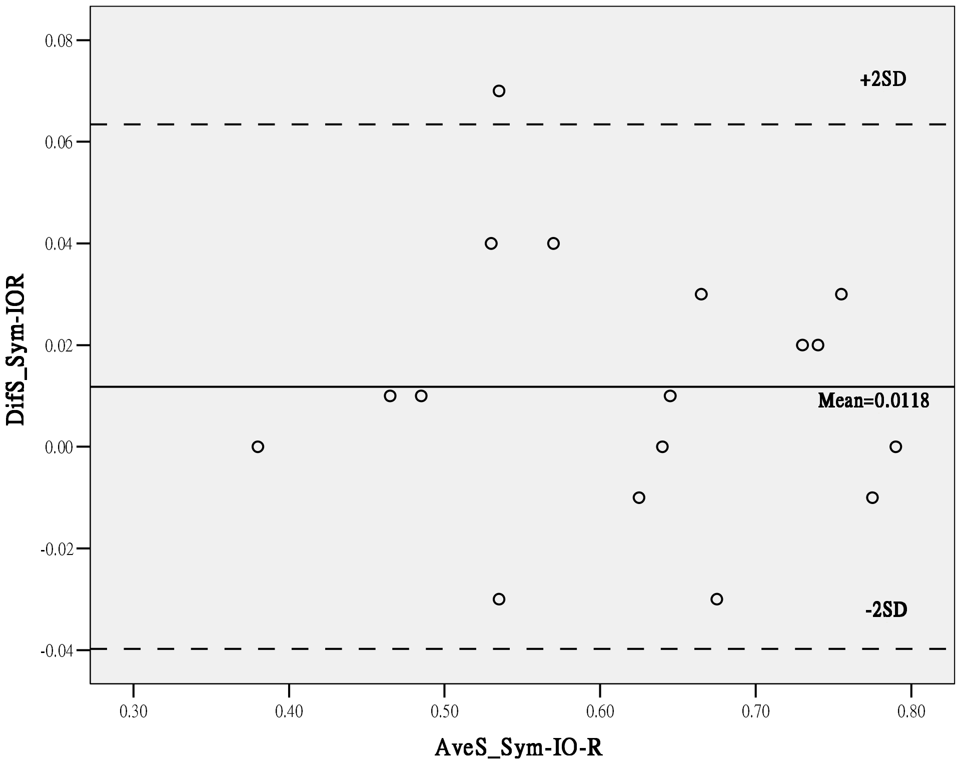

0.20
0.10
0.00
-0.10
DifF_Asym-TrAC
+2SD
Mean=0.0229
-2SD
0.00
0.20
0.40
0.60
0.80
AveF_Asym-TrA-C

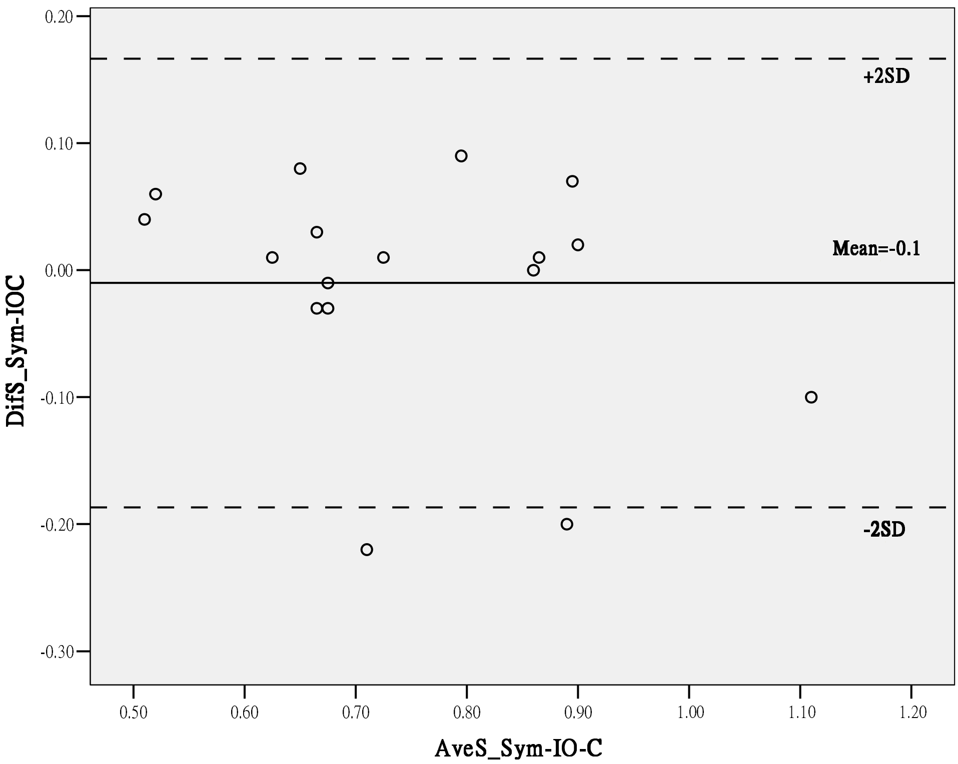

0.40
0.20
0.00
-0.20
-0.40
DifF_IRDR
+2SD
Mean=-0.0118
-2SD
1.00
2.00
3.00
4.00
5.00
AveF_IRD-R

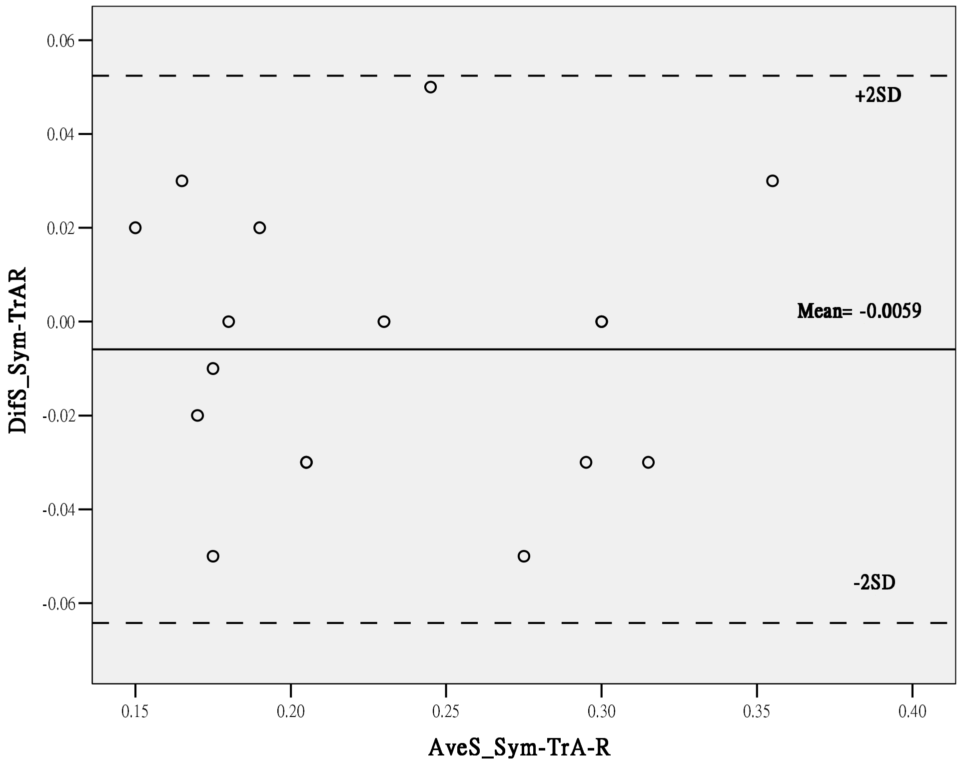

0.40
0.20
0.00
-0.20
-0.40
-0.60
DifF_IRDC
+2SD
Mean=-0.0265
-2SD
1.00
2.00
3.00
4.00
AveF_IRD-C

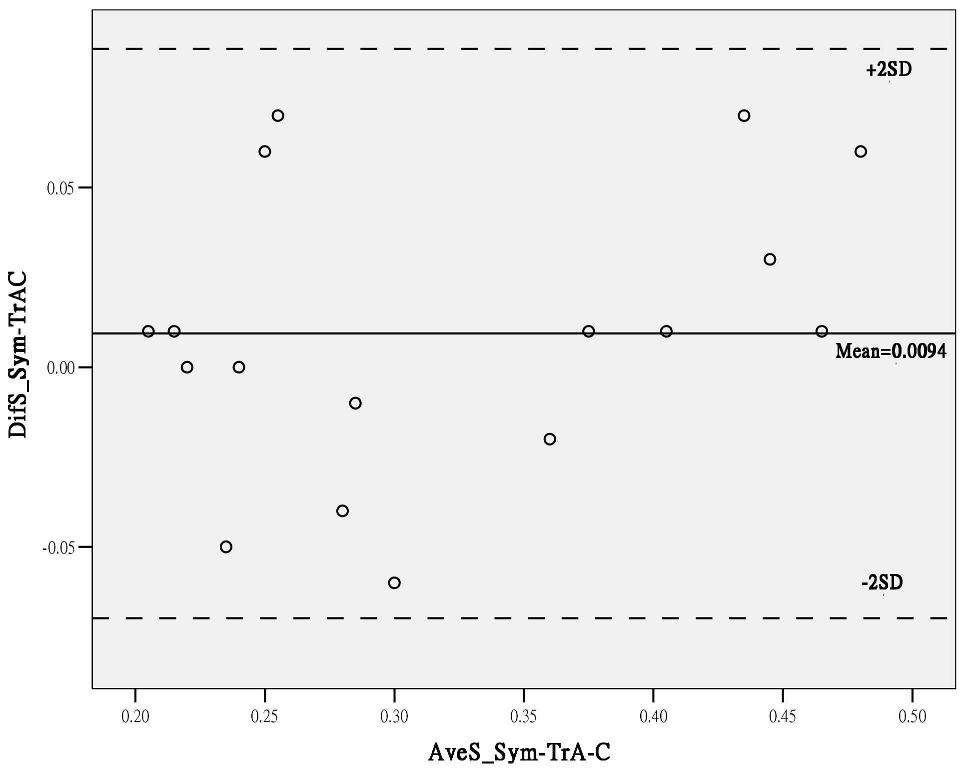

0.08
0.06
0.04
0.02
0.00
-0.02
-0.04
+2SD
Mean=0.0059
-2SD
DifS_Sym-EOR
0.20
0.30
0.40
0.50
0.60
0.70
AveS_Sym-EO-R

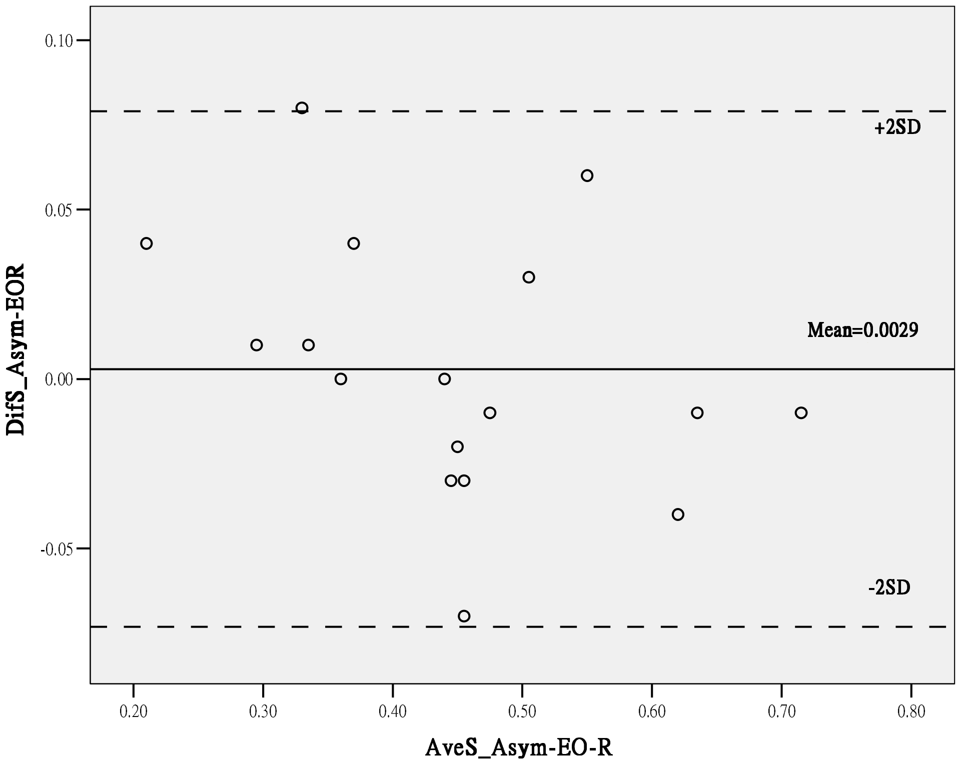

0.40
0.30
0.20
0.10
0.00
-0.10
+2SD
Mean=0.0488
-2SD
DifS_Sym-EOC
0.20
0.30
0.40
0.50
0.60
0.70
0.80
AveS_Sym-EO-C

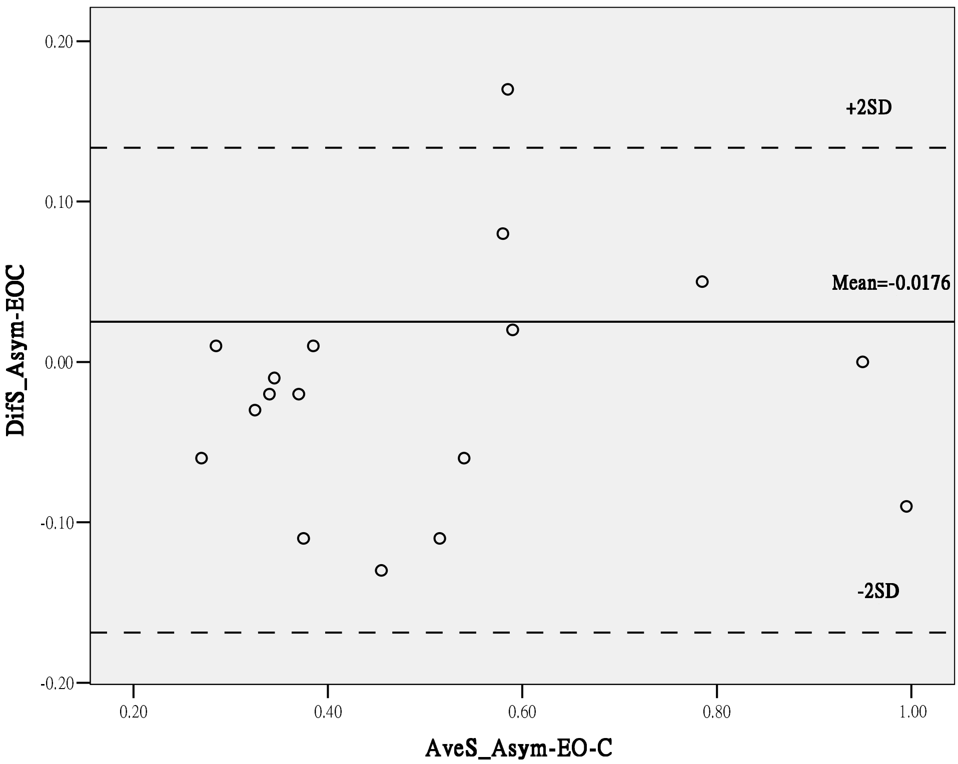

0.08
0.06
0.04
0.02
0.00
-0.02
-0.04
DifS_Sym-IOR
+2SD
Mean=0.0118
-2SD
0.30
0.40
0.50
0.60
0.70
0.80
AveS_Sym-IO-R

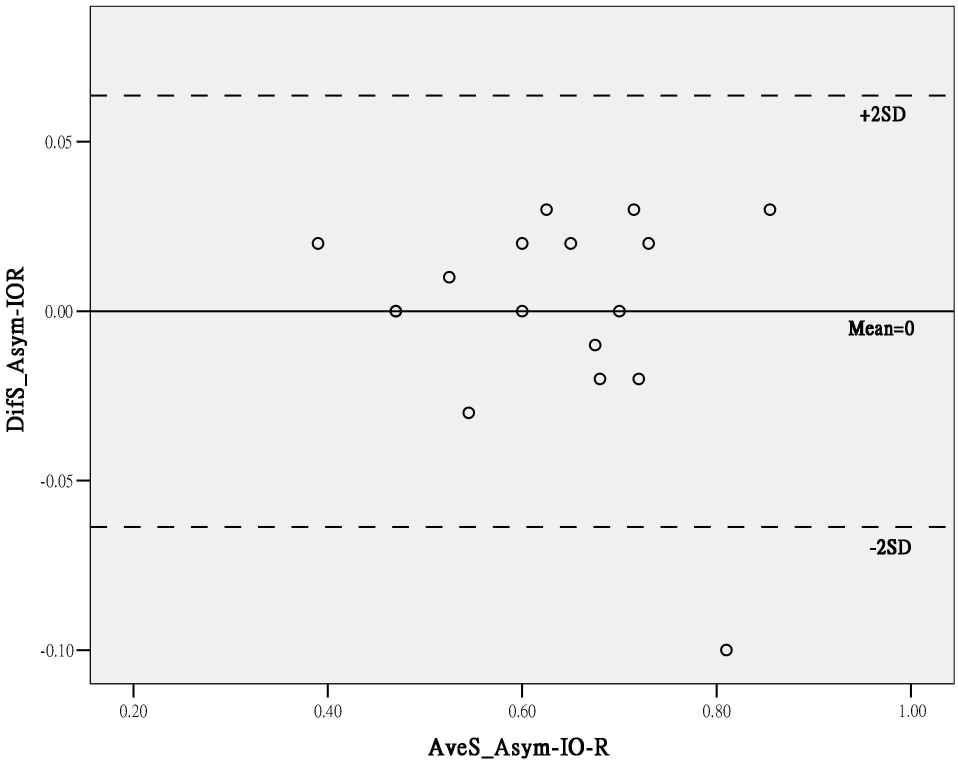

0.20
0.10
0.00
-0.10
-0.20
-0.30
DifS_Sym-IOC
+2SD
Mean=-0.1
-2SD
0.50
0.60
0.70
0.80
0.90
1.00
1.10
1.20
AveS_Sym-IO-C

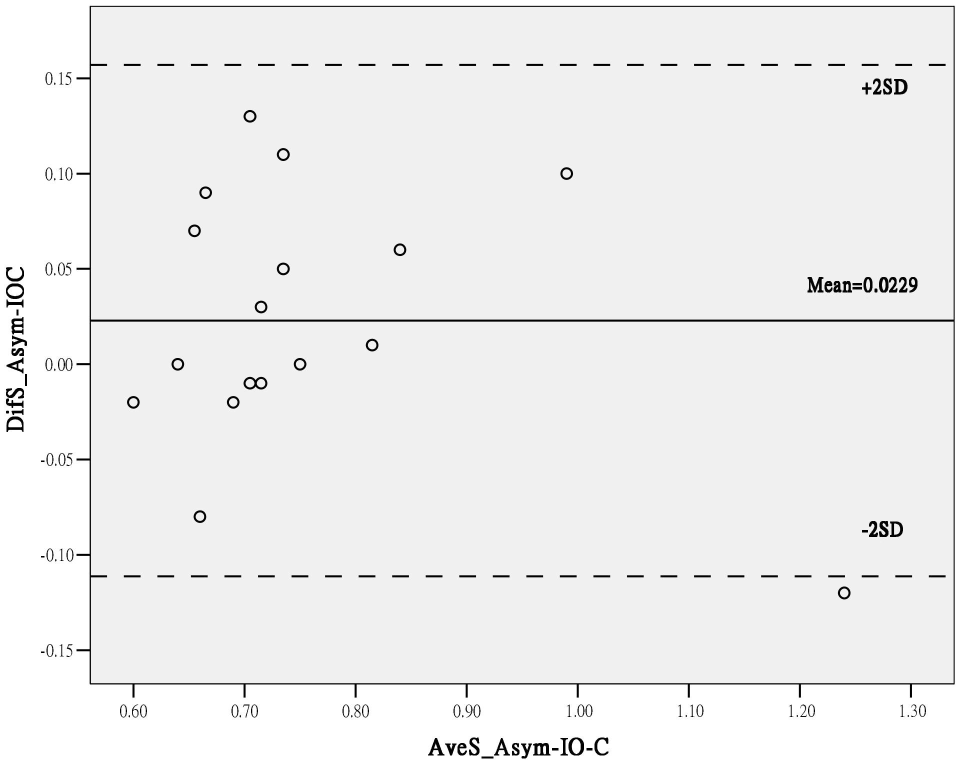

0.06
0.04
0.02
0.00
-0.02
-0.04
-0.06
+2SD
Mean= -0.0059
-2SD
DifS_Sym-TrAR
0.15
0.20
0.25
0.30
0.35
0.40
AveS_Sym-TrA-R

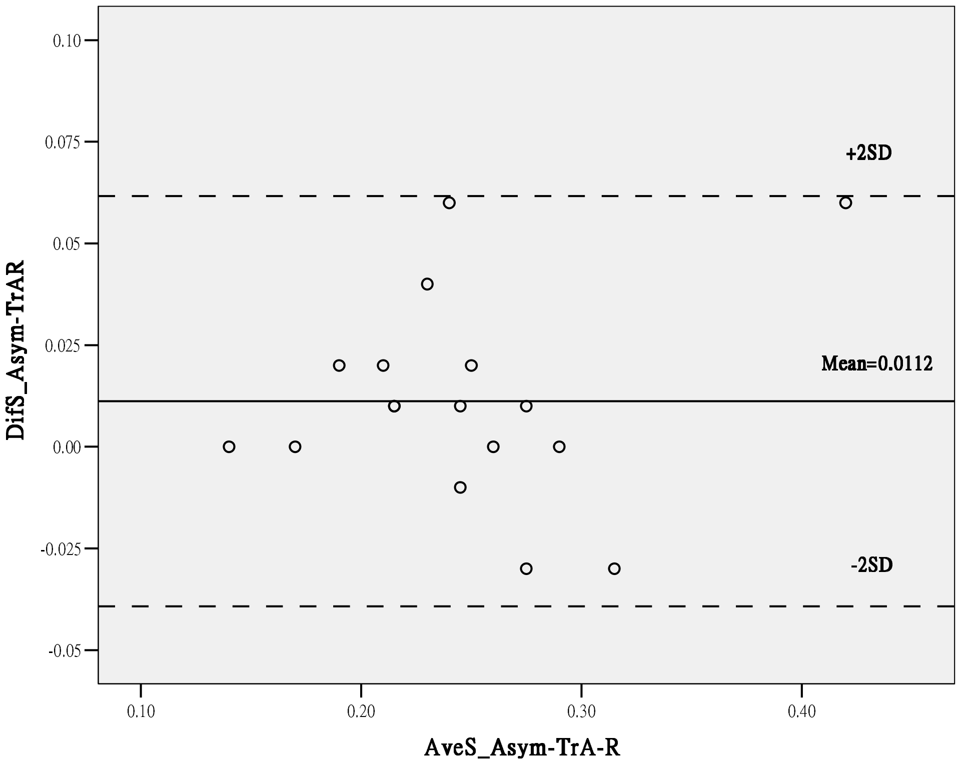

0.05
0.00
-0.05
+2SD
Mean=0.0094
-2SD
DifS_Sym-TrAC
0.20
0.25
0.30
0.35
0.40
0.45
0.50
AveS_Sym-TrA-C

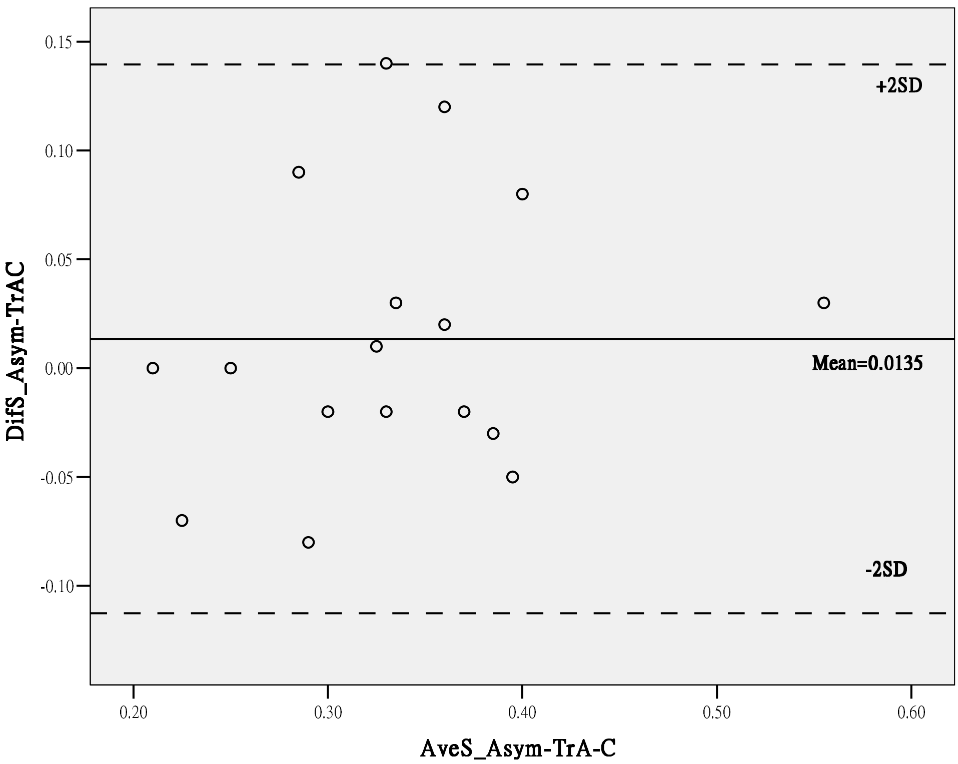

0.10
0.05
0.00
-0.05
+2SD
Mean=0.0029
-2SD
DifS_Asym-EOR
0.20
0.30
0.40
0.50
0.60
0.70
0.80
AveS_Asym-EO-R

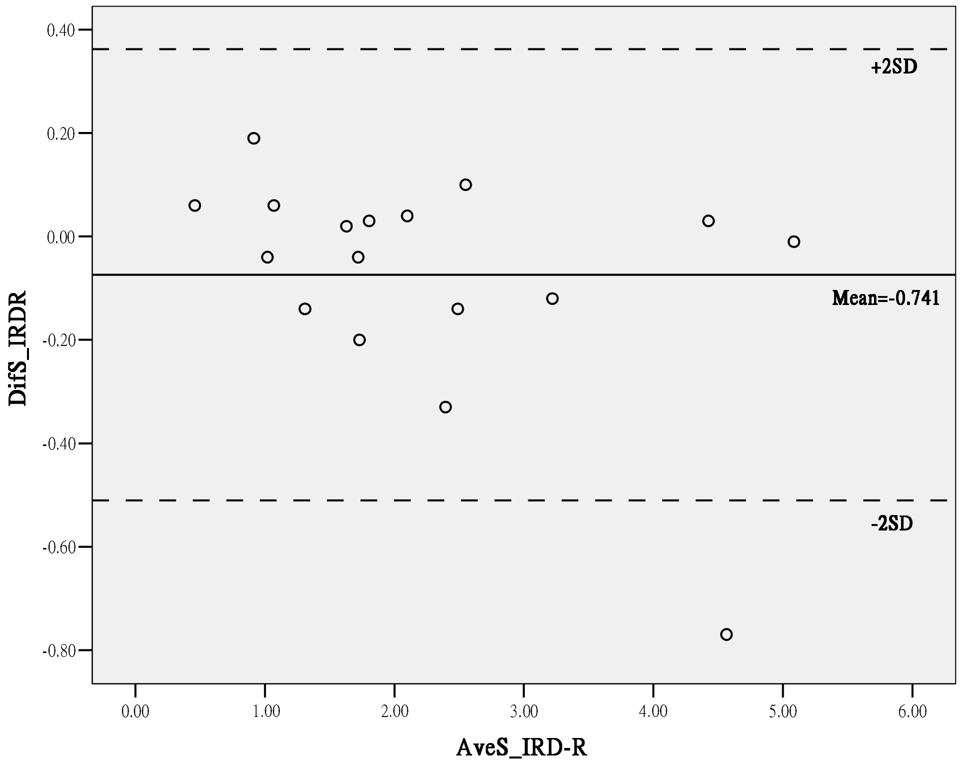

0.20
0.10
0.00
-0.10
-0.20
+2SD
Mean=-0.0176
-2SD
DifS_Asym-EOC
0.20
0.40
0.60
0.80
1.00
AveS_Asym-EO-C

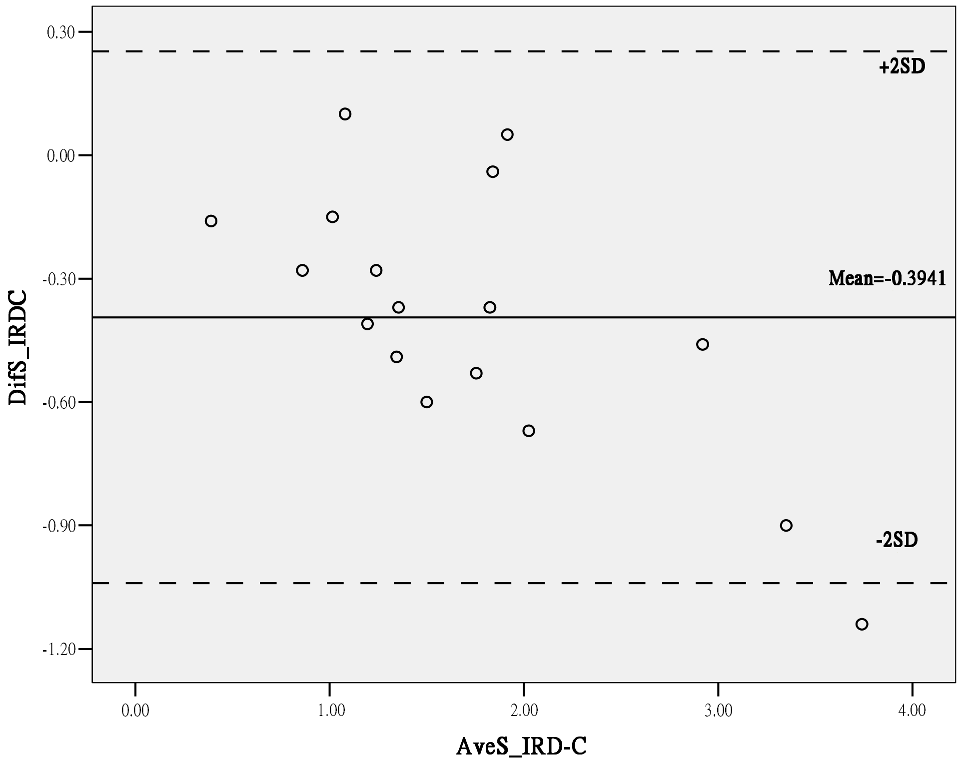

+2SD
Mean=0
-2SD
0.05
0.00
-0.05
-0.10
DifS_Asym-IOR
0.20
0.40
0.60
0.80
1.00
AveS_Asym-IO-R


+2SD
Mean=0.0229
-2SD
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
DifS_Asym-IOC
0.60
0.70
0.80
0.90
1.00
1.10
1.20
1.30
AveS_Asym-IO-C

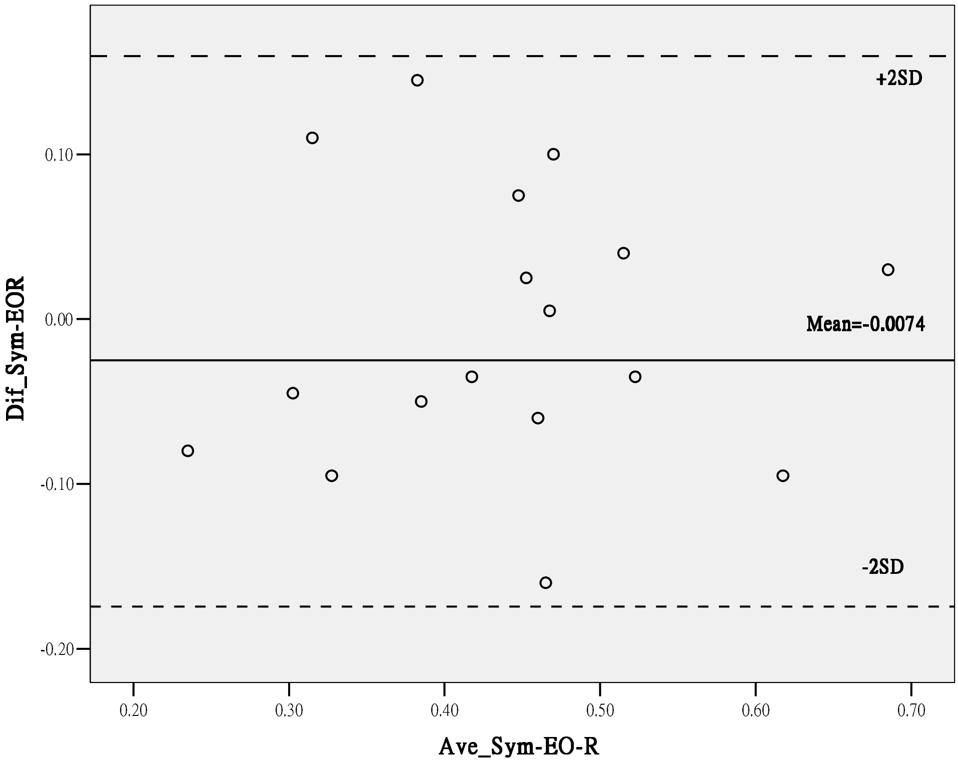

0.10
0.075
0.05
0.025
0.00
-0.025
-0.05
+2SD
Mean=0.0112
-2SD
DifS_Asym-TrAR
0.10
0.20
0.30
0.40
AveS_Asym-TrA-R

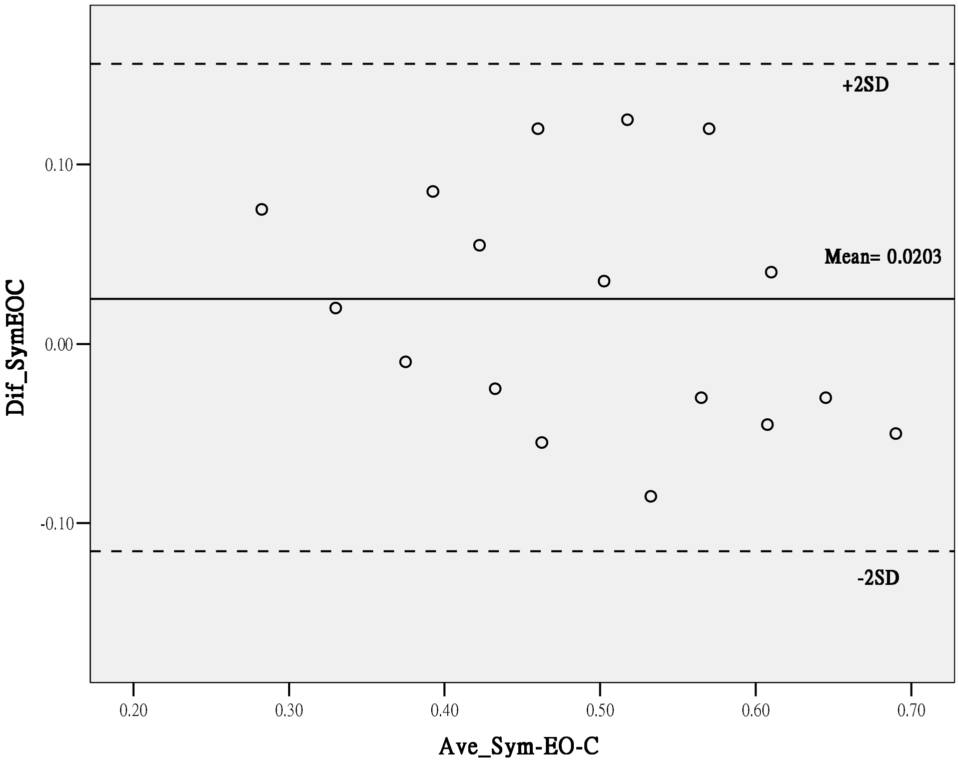

0.15
0.10
0.05
0.00
-0.05
-0.10
+2SD
Mean=0.0135
-2SD
DifS_Asym-TrAC
0.20
0.30
0.40
0.50
0.60
AveS_Asym-TrA-C

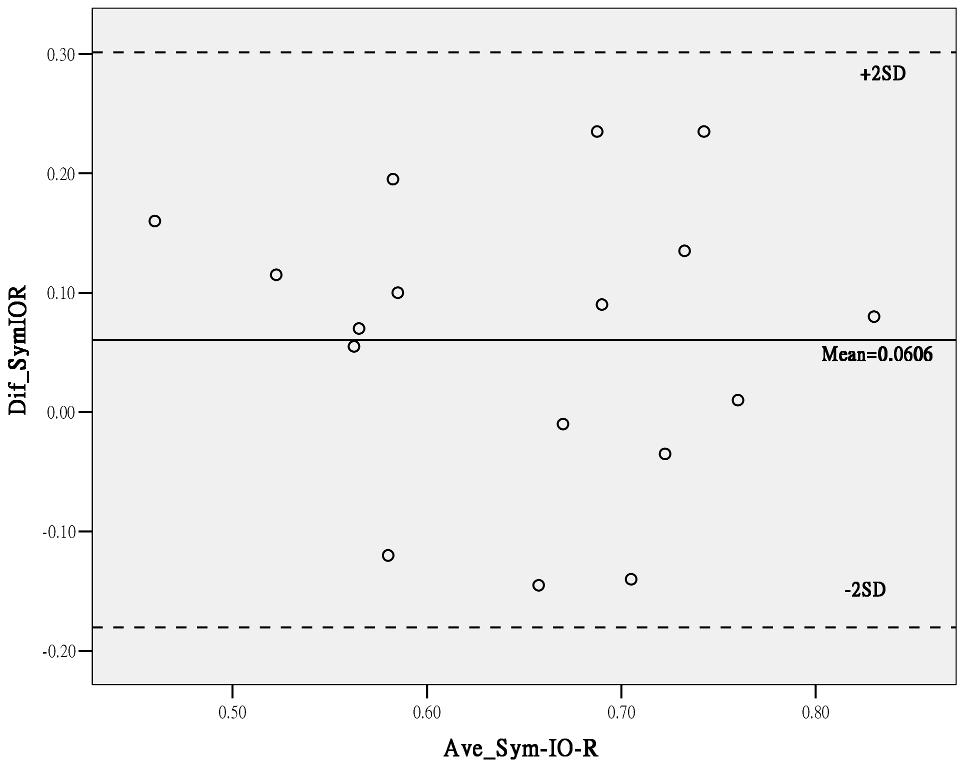

0.40
0.20
0.00
-0.20
-0.40
-0.60
-0.80
+2SD
Mean=-0.741
-2SD
DifS_IRDR
0.00
1.00
2.00
3.00
4.00
5.00
6.00
AveS_IRD-R

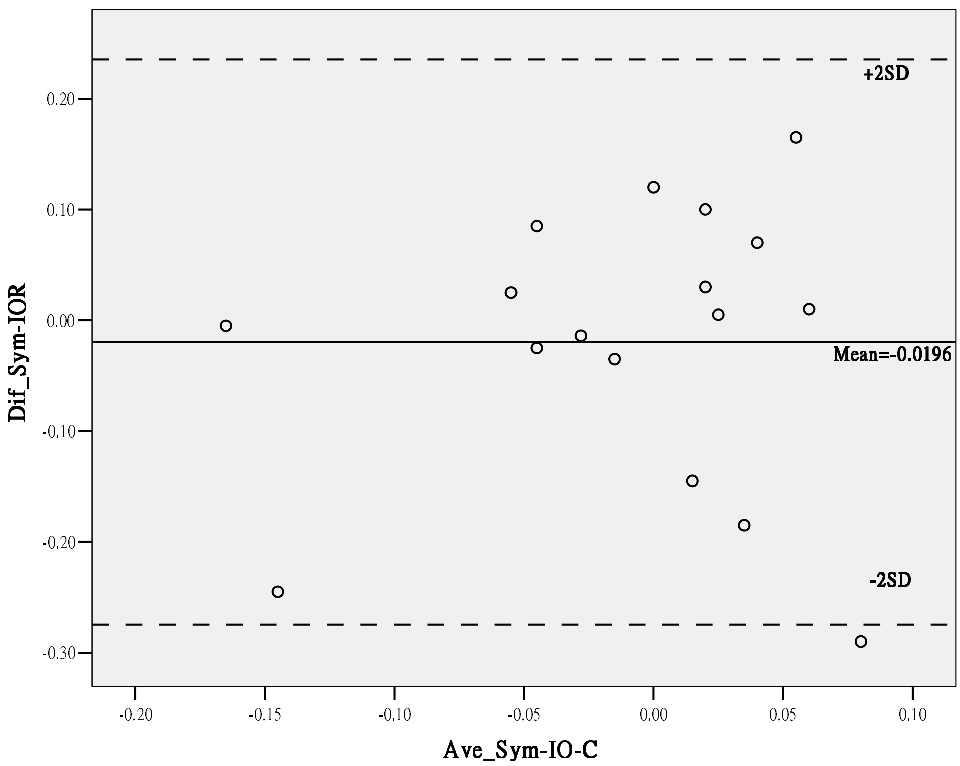

0.30
0.00
-0.30
-0.60
-0.90
-1.20
+2SD
Mean=-0.3941
-2SD
DifS_IRDC
0.00
1.00
2.00
3.00
4.00
AveS_IRD-C

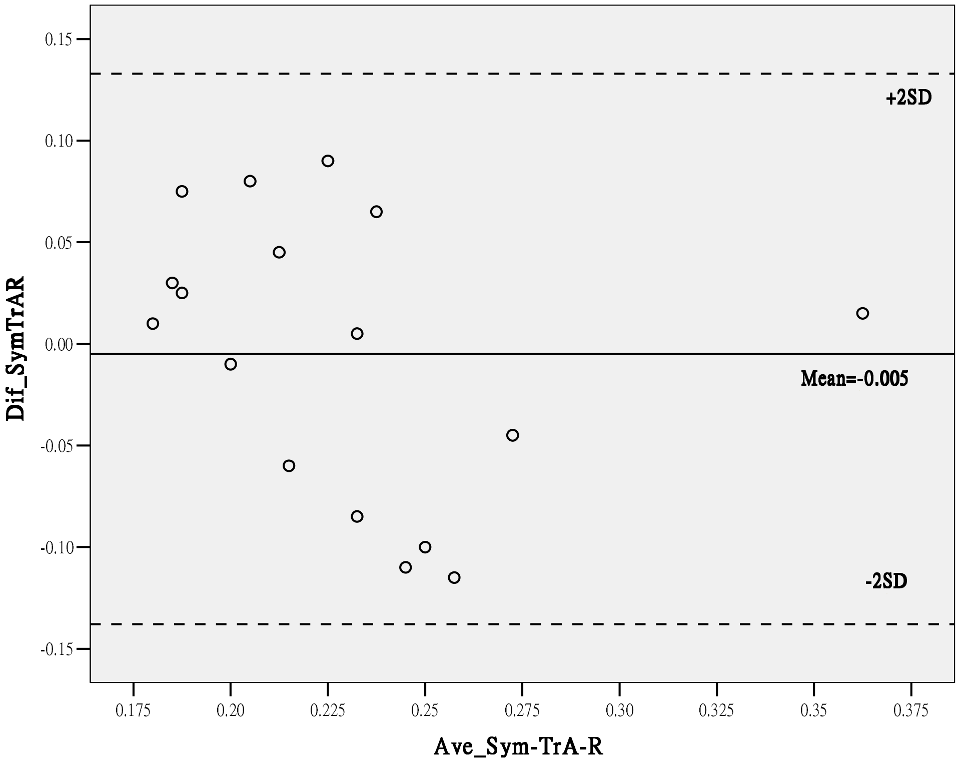
- **Between-days plotting**

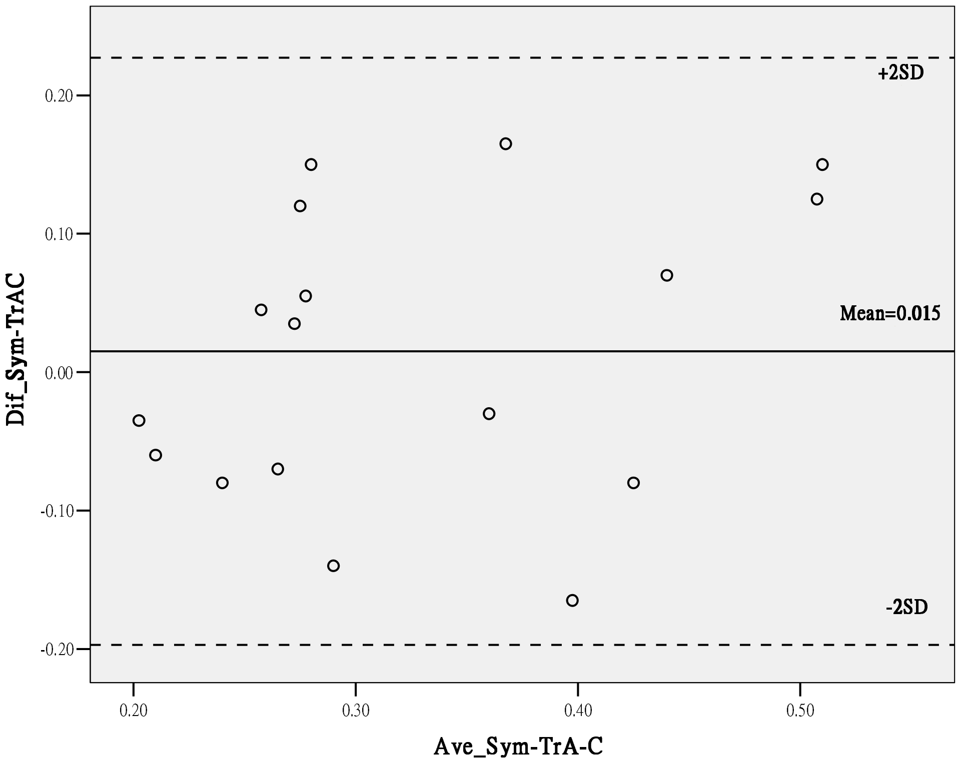


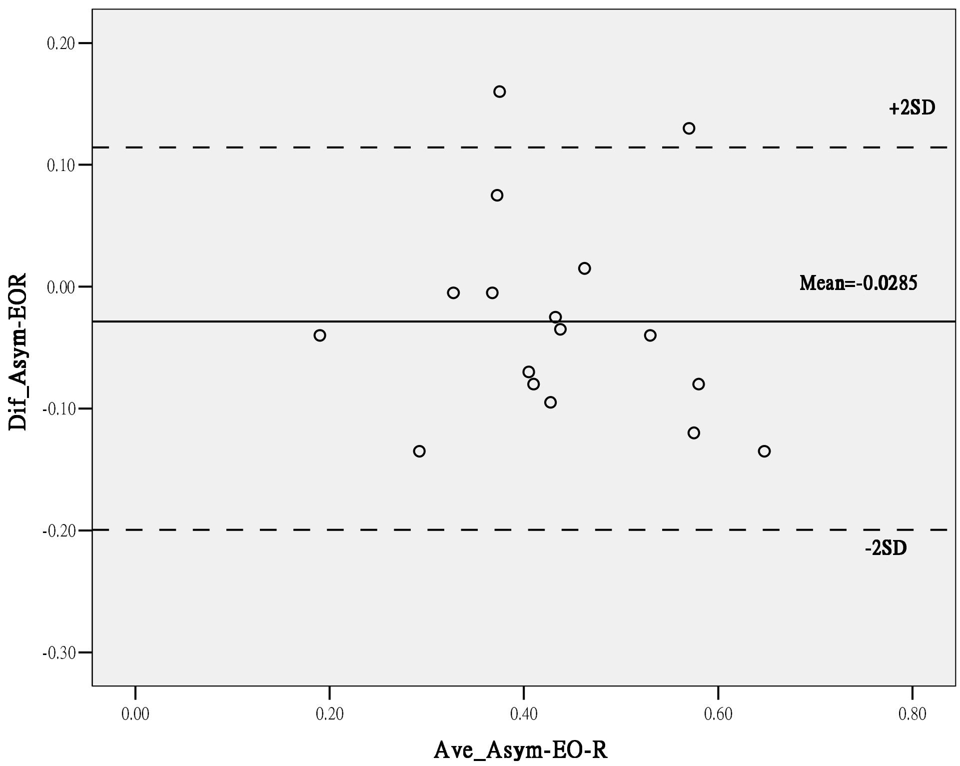



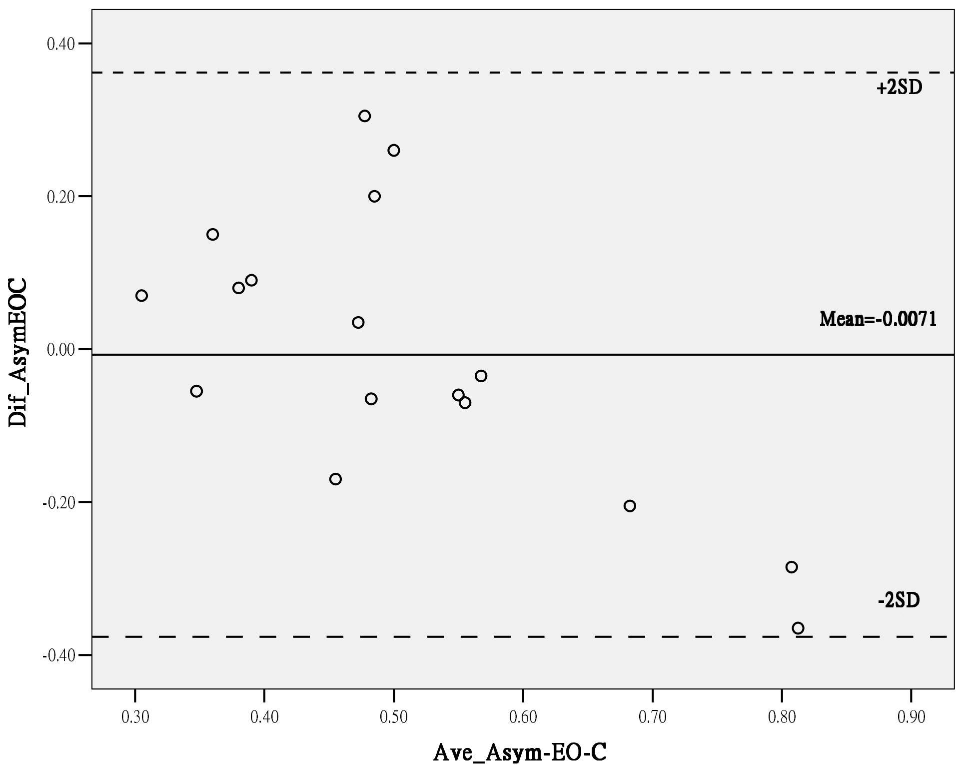

+2SD
Mean=0.0606
-2SD
Dif_SymIOR
0.30
0.20
0.10
0.00
-0.10
-0.20
0.50
0.60
0.70
0.80
Ave_Sym-IO-R

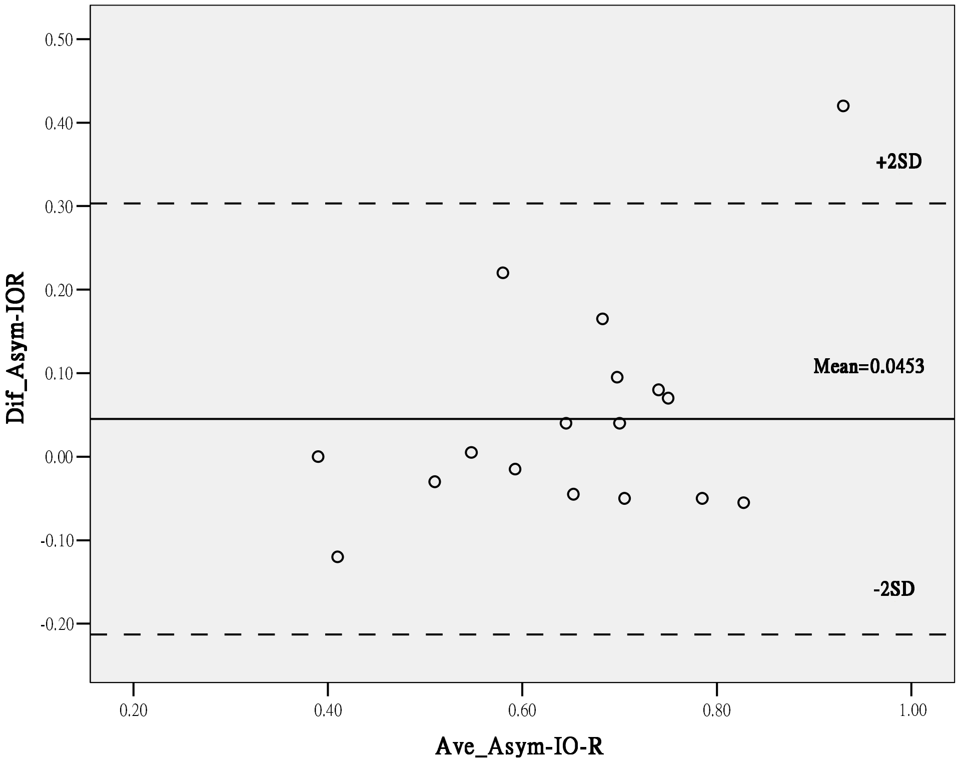

+2SD
Mean=-0.0196
-2SD
Dif_Sym-IOR
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.20
-0.15
-0.10
-0.05
0.00
0.05
0.10
Ave_Sym-IO-C


0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
Dif_SymTrAR
+2SD
Mean=-0.005
-2SD
0.175
0.20
0.225
0.25
0.275
0.30
0.325
0.35
0.375
Ave_Sym-TrA-R

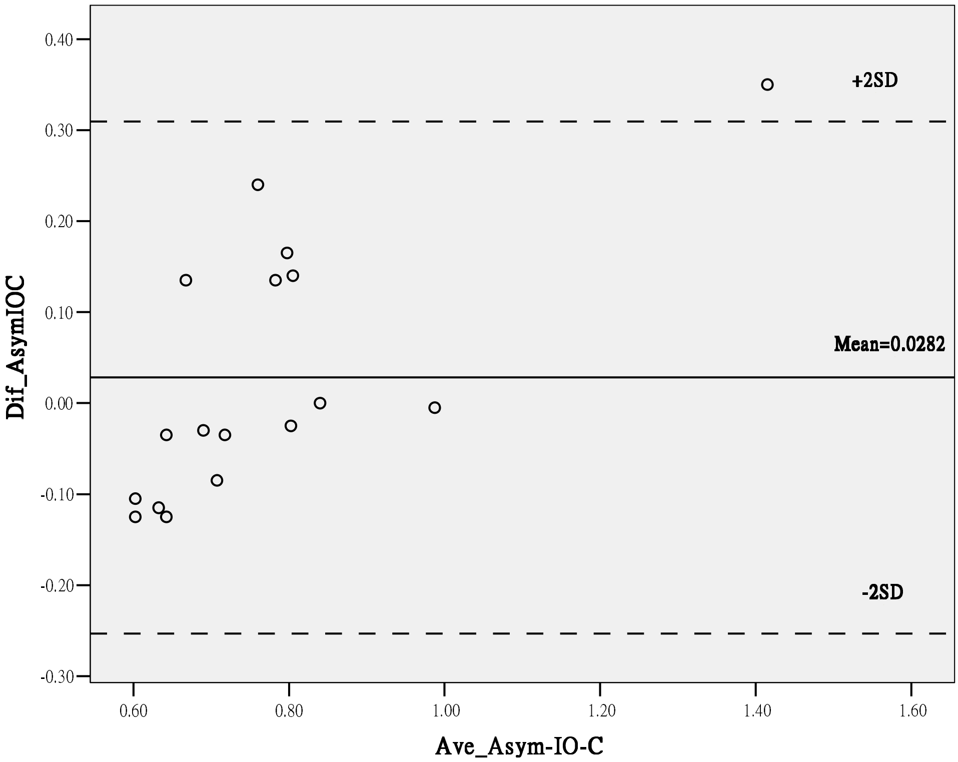

0.20
0.10
0.00
-0.10
-0.20
Dif_Sym-TrAC
+2SD
Mean=0.015
-2SD
0.20
0.30
0.40
0.50
Ave_Sym-TrA-C


+2SD
Mean=-0.0285
-2SD
Dif_Asym-EOR
Ave_Asym-EO-R
0.20
0.10
0.00
-0.10
-0.20
-0.30
0.00
0.20
0.40
0.60
0.80

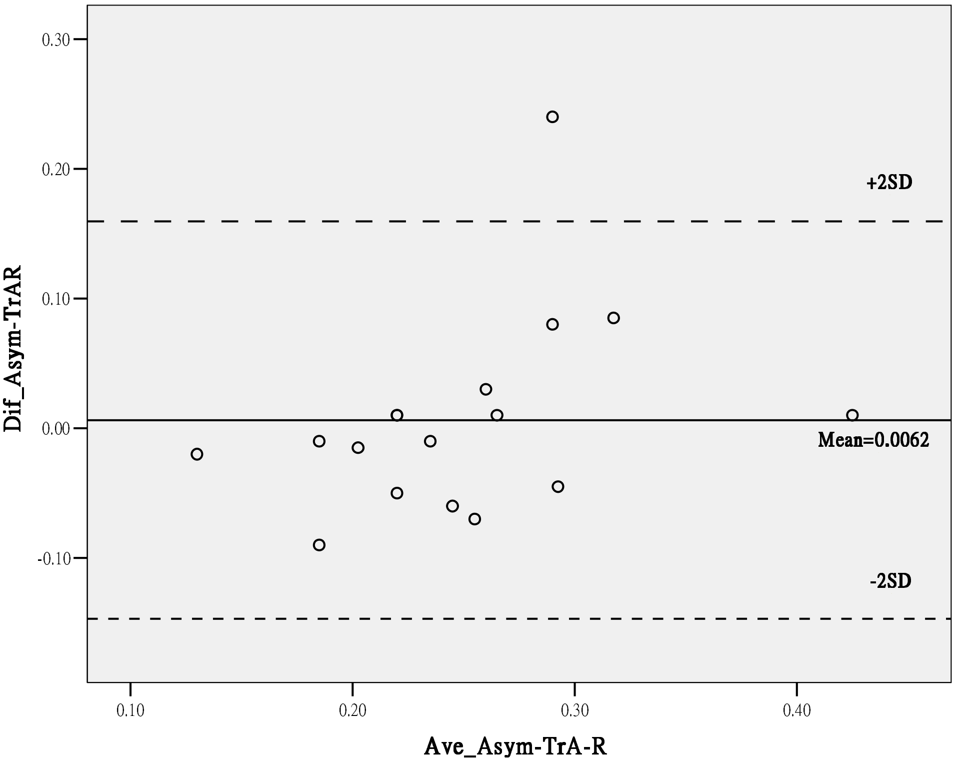

+2SD
Mean=-0.0071
-2SD
Dif_AsymEOC
Ave_Asym-EO-C
0.40
0.20
0.00
-0.20
-0.40
0.30
0.40
0.50
0.60
0.70
0.80
0.90



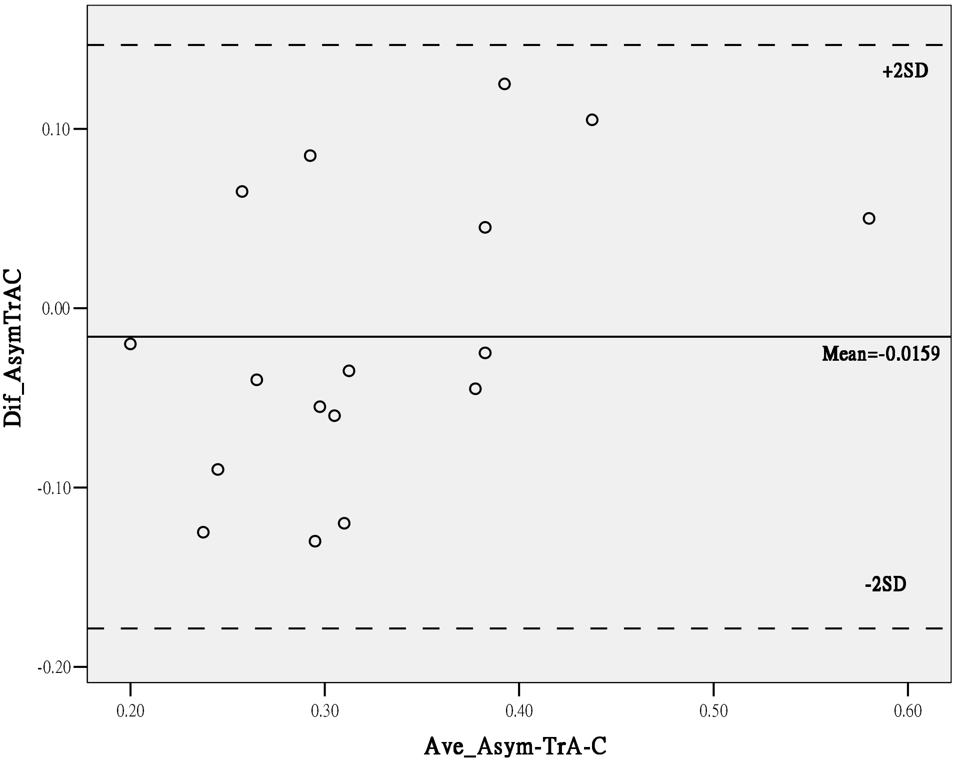
+2SD
Mean=0.0453
-2SD
Dif_Asym-IOR
Ave_Asym-IO-R

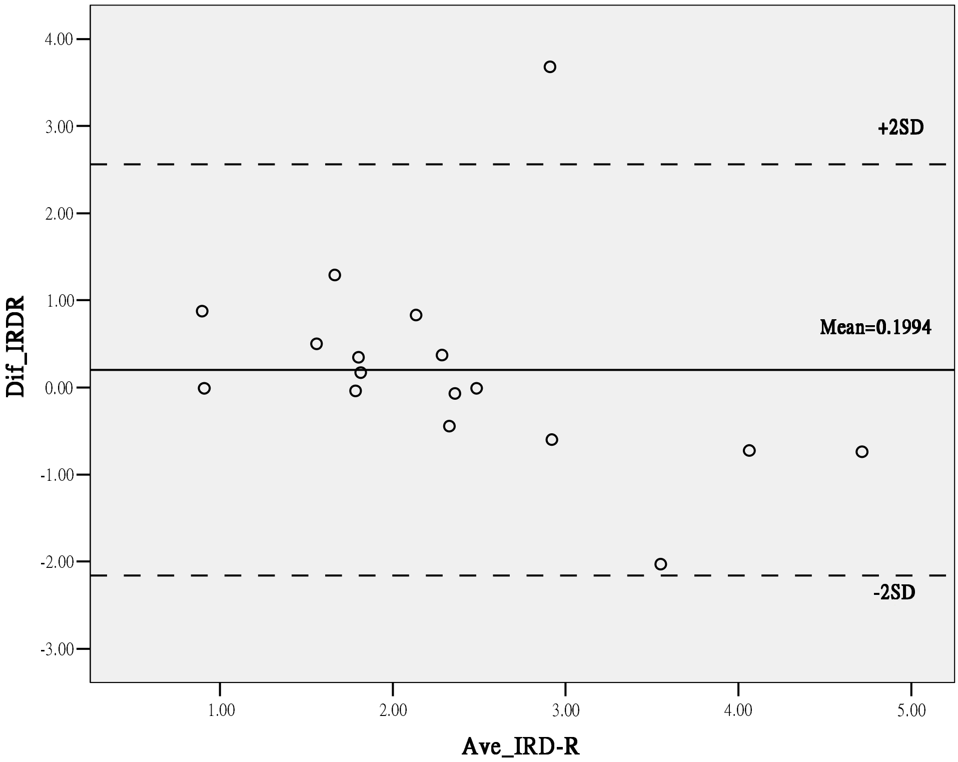
+2SD
Mean=0.0282
-2SD
Dif_AsymIOC
Ave_Asym-IO-C

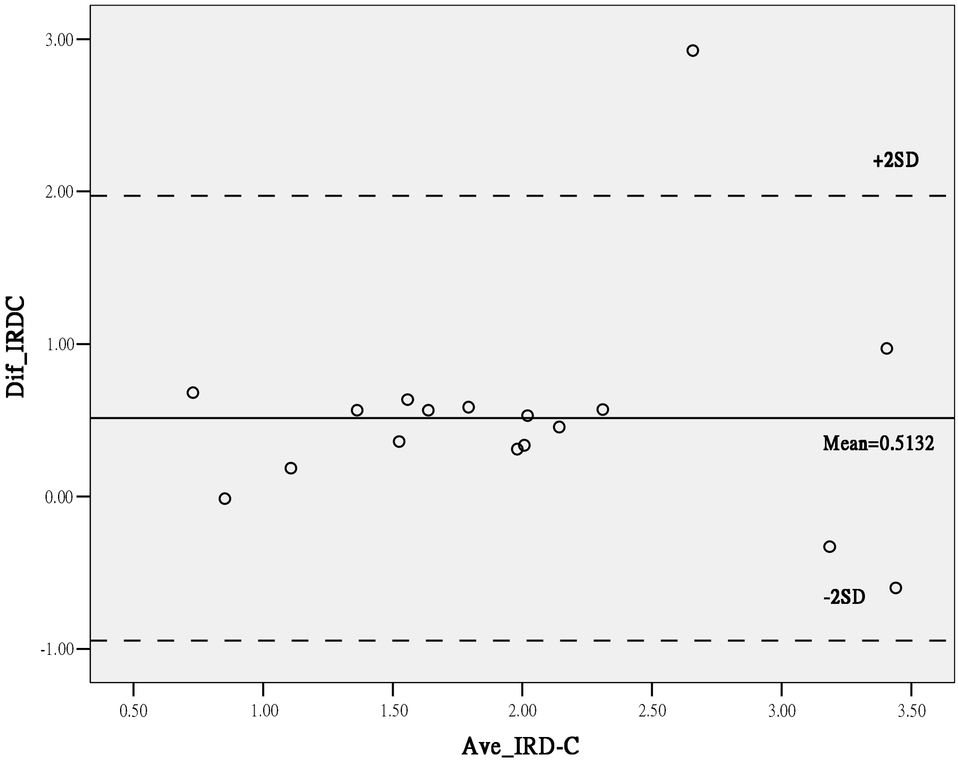


0.30
0.20
0.10
0.00
-0.10
+2SD
Mean=0.0062
-2SD
Dif_Asym-TrAR
0.10
0.20
0.30
0.40
Ave_Asym-TrA-R

0.10
0.00
-0.10
-0.20
+2SD
Mean=-0.0159
-2SD
Dif_AsymTrAC
0.20
0.30
0.40
0.50
0.60
Ave_Asym-TrA-C




**4. To compare the thickness changes in symptomatic side in patients and the averaged two sides in controls**

No significant difference between sides was reported in controls, so the averaged muscle thickness from controls was used to compare with patients with coccydynia.

| Side-muscles | Independent sample t test (p value) |
|---|---|
| Asym_Change in EO | 0.196 |
| Asym_Change in IO | **0.032*** |
| Asym_Change in TrA | 0.214 |
| Sym_Change in EO | 0.277 |
| Sym_Change in IO | **0.021*** |
| Sym_Change in TrA | 0.057 |

## Appendix 13.4. The additional data of CH6

1. Test of normality for the muscle thickness of TrA at different level contractions in controls

| | Kolmogorov-Smirnov(a) | | | Shapiro-Wilk | | |
|---|---|---|---|---|---|---|
| | Statistic | df | Sig. | Statistic | df | Sig. |
| Ave_RtR | .166 | 15 | .200(*) | .947 | 15 | .486 |
| Ave_Rt2 | .110 | 15 | .200(*) | .945 | 15 | .455 |
| Ave_Rt10 | .107 | 15 | .200(*) | .973 | 15 | .900 |
| Ave_LtR | .115 | 15 | .200(*) | .961 | 15 | .709 |
| Ave_Lt2 | .222 | 15 | .045 | .895 | 15 | .080 |
| Ave_Lt10 | .202 | 15 | .102 | .923 | 15 | .210 |

* This is a lower bound of the true significance.

a Lilliefors Significance Correction

2. Test of normality for the thickness change during contractions in controls

| | Kolmogorov-Smirnov(a) | | | Shapiro-Wilk | | |
|---|---|---|---|---|---|---|
| | Statistic | df | Sig. | Statistic | df | Sig. |
| Change_Rt2 | .184 | 15 | .181 | .911 | 15 | .141 |
| Change_Rt10 | .144 | 15 | .200(*) | .936 | 15 | .337 |
| Change_Lt2 | .226 | 15 | .038 | .889 | 15 | .065 |
| Change_Lt10 | .096 | 15 | .200(*) | .982 | 15 | .979 |

* This is a lower bound of the true significance.

a Lilliefors Significance Correction

3. Test of normality for the muscle thickness of TrA at different levels in patients

| | Kolmogorov-Smirnov(a) | | | Shapiro-Wilk | | |
|---|---|---|---|---|---|---|
| | Statistic | df | Sig. | Statistic | df | Sig. |
| ave_Sy_R | .156 | 15 | .200(*) | .931 | 15 | .279 |
| ave_Sy_2 | .108 | 15 | .200(*) | .971 | 15 | .875 |
| ave_Sy_10 | .133 | 15 | .200(*) | .978 | 15 | .952 |
| ave_Asy_R | .159 | 15 | .200(*) | .942 | 15 | .414 |
| ave_Asy_2 | .163 | 15 | .200(*) | .946 | 15 | .465 |
| ave_Asy_10 | .161 | 15 | .200(*) | .973 | 15 | .900 |

* This is a lower bound of the true significance.

a Lilliefors Significance Correction

4. Test of normality for the thickness change during contractions in patients

| | Kolmogorov-Smirnov(a) | | | Shapiro-Wilk | | |
|---|---|---|---|---|---|---|
| | Statistic | df | Sig. | Statistic | df | Sig. |
| Change_Sy_2 | .193 | 15 | .137 | .947 | 15 | .476 |
| Change_Sy_10 | .154 | 15 | .200(*) | .934 | 15 | .318 |
| Change_Asy_2 | .181 | 15 | .200(*) | .926 | 15 | .241 |
| Change_Asy_10 | .149 | 15 | .200(*) | .931 | 15 | .284 |

* This is a lower bound of the true significance.

a Lilliefors Significance Correction

## Appendix 13.5. The additional data of CH8

### 13.5.1. Between-trials reliability for IO latency in the pilot study

The IO latency is the difference between the timing of IO onset in the side of standing leg and the timing of opposite hip flexion.

#### First day Dominant IO latency

| | Intraclass Correlation | 95% Confidence Interval | | F Test with True Value 0 | | | |
|---|---|---|---|---|---|---|---|
| | | Lower Bound | Upper Bound | Value | df1 | df2 | Sig |
| Single Measures | .665 | .136 | .903 | 4.968 | 9 | 10 | .010 |
| Average Measures | **.799** | .239 | .949 | 4.968 | 9 | 10 | .010 |

One-way random effects model where people effects are random.

#### First day Non-dom IO latency

| | Intraclass Correlation | 95% Confidence Interval | | F Test with True Value 0 | | | |
|---|---|---|---|---|---|---|---|
| | | Lower Bound | Upper Bound | Value | df1 | df2 | Sig |
| Single Measures | .965 | .883 | .990 | 56.744 | 10 | 11 | .000 |
| Average Measures | **.982** | .938 | .995 | 56.744 | 10 | 11 | .000 |

One-way random effects model where people effects are random.

#### Second day Dominant IO latency

| | Intraclass Correlation | 95% Confidence Interval | | F Test with True Value 0 | | | |
|---|---|---|---|---|---|---|---|
| | | Lower Bound | Upper Bound | Value | df1 | df2 | Sig |
| Single Measures | .897 | .658 | .973 | 18.339 | 9 | 10 | .000 |
| Average Measures | **.945** | .794 | .986 | 18.339 | 9 | 10 | .000 |

One-way random effects model where people effects are random.

#### Second day Non-dom IO latency

| | Intraclass Correlation | 95% Confidence Interval | | F Test with True Value 0 | | | |
|---|---|---|---|---|---|---|---|
| | | Lower Bound | Upper Bound | Value | df1 | df2 | Sig |
| Single Measures | .667 | .140 | .904 | 5.011 | 9 | 10 | .010 |
| Average Measures | **.800** | .246 | .950 | 5.011 | 9 | 10 | .010 |

One-way random effects model where people effects are random.

### 13.5.2. Between-days reliability for IO latency in the pilot study

**Dominant IO latency**

| | Intraclass Correlation | 95% Confidence Interval | | F Test with True Value 0 | | | |
|---|---|---|---|---|---|---|---|
| | | Lower Bound | Upper Bound | Value | df1 | df2 | Sig |
| Single Measures | .111 | -.503 | .664 | 1.249 | 9 | 10 | .365 |
| Average Measures | **.199** | -2.026 | .798 | 1.249 | 9 | 10 | .365 |

One-way random effects model where people effects are random.

**Non-dom IO latency**

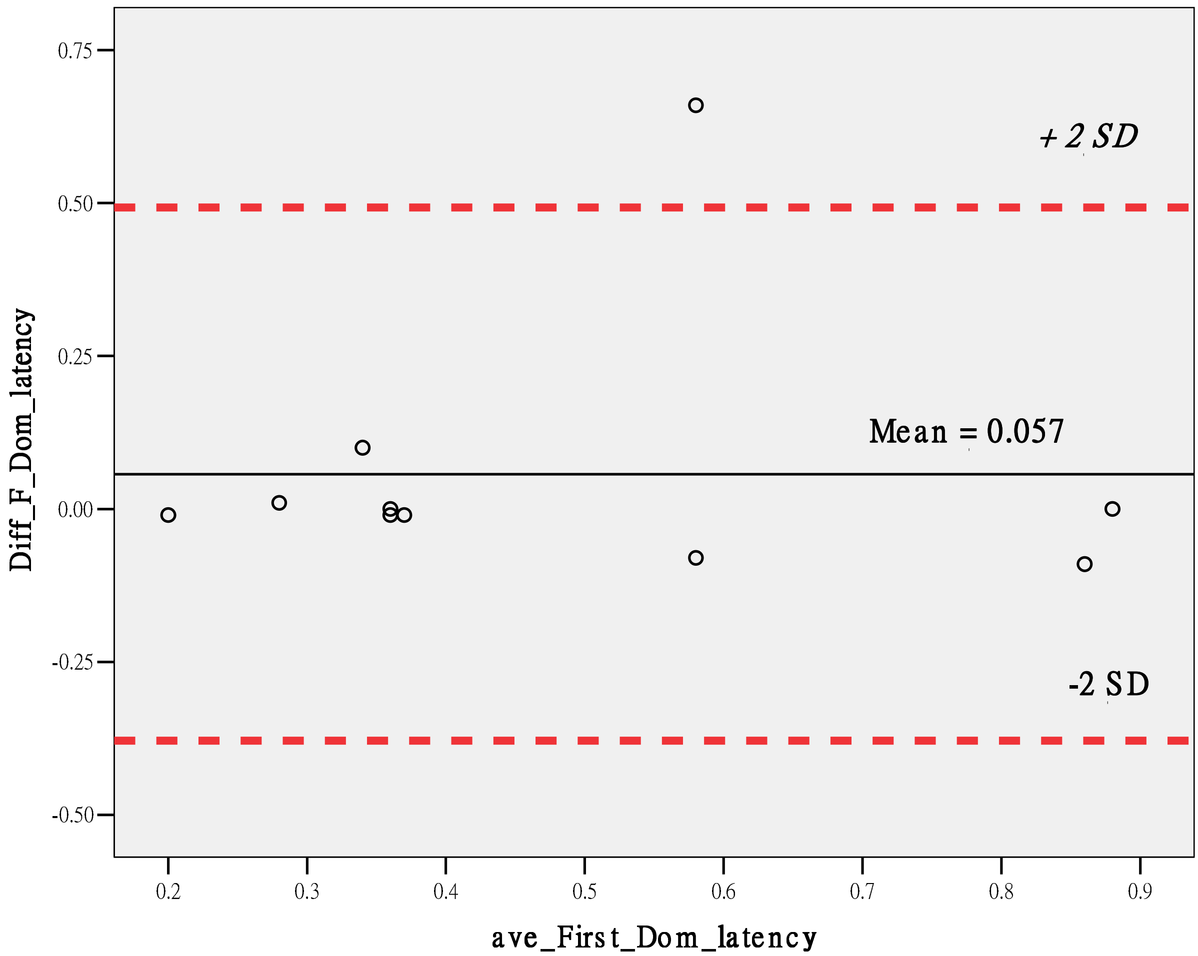
| | Intraclass Correlation | 95% Confidence Interval | | F Test with True Value 0 | | | |
|---|---|---|---|---|---|---|---|
| | | Lower Bound | Upper Bound | Value | df1 | df2 | Sig |
| Single Measures | .361 | -.279 | .788 | 2.129 | 9 | 10 | .127 |
| Average Measures | **.530** | -.775 | .881 | 2.129 | 9 | 10 | .127 |

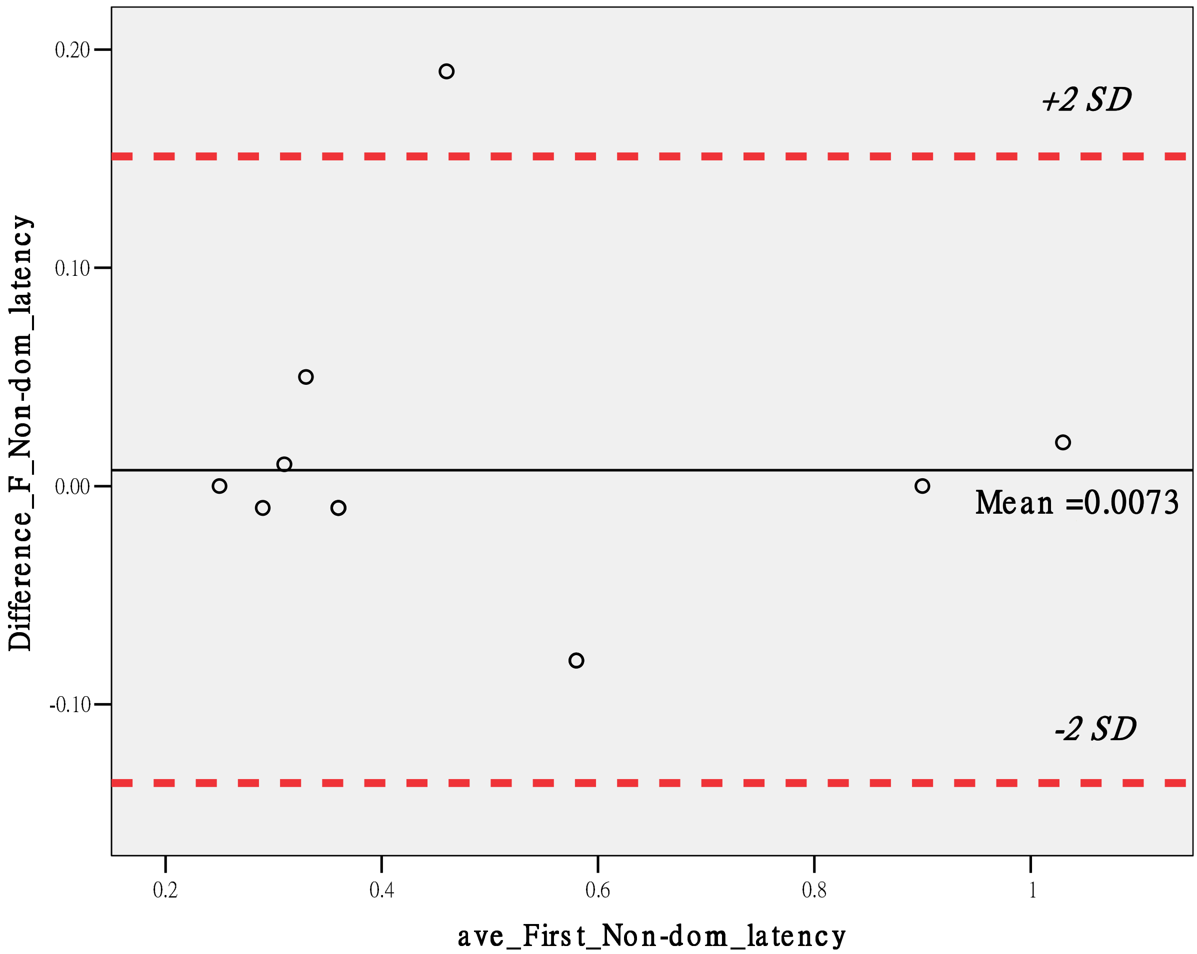
One-way random effects model where people effects are random.

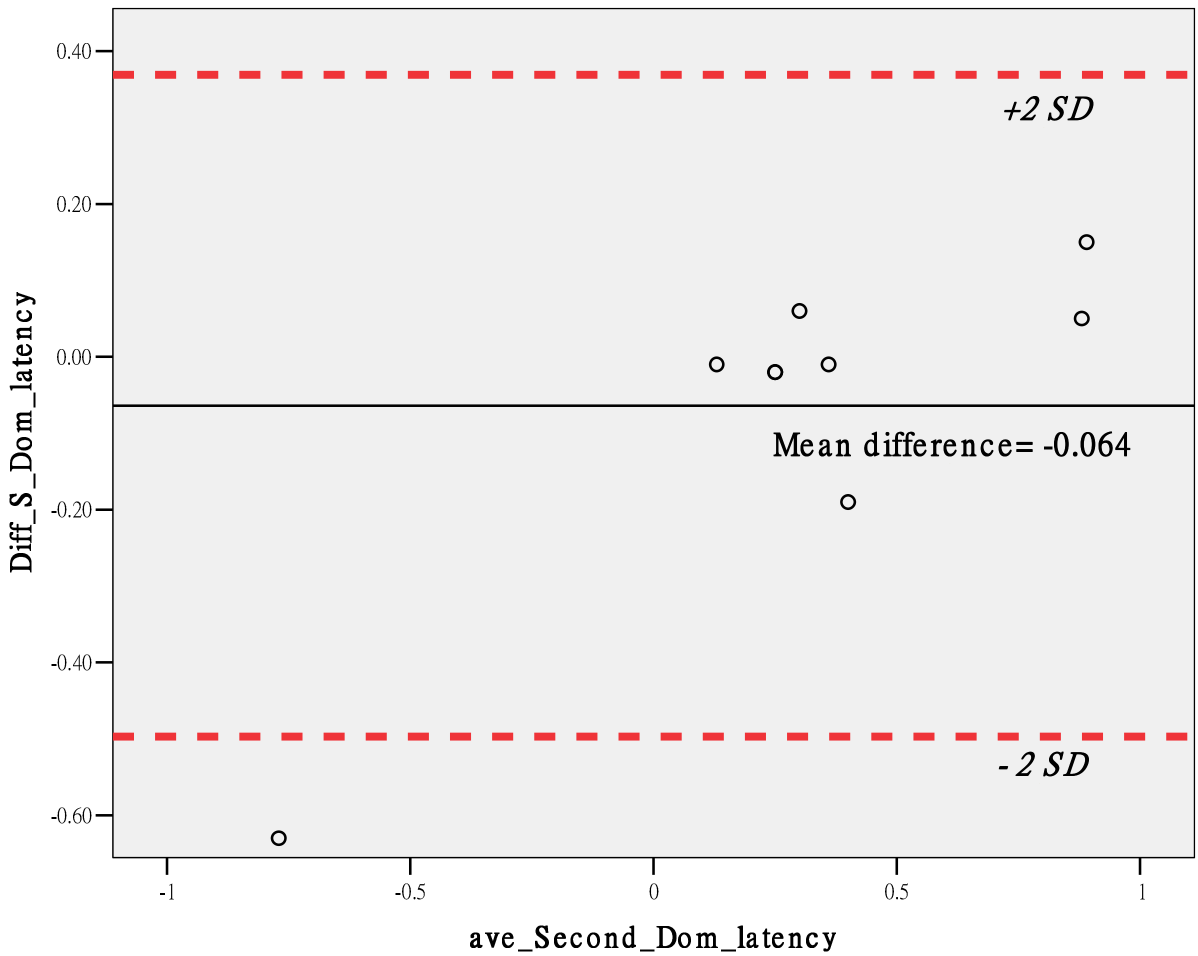
### 13.5.3. Bland-Altman plot for between-trials

| Between-trials measurement | | |
|---|---|---|
| Measurement | $\bar{d}$ (min) | 95% CI for $\bar{d}$ |
| $1^{st}$_ Dominant _latency | 0.057 | -0.379 - 0.493 |
| $1^{st}$_ Non-dom _latency | 0.0073 | -0.136 - 0.151 |
| $2^{nd}$ _ Dominant _ latency | -0.064 | -0.497 – 0.369 |
| $2^{nd}$_ Non-dom _latency | 0.035 | -0.2 - 0.271 |
| Between-days measurement | | |
| Measurement | $\bar{d}$ | 95% CI for $\bar{d}$ |
| Dominant _latency | 0.187 | -0.771 – 1.145 |
| Non-dom _latency | 0.033 | -0.462 – 0.528 |

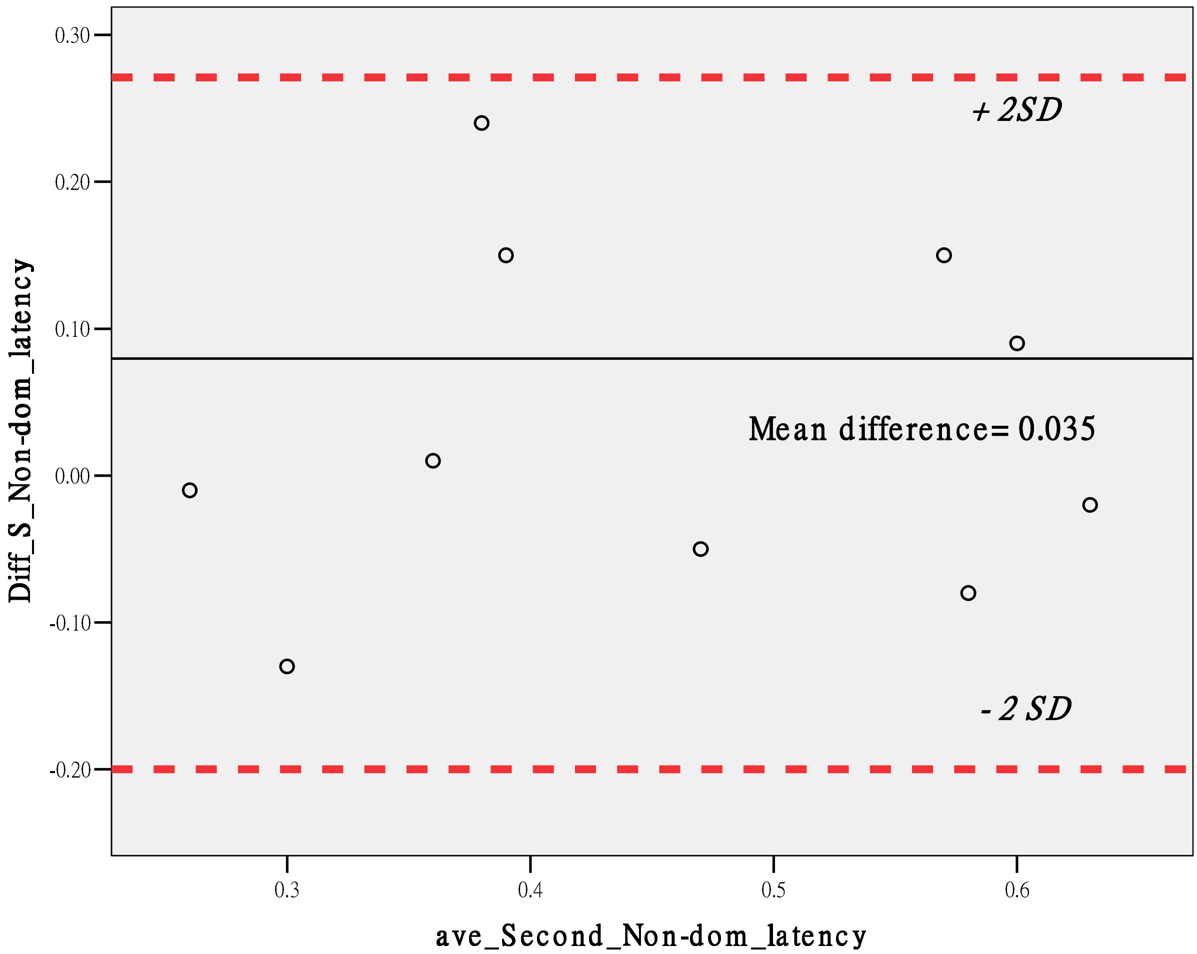
$1^{st}$ and $2^{nd}$ = trials on the first and second days respectively


0.75
0.50
0.25
0.00
-0.25
-0.50
Diff_F_Dom_latency
+ 2 SD
Mean = 0.057
-2 SD
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
ave_First_Dom_latency

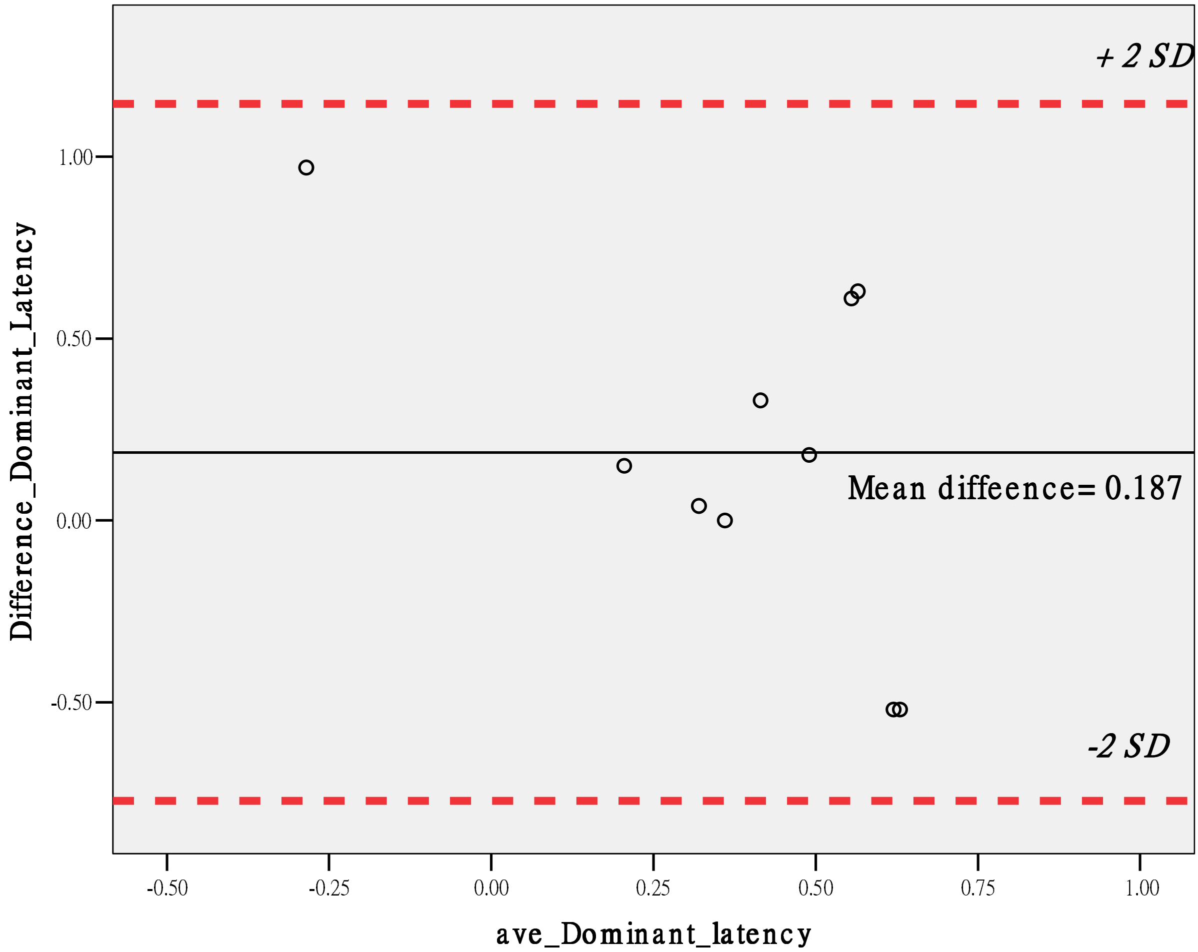

0.20
0.10
0.00
-0.10
Difference_F_Non-dom_latency
+2 SD
Mean =0.0073
-2 SD
0.2
0.4
0.6
0.8
1
ave_First_Non-dom_latency

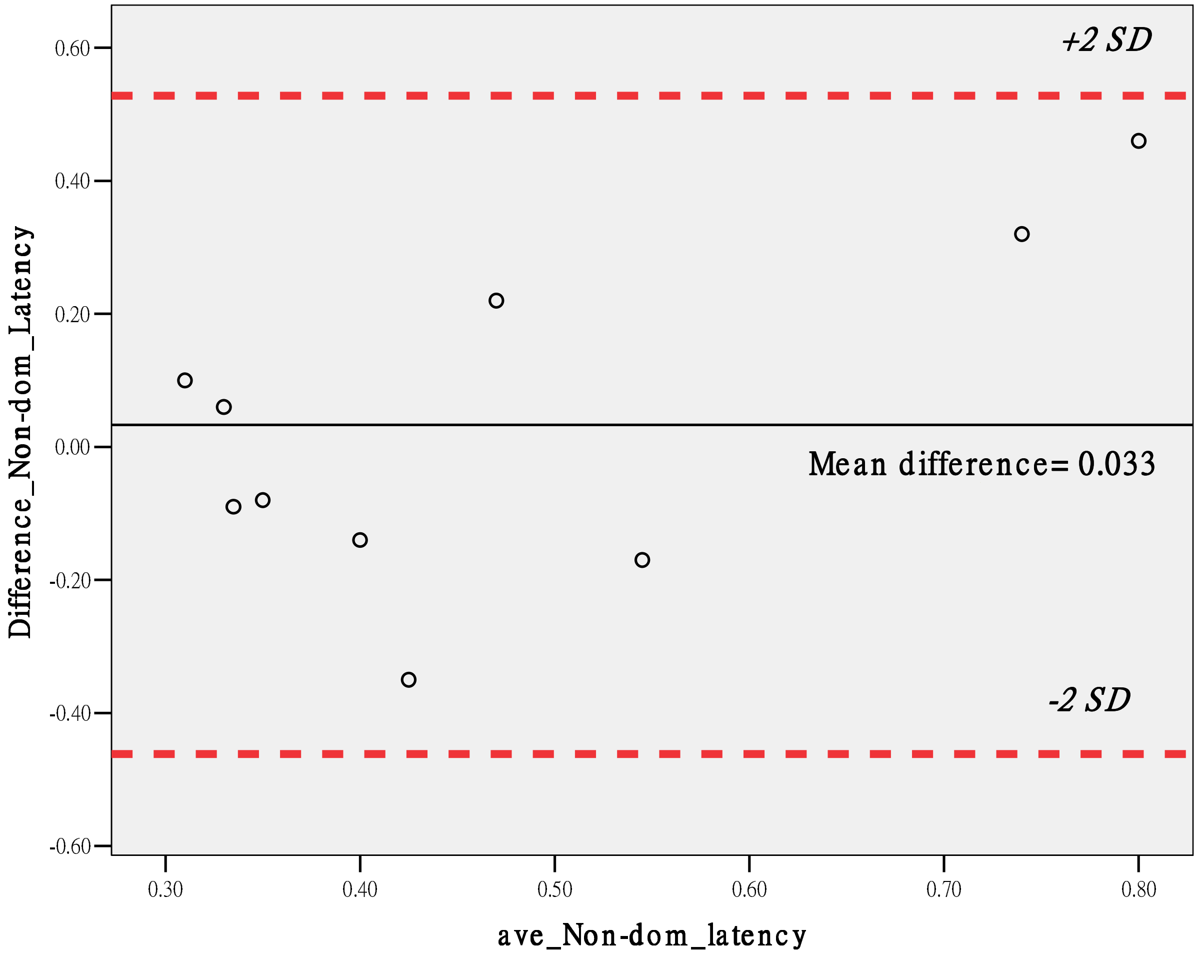


0.40
0.20
0.00
-0.20
-0.40
-0.60
+2 SD
Mean difference= -0.064
- 2 SD
-1
-0.5
0
0.5
1
Diff_S_Dom_latency
ave_Second_Dom_latency




**13.5.4. Bland-Altman plot for between-days**


+ 2 SD
1.00
0.50
0.00
-0.50
Difference_Dominant_Latency
Mean diffeence= 0.187
-2 SD
-0.50
-0.25
0.00
0.25
0.50
0.75
1.00
ave_Dominant_latency


+2 SD
Mean difference= 0.033
-2 SD
Difference_Non-dom_Latency
ave_Non-dom_latency
0.60
0.40
0.20
0.00
-0.20
-0.40
-0.60
0.30
0.40
0.50
0.60
0.70
0.80

## Appendix 13.6. The abstracts for conferences

### 13.6.1 MHLS Postgraduate conference, Southampton, UK. June 2009

**Reliability of measurements of abdominal muscle thickness on ultrasound imaging during the active straight leg raise test**

San-Pei Chen, School of Health Sciences

**Lay Statement**

A pilot study was conducted on Taiwanese women to assess the reliability of measurements made on ultrasound images of the abdominal muscles at rest and during a functional test termed the ASLR

**Purpose:** The abdominal muscles, specifically transversus abdominis (TrA) muscle, are thought be major stabilizers to protect the lumbar spine, so the assessment of these muscles is important in patients with low back pain. A type of back pain localized on the tail bone (coccyx), which is termed coccydynia, is a particular problem in Taiwan, mainly in women. Rehabilitative Ultrasound Imaging (RUSI) offers a direct way to visualize and measure muscles under different conditions. The active straight leg raise (ASLR) is a test used to examine the function of the lumbo-pelvic region. However, measurement of abdominal muscles during the ASLR task has not yet been examined for reliability. **Method:** Sixteen Taiwanese women, aged 20 to 35 years, attended for testing on two different days. The lateral abdominal wall was scanned bilaterally, twice at rest and twice during unilateral ASLR in each session, using an Aquila (Pie Data) ultrasound scanner with a 6MHz linear probe. Images were stored and muscle thickness was measured off-line using Image J software. The between-scans and between-days reliability of the measurements of muscle thickness were assessed using intra-class correlation coefficients (ICCs) and Bland-Altman plots. The smallest detectable change (SDC) and the standard error measurements (SEM) were calculated to provide an indication of clinically meaningful variations in measurements. A two-way analysis of variance (ANOVA) was used to calculate ICCs. **Results:** The thickness of the TrA muscle was similar on both sides at rest, right side mean 2mm, SD=0.07 during contraction 2.1mm, SD=0.06; left side at rest 2.1mm, SD=0.07, during contraction 2.2mm, SD=0.06. High ICCs (all >0.75) were found between-scans and between-days in both states. Specifically, for between-scans measurements, ICCs were 0.8- 0.99 at rest and 0.87-0.99 during ASLR. For between-days measurements, ICCs at rest were 0.87-0.9 and during ASLR 0.75-0.89. The SEM ranges were 0.01-0.03 found between-scans in both states and for between-days were 0.02 at rest and 0.02-0.03 during ASLR. The SDC ranges for between-scans were 0.04-0.21mm at rest and 0.05-0.19 mm during ASLR, and for

between-days were 0.15 mm at rest and 0.13-0.22 mm during ASLR. The Bland-Altman analyses showed good agreement, with the mean differences being close to zero. For example, for the between-day measurements of the right TrA at rest, the mean difference was 0 cm and 95% CI were 0.09- -0.09cm, on right TrA during ASLR was 0 cm and the 95% CI were 0.1- -0.1cm. **Conclusion:** The RUSI technique can be used reliably to measure TrA muscle thickness, whether performed at rest or during the functional ASLR test.

# RELIABILITIY OF MEASUREMENTS OF ABDOMINAL MUSCLE THICKNESS DURING ACTIVE STRAIGHT LEG RAISE (ASLR) TEST

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**This pilot study on healthy Taiwanese women examined the reliability of measuring thickness of the transversus abdominis (TrA) muscle at rest and during a functional task of active straight leg raising (ASLR), using real-time ultrasound imaging. The reliability of repeated measurements was assessed between-scans and between-days in 16 subjects using intra-class correlation coefficients (ICCs) and Bland-Altman analysis. High ICCs indicated good reliability of all measurements (ICC > 0.73), particularly at rest (ICC > 0.8) and good agreement was displayed by Bland-Altman results. The findings demonstrate that ultrasound imaging has sufficient reproducibility for examining the TrA muscles during the ASLR test.**

## I. INTRODUCTION

The abdominal muscles are considered to be stabilizers in the lumbo-pelvic region, so assessment of these muscles is recognized as being important. The transversus abdominis (TrA) muscle is thought to play a particularly important role as a stabilizer to protect the lumbar spine [1]. The abdominal muscles can become wasted and weak in people with low back pain. A type of back pain can arise from the tail bone (coccyx), which is termed coccydynia [2]. This is a particular problem in Taiwan, more so than in western countries, possibly due to lifestyle differences, although evidence to support this is only anecdotal. The incidence of coccydynia is five times greater in women than men [2]. Rehabilitative Ultrasound Imaging (RUSI) offers a direct way to visualize and measure the abdominal muscles at rest and during functional tasks [3]. The active straight leg raise (ASLR) is a test used to examine the function of the lumbo-pelvic region. However, the reliability of repeated measurement of abdominal muscles during the ASLR task has not yet been established.

## II. METHODS

A pilot study was carried out on 16 young Taiwanese women to establish the reliability of ultrasound measurements of TrA muscle thickness. Subjects aged 20 to 35 years-old were recruited from the Taiwanese students' society of the University of Southampton. They attended sessions for testing on two different days.

A real-time ultrasound scanner (Aquila, Pie Data) was used to obtain images of the muscles, using a 6MHz linear transducer (see Figure 1). The lateral abdominal wall was scanned bilaterally, twice at rest and twice during unilateral ASLR in each session. Alignment of the transducer was maintained as consistently as possible during the contraction, but some relative motion was unavoidable. Images were stored and muscle thickness was measured manually off-line using Image J software (http://rsb.info.nih.gov/ij/). The cursor was placed on the inside edge of superior and inferior muscle boarders in the middle region of the image where they are parallel horizontal.

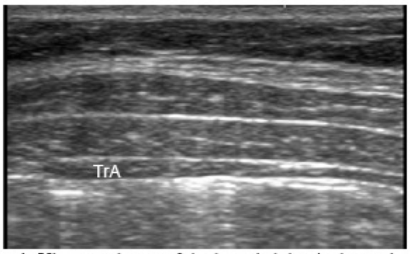


Figure 1: Ultrasound scan of the lateral abdominal muscles, indicating transversus abdominis (TrA), which is the deepest muscle.

Statistical analyses used to assess the between-scans and between-days reliability of the measurements of muscle thickness were intra-class correlation coefficients (ICCs) and Bland-Altman plots. The smallest detectable change (SDC) reflects the smallest within-groups changes in scores [5]. The standard error of measurement (SEM) and SDC were calculated to provide an indication of clinically meaningful variations in measurements. A two-way analysis of variance (ANOVA) was used to compare the differences between sides and between different states (i.e. rest and contraction) to calculate ICCs.

## II. RESULTS

The thickness of the TrA muscle under the different conditions is shown in Table 1.

Table 1. Descriptive findings of transversus abdominis (TrA) muscle thickness (mm) obtained from the right (Rt) and left (Lt) sides of the abdomen, in states of rest and contraction during an active straight leg raise (ASLR)

| Side/States | Mean (mm) | *SD (mm)* |
|---|---|---|
| Rt/Rest | 2.1 | *0.7* |
| Rt/ASLR | 2.09 | *0.65* |
| Lt/Rest | 2.1 3 | *0.63* |
| *Lt/ASLR* | *2.2 2* | *0.56* |

High ICCs (ranges 0.75-0.99) were found between-scans and between-days, both at rest and during contractions (see Table 2).The SEM values were vey small ranging from 0.06-0.33 mm. The SDC values were also small, ranging from 0.04-0.22 mm.

Table 2. Results for intraclass correlations (ICCs), standard error measurement (SEM) and smallest detectable changes (SDC).

| Between-scans measurement | | | |
|---|---|---|---|
| **Side/States/ Day** | ICCs | SEM (mm) | SDC (mm) |
| **Rt/Rest/1st** | 0.85 | 0.26 | 0.18 |
| **Rt/Rest/2nd** | 0.87 | 0.28 | 0.19 |
| **Rt/ASLR/1st** | 0.96 | 0.18 | 0.12 |
| **Rt/ASLR/2nd** | 0.94 | 0.19 | 0.13 |
| **Lt/Rest/1st** | 0.8 | 0.3 | 0.21 |
| **Lt/Rest/2nd** | 0.88 | 0.23 | 0.16 |
| **Lt/ASLR/1st** | 0.99 | 0.06 | 0.04 |
| **Lt/ASLR/2nd** | 0.99 | 0.07 | 0.05 |
| **Between-days measurement** | | | |
| **Side/States** | ICCs | SEM (mm) | SDC (mm) |
| **Rt/Rest** | 0.9 | 0.22 | 0.15 |
| **Rt/ASLR** | 0.75 | 0.33 | 0.22 |
| **Lt/Rest** | 0.87 | 0.23 | 0.15 |
| **Lt/ASLR** | 0.89 | 0.19 | 0.13 |

1st and 2nd = mean of scans on the first and second days respectively; Rt and Lt = mean values for the right and left sides.

The Bland-Altman analyses for between-scans and between-days reliability showed good agreement, with the mean differences being close to zero (see Table 3).

Table 3. Results of the Bland and Altman analyses: mean difference ( $\bar{d}$ ) and the 95% limits of agreement

| | Bland and Altman | |
|---|---|---|
| | $\bar{d}$ | 95% CI for $\bar{d}$ |
| **Between-scans measurement** | | |
| **1st /Rt /Rest** | 0 | 0.11 → -0.1 |
| **1st /Rt/ ASLR** | 0 | 0.11 → -0.13 |
| **1st/Lt/Rest** | 0.03 | 0.15 → -0.09 |
| **1st/Lt/ASLR** | 0 | -0.1→0.1 |
| **2nd /Rt /Rest** | 0.01 | 0.08 → -0.07 |
| **2nd /Rt/ ASLR** | -0.01 | 0.07 → -0.08 |
| **2nd /Lt/Rest** | 0.01 | 0.08 → -0.06 |
| **2nd /Lt/ASLR** | -0.01 | 0.07 → -0.1 |
| **Between-days measurement** | | |
| **Rt/ Rest** | 0 | 0.09 → -0.09 |
| **Rt/ASLR** | 0 | 0.1 → -0.1 |
| **Lt/Rest** | -0.02 | 0.1 → -0.14 |
| **Lt/ASLR** | -0.01 | 0.15 → -0.17 |

$\bar{d}$ is the mean difference between measurements of muscle thickness; 95% CI is the confidence intervals for the mean difference; 1st and 2nd = mean of scans on the first and second days respectively; Rt and Lt = mean values for the right and left sides.

## IV. DISCUSSION

This is the first study to use real-time ultrasound imaging to measure the thickness of TrA muscles during the ASLR functional task. Similar muscle thicknesses of TrA at rest were found on both sides (Table 1) which is consistent with the literature [4].

All ICC values were high (>0.75), indicating that the technique has good reliability. The greater ICC values for the measurements made at rest than during contraction were consistent with existing published work for voluntary contractions of the TrA muscle [3]. The greater measurement errors during contractions may be caused by movement of the transducer over the skin surface or movement of the muscles beneath the skin relative to the transducer. Another explanation might be that the degree of contraction may not be identical between efforts, as this is difficult to standardise for the abdominal muscles.

The SEM and SDC values were very small and again tended to be greater for measurements made during contraction than at rest. The SDC is interpreted as a "real" change [5], so the small values found in our results can be interpreted as small measurement errors.

The limitation of the holding the transducer manually would have potentially involved changes in its angle relative to the muscle, but obviously not sufficiently enough to produce poor reliability on repeated testing. Despite the greater degree of error in measuring scans obtained during the ASLR task than at rest, all measurements were sufficiently reliable for the ultrasound technique to be used in further study of young Taiwanese women with coccydynia.

## V. CONCLUSION

The application of ultrasound imaging for measuring TrA muscle thickness showed good reliability, whether performed at rest or during a functional movement using the ASLR tests.

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### 13.6.3. The 2nd Asia-Oceanian Conference of Physical and Rehabilitation Medicine, Taipei, Taiwan. April , 2010

## Rehabilitative ultrasound imaging of transversal abdominis muscles in Taiwanese women: effects of age and different contraction states

San-Pei Chen[1,2], Li-Wei Chou[1,3,4], Maria Stokes[2]

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[2] School of Health Sciences, University of Southampton, Southampton (UK)
[3] School of Chinese Medicine, College of Chinese Medicine, China Medical University (Taiwan)
[4] Department of Physical Therapy, China Medical University (Taiwan)

**Purpose:**

The abdominal muscles, in particular the transversus abdominis (TrA) muscle, are considered to be stabilizers of the spine in the lumbo-pelvic region, so assessment of these muscles is recognized as being important. The TrA can become wasted and its activity pattern relative to other muscles may be altered during functional tasks in people with low back pain. Rehabilitative ultrasound imaging (RUSI) offers a direct way to visualize and measure muscles non-invasively. However, research has mainly been limited to Western populations and the abdominal muscles have not yet been examined in Taiwanese women. A preliminary study has shown that the reliability of RUSI in a population of Taiwanese women was sufficiently high enough (ICC>0.75) to apply the technique in further studies (published in conference proceedings of Biomedical Engineering and Medical Physics, Oxford, June 2009, Chen et al.). The present study aimed to characterize the morphometry of TrA in Taiwanese women of different ages, both at rest and during a functional activity using the active straight leg raise (ASLR) test to produce abdominal muscle contraction.

**Materials and methods:**

Thirty-three healthy Taiwanese women aged 18 to 65 years were studied; 16 participants were recruited through the Taiwanese Student Society at the University of Southampton UK, to establish the reliability of the RUSI technique, and 17 participants were recruited at the China Medical University Hospital (CMUH) in Taiwan as part of an age-matched control group for a related study on back pain. In each session, the lateral abdominal wall was scanned bilaterally, twice at rest and twice during a unilateral ASLR. The mean values for the two scans taken in each contraction state were used in the analysis. In Southampton, an Aquila (Pie Data) ultrasound scanner with a 6MHz linear probe was used to obtain images. In Taiwan, a GE ultrasound scanner with a 7L linear probe (2.5-7 MHz) was used. All images were stored and muscle thickness was measured off-line using Image J software.

**Results:**

Due to the age differences between the two study cohorts in the UK and Taiwan, the muscle thicknesses results are presented for the two groups separately. In the younger group (mean age =25.9 ± SD 3.3 years), TrA thickness was smaller than in the older group (mean age =43.6 ± SD 12.8), both at rest and during the ASLR (right TrA thickness at rest, mean ± 1 standard deviation; 2.1±0.7mm and 2.1±0.6mm respectively; during ASLR 2.1±0.7mm young group and 2.8 ±1.5mm older group). It is interesting to note that the younger group did not appear to recruit their TrA during the ASLR test. The thickness of TrA was similar on both sides at rest and during contraction in both groups.

**Conclusion:**

This study provides normal reference values for TrA muscle thickness in healthy Taiwanese women of different ages as a basis for studying pathological groups. The findings in the younger women show less thickness changes than in the older. The present findings confirm the symmetry of TrA thickness between the two sides of the body found in Western populations. The lack of change in TrA thickness during the ASLR in young women warrants further study of motor control mechanisms in this age group.

### 13.6.4. MHLS Postgraduate conference, Southampton, UK. June, 2010

**Rehabilitative ultrasound imaging of transversus abdominis muscles in healthy Taiwanese women**

San-Pei Chen, School of Health Sciences

**Lay statement**

Abdominal muscle thickness was measured in healthy Taiwanese women of different ages to provide normal reference values for comparison with women with low back pain.

**Purpose:** The abdominal muscles, specifically the transversus abdominis (TrA) muscle, are considered to be stabilizers of the spine in the lumbo-pelvic region. The TrA can become wasted and its activity pattern relative to other muscles may be altered during functional tasks in people with low back pain. Rehabilitative ultrasound imaging (RUSI) offers a non-invasive way to visualize and measure muscles. A preliminary study has shown the reliability of RUSI is good enough (ICC>0.75) to apply it to further studies. The present study aimed to characterize the morphometry of TrA in Taiwanese women of different ages, both at rest and during a unilateral active-straight-leg-raise (ASLR) test to produce abdominal muscle contractions. **Methods:** Thirty-three healthy Taiwanese women aged 20-65 years were studied; 16 were recruited through the Taiwanese Student Society, University of Southampton UK (aged 20-35 years), to establish the reliability of the RUSI technique, and 17 at the China Medical University Hospital (CMUH) in Taiwan (aged 30-65 years). The lateral abdominal wall was scanned bilaterally, twice at rest and twice during ASLR. The images were obtained using an Aquila (Pie Data) ultrasound scanner with a 6MHz linear probe in Southampton and a GE ultrasound scanner with a 7L linear probe (2.5-7 MHz) was used in Taiwan. All images were stored and muscle thickness was measured off-line using Image J software. **Results:** Due to the age differences between the two study cohorts in the UK and Taiwan, the muscle thicknesses results are presented for the two groups separately. In the younger group (mean age 25.9 ± SD 3.3, body weight 52.8 ± SD 7.6 kg ), TrA thickness was smaller than in the older group (mean age 43.6 ± SD 12.8; weight 57.3 ± SD 10.8 kg), both at rest (2.1±0.7 mm and 2.1±0.6mm) and during the ASLR (2.1±0.7mm and 2.8±1.5 mm). The younger group did not appear to recruit their TrA during the ASLR test. The thickness of TrA was similar on both sides at rest and during contraction in both groups.**Conclusion:** This study provides normal reference values for TrA muscle thickness in healthy Taiwanese women of different ages as a basis for studying pathological groups. The findings in the younger women show less thickness change than in the older women. The present findings confirm the symmetry of TrA thickness between the two sides of the body found in Western populations. The lack of change in TrA thickness during the ASLR in young women warrants further study of motor control mechanisms in this group.

## Appendix: 13.7. Paper preparation for publication

13.7.1 Consistency of abdominal muscle thickness changes during different levels of effort of contraction in Taiwanese women with coccydynia compared to healthy controls. (CH6)

13.7.2. Abdominal muscle thickness and recruitment during functional tasks in women with coccydynia and healthy controls. (CH 5 & CH8)

13.7.3 Difference in change in lumbo-pelvic angles between patients with coccydynia and healthy controls. (CH 7)

13.7.4 Case studies using pelvic belt in the management of symptoms in patients with coccydynia (CH 9)

## Appendix 13.8. Ultrasonography for Pelvic floor muscles/ assessment of the bladder

### 1. Background of the applied technique

Pelvic floor muscles (PFM) are critical in the lumbopelvic region, but are difficult to objectively assess. The ultrasound imaging technique offers a way to directly visualize the PFM and assess the performance of bladder. Transperineal ultrasound (TP) and transabdominal ultrasound (TA) are two ways to inspect the PFM and bladder, and the reliability of TP has been established to evaluate women with incontinence (Thompson et al., 2005 ). Because the PFM cannot be measured directly, the movement of pelvic floor or the bladder would be a better way to justify the function of PFM. Thompson et al, (2005) assessed the reliability of TA and TP imaging during a PFM contraction and Valsalva manoeuvre in both transversal and sagittal views in 120 women. Although both ways showed good reliability of measurement on bladder neck assessment, TA was less reliable than TP in particular during PFM contraction. A significant agreement between TA and TP for assessing the direction of movement during PFM contraction has been reported. However, the diverse measures in 18 subjects were reported across continent and incontinent subjects. Thompson quoted the findings from Murphy et al, (2006) reported a good inter-rater reliability for measurements made during PFM contraction. They compared the measurements on sagittal and transverse views, and found the sagittal view was more reliable for measurements during PFM contraction.

TP is viewed as an invasive way to assess the PFM, and a bony mark of the pubis can be used as reference point to decrease the errors of measurement (see figure 1). However, due to it being an invasive application, it is not widely accepted in the clinical area or in physiotherapy. The TA imaging offers a non-invasive way for clinicians to assess the movement of PFM and bladder, but the reliability is poorer than with the TP method, this is due to the greater movement of the probe over the abdomen or the influence of IAP on the bladder neck (Thompson et al., 2005 ).

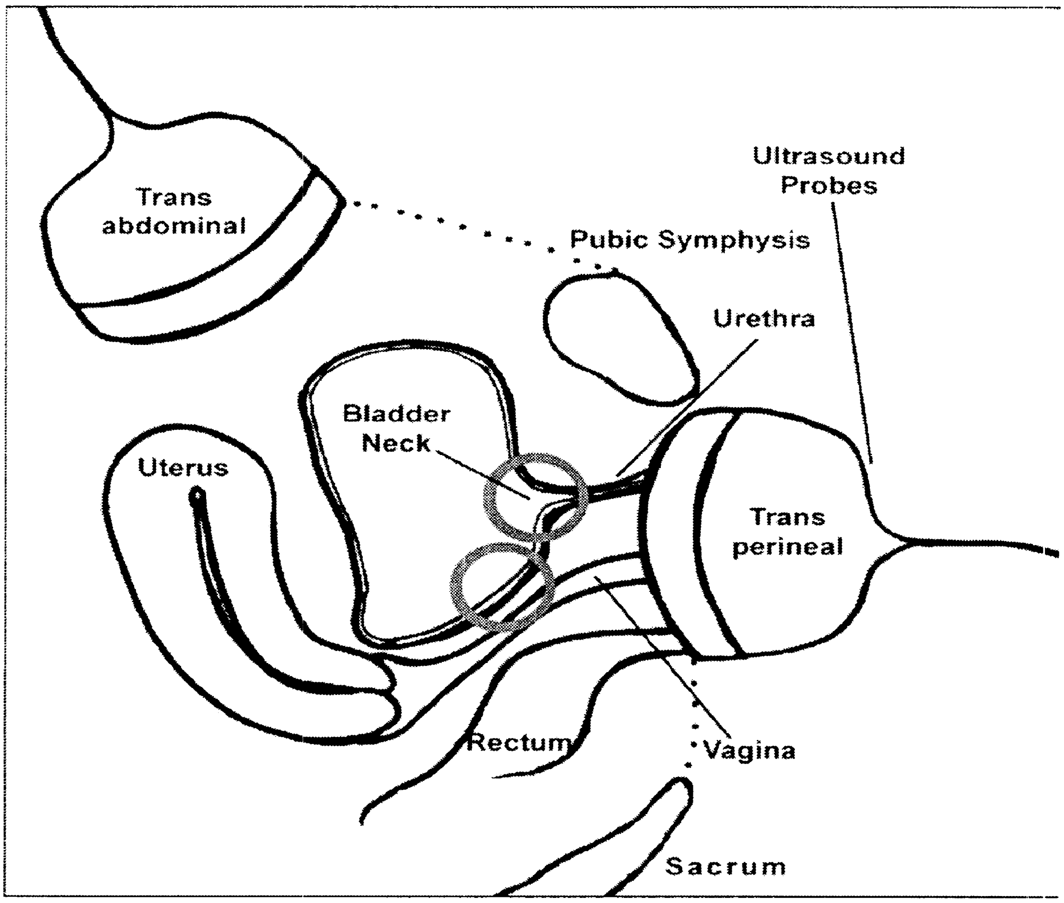



**Figure.1. Probe placement for transperineal and transabdominal ultrasound methods showing the areas where the movement is visualized; bladder neck for transperineal ultrasound and bladder base for transabdominal ultrasound (adopted from Thompson et al, 2005)**

Previous studies demonstrated that the TA method is also a reliable way to inspect the PFM with a more acceptable method. The TA measurements on the sagittal view were more reliable than in the transverse view, during PFM contraction. Future studies are necessary to justify the reliability of TA in normal subjects and patient groups. Thompson et al, (2006) assessed the association between different measurements of PFM function in continent and incontinent women, and found ultrasound to be a useful tool to determine the direction of pelvic floor movement in clinical assessment (Thompson et al., 2006a). Additionally, the correlation of PFMs performance (hypertonicity or hypotonicity) and a specific dysfunction (such as coccydynia, incontinence or LBP) has not yet been established to support our suggestion, that lumbo-pelvic dysfunction such as coccydynia and backache may co-exist with hypertonic PFM.

**2. The experimental procedure**

A standard protocol of bladder filling was adopted from Thompson et al (2005, 2006). Each participant was asked to empty their bladder one hour before examining and then to drink 500ml water and not drink again until the completion of the ultrasound scanning (Thompson et al., 2006a, Thompson et al., 2005 , Thompson et al., 2006 , Thompson et al., 2006b). All rest images were frozen and obtained at the end of the expiration. The investigator instructed the participants to do the activation movements correctly, prior to the collection of the images in contraction.

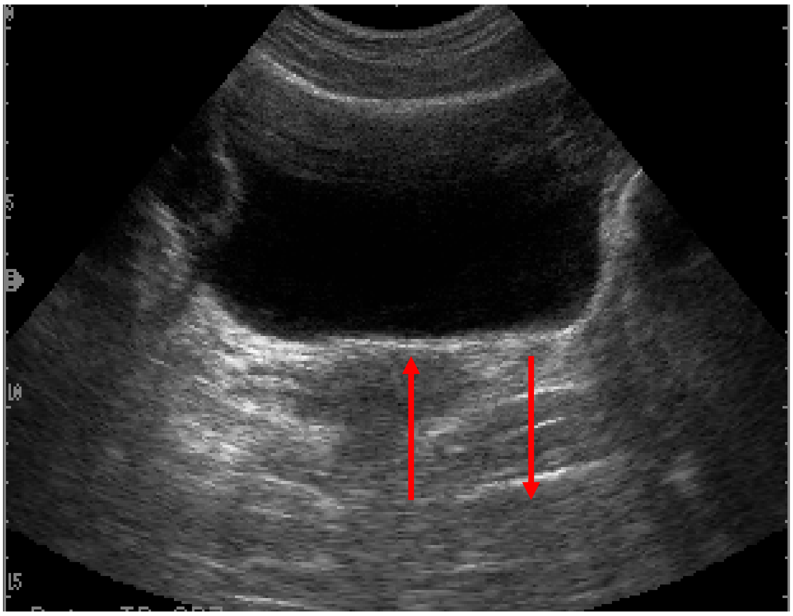
The images of the bladder at rest and during spinal loading, with the aid of a curvilinear probe, were taken in a sagittal and transversal view, whilst the subjects were kept in the same position. To gain the sagittal views, the investigator placed the probe in a sagittal orientation inferior to the umbilicus and moved down until it encountered the superior aspect of the symphysis pubis. The probe was manipulated slightly inferior and posterior, in order to allow a clear image of the proximal part of neck and the bladder. Afterward, the subject was asked to do pelvic floor muscles (PFM) contraction. The maneuver was replicated from a series of studies by Thompson et al (2005, 2006). They instructed participants "*draw in and lift the pelvic floor muscles*" to activate PFMs. Subsequently the probe was changed to place in a transversal orientation directly over the superior part of the symphysis (Thompson et al., 2006b, Thompson et al., 2006a, Thompson et al., 2005, Thompson et al., 2006 ). The investigator manipulated the angle of the probe inferior and posterior between 45° and 60° to obtain a clear image and then asked the subject performing PFM contraction to gain the image in contraction. Finally, the subject was asked to empty their bladder before coming back to receive a scan in order to check any urine retention.

The reason for using the PFM contractions as the way to activate the PFM is based on the findings of Thompson et al (2006). They compared the assessments of the movement in bladder neck or pelvic floor between transabdominal (TA) and transperineal (TP) ultrasounds and found TA ultrasound to be less reliable than TP ultrasound for measurement during a Valsalva manoeuvre. However, significant agreement was demonstrated between TA and TP ultrasounds during PFM contraction. The difference may be due to the significant generation of intra-abdominal pressure (IAP) during a Valsalva manoeuvre. The increased IAP that resulted in bladder base depression, and the increase of muscle activity in abdominal walls, had influence on the of TA ultrasound examination (Thompson et al., 2006a). Therefore, PFM contraction is a better way to activate muscles with minimal synchronous activations of the abdominal walls.

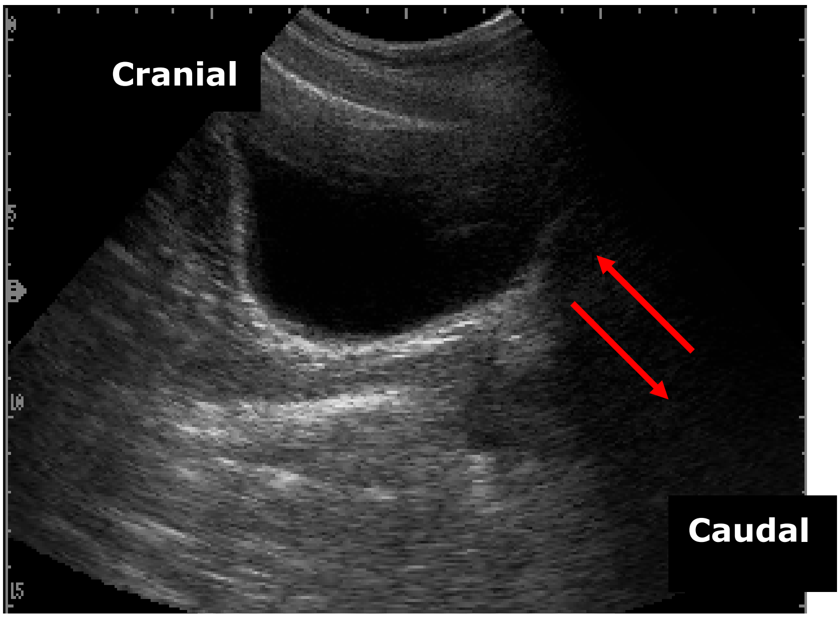
**3. Outcome measurements**

Pelvic floor muscles (PFMs) cannot be investigated directly, but the shape of bladder, neck and movement of bladder can be recorded, according to the direction of movement, such as;

elevated, descending, cranial, and caudal or no motion, during the experimental sessions (Figure 2).



A.




B.

**Figure 2 USI assessments of the function of PFM. (A) The transversal view of bladder. The arrows indicate the directions of bladder (i.e. elevating or descending). (B) The sagittal view of bladder. The arrows indicate the direction of bladder motion (i.e. cranial or caudal).**

In the transversal view, each image of the bladder was recorded in terms of the symmetrical or asymmetrical. The information of bladder neck motion was obtained from the sagittal views. The ability to empty the bladder was assessed in regard to the bladder function. The mentioned information for each participant, as referred to above, was recorded in table 1.

**Table 1: the recording of bladder function was listed.**

| Bladder- Transversal view | | | |
|---|---|---|---|
| Date | Coding | File name | |
| | | TFR<br>**T**ransversal<br>**F**illed Bladder<br>**R**est | Resting shape<br>☐ Flat base<br>☐ Asymmetrical base<br><br>Remark: ________________ |
| | | TFC<br>**T**ransversal<br>**F**illed Bladder<br>**C**ontraction | Changes of Bladder base<br>☐ Elevation of the bladder base<br>☐ No motion changes<br>☐ Drop of the bladder base<br><br>Remark: ________________ |
| | | TER<br>**T**ransversal<br>**E**mpty Bladder<br>**R**est | Can they empty the bladders<br>☐ Yes<br>☐ No |

| Bladder- Sagittal view | | | |
|---|---|---|---|
| Date | Coding | File name | |
| | | SF<br>**S**agittal<br>**F**illed Bladder<br>**R**est | |
| | | SFC<br>**S**agittal<br>**F**illed Bladder<br>**C**ontraction | Direction of bladder neck movement<br>☐dorsal<br>☐ caudal<br>☐ elevation<br>☐ drop |
| | | SER<br>**S**agittal **E**mpty<br>Bladder **R**est | Can they empty the bladders<br>☐ Yes<br>☐ No |

**4. References:**

Thompson, J., O'sullivan, P., Briffa, N. & Neumann, P. (2006a) Comparison of transperineal and transabdominal ultrasound in the assessment of voluntary pelvic floor muscle contractions and functional manoeuvres in continent and incontinent women *Int Urogynecol J*.

Thompson, J., O'sullivan, P., Briffa, N. & Neumann, P. (2006b) Differences in muscle activation patterns during pelvic floor muscle contraction and Valsalva manouevre *Neurourology and Urodynamics,* 25**,** 148-155.

Thompson, J., O'sullivan, P., Briffa, N. & Neumann, P. (2006 ) Altered muscle activation patterns in symptomic women during pelvic floor muscle contraction and Valsalva manouuevre *Neurourology and Urodynamics.,* 25**,** 268-276.

Thompson, J., O'sullivan, P., Briffa, N., Neumann, P. & Court, S. (2005 ) Assessment of pelvic floor movement using transabdominal and transperineal ultrasound *International urogynecology Journal and pelvic floor dysfunction* 16**,** 285-292.

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