

IMPACT OF PRIOR HYSTERECTOMY ON RISK OF SUBSEQUENT BACK INJURY IN  
FRONT LINE HEALTHCARE WORKERS

by

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## Abstract

Low back injury (LBI) is associated with altered core muscle function and studies have validated the role of these deep stabilizing muscles in prevention and treatment of back pain and injury. No previous studies have evaluated the impact of surgery such as abdominal hysterectomy (AH) on these deep stabilizers and the potential for increased risk of LBI following surgery. The aims of this research were to investigate a link between AH and LBI first with administrative health data analysis and then clinically by measuring muscle thickness with rehabilitation ultrasound imaging (RUSI) before and after surgery.

A retrospective cohort of 37,057 female frontline healthcare workers, a population at high risk of occupational LBI due to the heavy nature of their work, was extracted. Exclusion of 27,987 due to a history of back pain or injury, prior hysterectomy or failure to meet the provincial residency requirement of five years left a sample size of 9,070. Within this research sample, 634 (7%) had undergone hysterectomy, a prevalence much lower than the published value of 30%. Statistical analysis revealed no increased risk of LBI in this cohort of healthcare workers without prior history of LBI. Clinical RUSI assessment of the core muscles would investigate if this was because there was no change in the muscle function post-surgically.

Validity and reliability of RUSI to evaluate core muscle function have been established for intersessions up to two weeks. A group of women not undergoing AH was used to establish reliability over intervals of four, eight and twelve weeks. Intraclass correlations ( $ICC_{3,1}$ ) ranging from 0.75 to 0.90 for measured muscle thickness in the deep abdominal and lumbar muscles exceeded the minimum standard of 0.70 for research purposes. Percent change measures did not meet this standard.

A prospective descriptive case series involving nine individuals undergoing AH found post-surgical decreases in measurements of the deep abdominal stabilizers most notably in the participants with a history of previous low back pain/injury or who were obese. These findings support continued investigation of the relationship between AH and LBI including individuals with risk factors such as prior low back pain/injury and/or obesity.

## Preface

The work in this dissertation was conceived, conducted and written by Lois Lochhead. The research described in this dissertation was approved by the University of British Columbia's (UBC) Behavioural Research Ethics Board: H10-01684 and the UBC Clinical Research Ethics Board: H12-00382. Data access for the administrative database study was granted by the Ministry of Health and WorkSafeBC Data Stewards. *All inferences, opinions, and conclusions drawn in this doctoral research are those of the author, and do not reflect the opinions or policies of the Data Steward(s).*

The clinical research was carried out at the Centre for Women's Health Research Community Care Facility at the University of Northern British Columbia (UNBC) in Prince George, BC and was approved by the UNBC Research Ethics Board: E2122.0215.024.00. The clinical research formed part of a UNBC collaboration, "Recovery from Hysterectomy: Impact on core muscle function and embodied self-perception" wherein some participants who underwent hysterectomy were also interviewed by Dr. Lela Zimmer about their experience.

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Chapter 2 is based on work conducted by Lois Lochhead and Dr. Mieke Koehoorn. Patrick Daniele assisted with data analysis. Lois Lochhead was responsible for the study design, data requests, data analysis and writing and revising the manuscript. Dr. Koehoorn assisted in designing the study, requesting the data, analyses and interpretation as well as editing the manuscript. Drs. Backman, Parent and Franche assisted in editing the manuscript.

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## List of Abbreviations

### A

ADIM – Abdominal Drawing in Manoeuvre  
ANCOVA – Analysis of Covariance  
ANOVA – Analyses of Variance  
ASIS – Abdominal Surgery Impact Scale  
ASLR – Active Straight Leg Raise Test

### B

B-Mode – Brightness Mode  
BMI – Body Mass Index  
BC - British Columbia

### C

CA – Care Aide  
CAL – Contralateral Arm Lift  
CCI - Classification of Health Interventions  
CCP - Canadian Classification of Diagnostic, Therapeutic and Surgical Procedures  
CI – 95% Confidence Interval  
CIHI - Canadian Institute for Health Research  
cm – Centimetres  
CU - Classification Unit  
CV – Coefficient of Variation

### D

DAD - Discharge Abstracts Database

### E

EMG – Electromyography  
fwEMG - Fine Wire Electromyography

### I

IAP – Intra-abdominal Pressure  
ICC – Interclass Correlation Coefficient  
ICD - International Classification of Disease  
ICF - International Classification of Functioning, Disability and Health

### H

HCW – Health Care Worker

### L

LAW – Lateral Abdominal Wall  
LBI – Low Back Injury  
LBP – Low Back Pain

LM – Lumbar Multifidus  
LPN – Licensed Practical Nurse  
LPP - Lumbopelvic pain

### M

MDC – Minimum Detectable Change  
mm – Millimeters  
M-Mode – Motion Mode  
MRI – Magnetic Resonance Imaging  
MSI - Musculoskeletal Injuries  
MSP – Medical Services Plan  
MVC - Maximum Voluntary Contraction

### O

OCM Occupational Classification Manual  
OR - Odds Ratio

### P

PBI – Prior Back Injury  
PFM – Pelvic Floor Muscles  
PopDataBC – Population Data BC

### R

RN – Registered Nurse  
RUSI – Rehabilitative Ultrasound Imaging  
RRTW - Readiness for Return to Work

### S

SAS - Statistical Analysis System  
SCH - Supracervical Hysterectomy  
SD – Standard Deviation  
SEM – Standard Error of Measurement  
SPSS – Statistical Package for the Social Sciences  
SRE - Secure Research Environment

### T

TrA – Transversus Abdominis  
TAH - Total Abdominal Hysterectomy

### W

WSBC - WorkSafeBC

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*To my boys...*

*It always seems impossible until it's done*

*-Nelson Mandela*

# 1. Introduction, Background and Literature Review

This chapter begins with a brief introduction to the motivation and rationale for investigating the impact of abdominal hysterectomy on subsequent low back injury along with the proposed mechanism of injury. This is followed by background information and a literature review of the epidemiology of low back injury in female front line healthcare workers as a group at high risk of low back injury. This chapter concludes with a critical appraisal of the current literature on the role of the trunk muscles, specifically the transversus abdominis (TrA), lumbar multifidus (LM) and the pelvic floor muscles (PFM), in spinal stability and altered motor control of these muscles in individuals suffering with lumbopelvic pain (LPP).

## 1.1 Introduction

Low back injuries (LBI) in female front line healthcare workers in British Columbia, including Registered Nurses (RNs), Licensed Practical Nurses (LPNs) and Care Aides (CAs), constitute a major source of morbidity in the workplace,<sup>[1]</sup> often limiting participation in activities both at work and at home<sup>[2]</sup> and having a negative impact on overall quality of life.<sup>[3]</sup> Back injuries are taxing on both provincial medical services as well as workers' compensation systems across the country costing billions of dollars each year in healthcare costs and lost wages.<sup>[4, 5]</sup> Engkvist et al.<sup>[6]</sup> reported a six fold excess risk of back injuries in assistant nurses compared with other employed women in Sweden. A recent systematic review of low back pain by Yassi and Lockhart<sup>[7]</sup> confirmed similar risks in all nursing personnel. WorkSafeBC (2012), the workers' compensation system in the province of British Columbia, reports that between 2003 and 2012 back strain injury claims for women in health and medicine occupations accounted for the 31% of all back injury claims for women. This was the most prominent subsector for women aged 25 and over. Care aides were responsible for 46% of claims, RNs for 27% of claims and LPNs for 17% of claims from the health and medicine sector.<sup>[4]</sup>

The risk of developing a low back injury is multifactorial.<sup>[8, 9]</sup> Many risk factors for low back injury have been identified and Cholewicki et al.<sup>[10]</sup> proposed that they can be parsed into three general categories: biomechanical, psychosocial and personal. Biomechanical risks are associated with activities such as patient handling<sup>[8, 11-13]</sup> and patient care requiring awkward postures.<sup>[14, 15]</sup> Psychosocial risk factors associated with low back injury include depression, job

satisfaction, perceived control and support in the workplace.<sup>[8]</sup> Personal risks include lifestyle,<sup>[16, 17]</sup> gender,<sup>[18, 19]</sup> age,<sup>[20]</sup> weight,<sup>[21]</sup> smoking,<sup>[18]</sup> and prior incidence of low back pain or injury.<sup>[8, 19, 22, 23]</sup> Another proposed risk factor that could be classed as personal and/or biomechanical<sup>[24, 25]</sup> and supported in studies by Cholewicki et al.<sup>[10]</sup> and Radebold et al.<sup>[26]</sup> is that of impaired motor control/stability of the lumbar spine.

Prevention of lumbar spine injury requires "sufficient stability"<sup>[27]</sup> in the muscles, ligaments and discs that make up the lumbar support system. Tensioning of the myofascial ring or stocking which contains the abdominal and multifidus muscles along with their interconnected fascia provides stability for the lumbar spine during load transfer.<sup>[28]</sup> Instability resulting from compromise to this system can increase risk of back injury.<sup>[29]</sup>

As a physiotherapist treating front line healthcare workers with LBI, a hypothesized link between prior abdominal hysterectomy and LBI emerged during my professional practice. Assessment of patients who had undergone hysterectomy prior to LBI revealed reduced core stability and clinical reasoning included the hypothesis that the stability system had been impacted by surgical insult and had not returned to full function. Treatment addressed this deficit and most returned to work. However, earlier treatment to address the reduced core stability may have prevented the LBI episode and resulting lost time from work, which would be a superior outcome. Consideration of the contributing factors to inform best practice led to the development of this thesis topic.

Dean's<sup>[30]</sup> Psychobiological Adaptation Model for physiotherapy practice states that the object of physiotherapy is that of optimal treatment outcome. This model highlights the interaction between factors relating to the patient as well as those relating to the therapist in optimizing the treatment outcome. Primary patient-related factors include psychobiological factors - pathology, anatomy, physiology, and psychology as well as secondary psychosocial factors - sociological, stress management, lifestyle and occupational/environment factors. Primary clinical professional factors include therapeutic techniques, modalities, patient education and prevention. Secondary professional factors include research and education. While recognizing the complexity of biopsychosocial factors of the patient and clinical skills of the therapist in the determination of optimal outcomes, it is not feasible to simultaneously study all relevant factors. This thesis focuses on the patient-related biological factors of pathology,

anatomy and physiology to study the potential of surgical interruption to the abdominal fascia during hysterectomy on risk of subsequent LBI.

According to the Health Indicators Report (2013) by the Canadian Institute for Health Information (CIHI),<sup>[31]</sup> after caesarian section, hysterectomy is the most common surgery for women in Canada with an age standardized rate in the province of British Columbia of 285 per 100,000 women. Substantial regional variations exist across the province from 137 per 100,000 in the city of Vancouver (also the lowest rate in Canada) to 575 per 100,000 in the Northern Interior Region (one of the highest rates in Canada).

A search of Medline, CINAHL, Embase, Web of Knowledge, and Google Scholar produced no articles that specifically addressed the issue of abdominal muscle morphology or function following abdominal hysterectomy. A similar search of back injury or pain and hysterectomy yielded the following: three case studies of gynecological conditions presenting as back pain;<sup>[32-34]</sup> one cross-sectional study indicating hysterectomized women had a threefold risk of back pain;<sup>[35]</sup> a five-year randomized control trial of hysterectomy versus an intrauterine system to treat menorrhagia that found an increase in back pain in the hysterectomized group at five years;<sup>[36]</sup> the MORGEN study that reported back pain following abdominal approach hysterectomy but postulated it was pre-operative pain lingering after surgery;<sup>[37]</sup> a randomized intervention trial that found no difference in back pain between vaginal and abdominal approach hysterectomies in a two year time frame;<sup>[38]</sup> and a prospective cohort study<sup>[39]</sup> that found a significantly higher rate of post-operative back pain following abdominal approach compared to vaginal approach hysterectomies with pain persisting to the end of the one year follow up period. The authors for the latter study found this puzzling but opined that it could not be the fault of the trans-abdominal approach, as the muscle splitting procedure (where the abdominal fascia is cut and repaired) did not compromise the muscles. A retrospective database analysis of the Women's Health and Aging study in the United States that included self reported back pain, revealed that hysterectomy increased the risk of moderate low back pain in women aged 65 and over.<sup>[40]</sup> The authors postulated that the surgical interruption of the deep stabilizers of the trunk interfered with lumbopelvic stability and hypothesized that this could be the precipitating factor in subsequent back pain. In summary, the current evidence across different type of research studies suggest a plausible link between hysterectomy (with compromised muscles) and low back pain.

Porcine studies carried out by Hodges et al.<sup>[41]</sup> demonstrated that the mechanism through which the deep abdominal muscles affected lumbopelvic stability was through increasing tension on the fascial stocking that envelopes the muscles and attaches the transversus abdominis to the spine. This increases intra-abdominal pressure (IAP) and resistance to vertebral displacement while reducing vertebral motion. This effect was reduced when a hole in the abdominal wall prevented IAP increase or when the fascial attachment of the TrA muscle was cut.

Further animal studies using the Sprague-Daley rat, an effective human model,<sup>[42]</sup> showed that force transmission from the abdominal muscles does travel through the abdominal aponeurosis.<sup>[43]</sup> A study of midline laparotomy hernias showed that the unloaded muscles go through atrophic changes<sup>[44]</sup> and Brown and Tiernan,<sup>[45]</sup> in a Cochrane Review, noted better outcomes for transverse rather than midline incisions for abdominal surgery in terms of healing, post-operative pain and complication rates. No study was found that specifically addressed abdominal stability/core muscle function following abdominal surgery such as hysterectomy. To address the preceding gap in the literature, the following research questions were developed:

1. Is prior abdominal hysterectomy a risk factor for subsequent low back injury in female front line healthcare workers in British Columbia (BC), as a large workforce at high risk for back injury?
2. Are there changes to the muscles of the abdominal wall following surgery that could reduce spinal stability?

To investigate these questions, the following research studies were carried out.

The first study (Chapter 2) used a population-based approach that linked health databases to investigate if abdominal hysterectomy increases the risk for subsequent work-related and non work-related low back injury in a cohort of frontline female healthcare workers. The cohort was constructed from data in the BC Medical Services Plan (MSP) Registry file<sup>[46, 47]</sup> linked to Hospital Discharge records,<sup>[48]</sup> outpatient medical services records<sup>[47]</sup> and workers' compensation claim records.<sup>[49]</sup> Two incidence models investigated (a) the risk of a work-related low back injury and (b) any back injury in a cohort without prior back injury. This enabled evaluation of the temporal relationship between hysterectomy and back injury in a large sample of healthcare workers.

For the second research question, a clinical study of women undergoing hysterectomy was undertaken using rehabilitative ultrasound imaging (RUSI) to investigate potential changes in the

TrA and LM muscle thickness before and after surgery, in resting and contracted states, as well as PFM function through observation of change in bladder base position from resting to contracted states. Measurements were taken before hysterectomy and at 3 four-week intervals following surgery. Additionally, a comparison group was measured using the same intervals to establish reliability of these measures over the longer intersession period. These results can be found in Chapters 3 (Comparison Group) and 4 (Hysterectomy Group).

## **1.2 Background & Literature Review**

This section begins with a review of low back injury in female front line healthcare workers and an overview of initiatives undertaken over the past two decades to reduce rates of injury. This is followed by a sub-section on hysterectomy, outlining rates, population demographics and surgical indications. Next a critical appraisal of the literature as it applies to the investigation of back injury following hysterectomy is presented. Finally, a review of the functional anatomy and the current understanding of motor control of the lumbar stability system is presented.

### **1.2.1 Front line Healthcare Workers and Low Back Injury**

WorkSafeBC (2010) reports that “British Columbia’s healthcare sector employs approximately 300,000 workers – about 12% of the provincial workforce. On average, British Columbia (BC) healthcare workers have over 7,500 time-loss claims associated with over 330,000 lost work days and \$56 million in claims costs each year.”<sup>[50]</sup> Injury claims in the BC healthcare sector have risen from 6,400 per annum or an incidence density rate of 3.5 injuries per 100 person-years in 2004 to 8,516 per annum or 3.8 per 100 person-years in 2012,<sup>[4]</sup> with 46% of claims due to overexertion (musculoskeletal injury).<sup>[50, 51]</sup> Comparatively, the all-sectors injury rate has dropped from 3.1 injuries per 100 person-years in 2004 to 2.3 in 2012. Healthcare claims were 1.06 times the all-sectors claims rate in 2004 and now in 2012, they are 1.65 times the all-sectors rate, indicating a population at high risk of injury and high risk of back injury.

According to the WorkSafeBC 2012 Statistics Report, the share of claims for back injury has continuously increased in the past three decades and in 2012 the proportion of back injury claims for women increased to 40%.<sup>[4]</sup> The authors opine that this is due to an increased participation of women in the labour force most markedly in service related industries and occupations such as the healthcare sector.

The healthcare industry in BC is a female dominated workforce (90-94%)<sup>[52]</sup> who, compared to their male counterparts, are reported to have a significantly higher risk of work-related musculoskeletal injuries or MSIs (rate ratio (95% CI)=1.43(1.11-1.85))<sup>[53]</sup> with low back injury accounting for the largest proportion of MSIs.<sup>[54]</sup> Studies indicate that women may be more severely affected by back injury than men. Chenot et al.<sup>[55]</sup> reported an odds ratio of 1.7 for reduced functional capacity in females at 12 months after initial low back pain presentation. Harrold et al.<sup>[56]</sup> reported an odds ratio of 1.42 for females having future work concerns following a work-related low back injury.

Jang et al.<sup>[57]</sup> investigated biomechanical factors relating to low back injuries in direct care workers and found that trunk moment, axial rotation and patient weight were significant contributors to elevated risk of back injury. Alamgir et al.<sup>[54]</sup> noted that care aides were at the highest risk for back injury due to the nature of their work which involved lifting and twisting. Eriksen et al.<sup>[57]</sup> noted an increased risk of low back pain, as an indicator of back injury, for nursing aides when positioning individuals in bed provided this activity occurred more than four times per shift (Odds Ratio (OR)=1.63 (95%CI:1.14-2.31). Smedley et al.<sup>[58]</sup> found an increased risk of back pain in nursing personnel when transferring patients more than four times per shift from bed to chair (OR=1.6 (95%CI 1.1-2.3) and similarly re-positioning patients in bed more than ten times per shift (OR=1.7, 95% CI:1.1-2.5).

To address this documented increased risk of back injuries in the healthcare sector, many primary prevention strategies as outlined by Frank et al.<sup>[59]</sup> have been proposed and implemented. Most of these target the work environment with training programs and ergonomic interventions. A systematic review by Bos et al.<sup>[60]</sup> evaluating thirteen studies of occupational interventions for primary prevention of musculoskeletal injury in healthcare workers showed insufficient evidence to support that knowledge of risk factors at work and ergonomic principles reduced injuries at work. They recommended a multi-factorial approach that combined physical training along with the ergonomic and educational interventions. Warming et al.<sup>[61]</sup> found no reduction in low back pain in healthcare workers with implementation of improved patient transfer techniques. They also recommended a multi-factorial approach to mitigating the risk of back injury. Ronald et al.<sup>[62]</sup> found that the rate of MSI caused by lifting/transferring patients was significantly reduced (58% reduction,  $p = .011$ ) after ceiling lift installation, but rates of all MSI and MSI caused by repositioning did not statistically decline ( $p > .05$ ). In contrast, Silverwood et al.<sup>[63]</sup> found that in

the Richmond Hospital Intensive Care Unit (Richmond, BC) lifts reduced lost time injuries and promoted a positive work environment. The preceding studies indicate that patient lifting is a risk factor for low back injury for healthcare workers, largely as a result of the biomechanical strain placed on the muscular system. Women with hysterectomy may be at a particularly increased risk in healthcare occupations if the biomechanical demands of work tasks are compounded by surgical assault to the musculoligamentous system without proper rehabilitation.

Secondary prevention strategies have also been proposed by Frank et al.<sup>[64]</sup> which focus on factors that will reduce disability/re-injury following insult or injury. Given the high annual prevalence of back injuries of 40 to 50% along with the lifetime prevalence of back injury of 35 to 80% in the nursing population,<sup>[65]</sup> and the high rate of hysterectomy in western populations, investigation of secondary prevention strategies is worthwhile. According to the World Health Organization's (WHO) International Classification of Function, Disability and Health (ICF)<sup>[66]</sup> disability occurs as a consequence of dysfunction related to impairment in body functions or structures, the ability to perform an activity and/or participate in a life situation. Within this model, the term "Body Function" includes body structures such as the musculoskeletal system. Impairments can result from changes in the structural body. This thesis investigates the impact of surgical insult, specifically abdominal hysterectomy to the muscles of the trunk that provide stability to the spine. Evidence of a link between hysterectomy, muscle stability and risk of injury would help inform rehabilitation and disability programs. Secondary prevention strategies such as referral to physiotherapy following abdominal surgery could reduce risk of back injury.

### 1.2.2 Hysterectomy

The Health Indicators Report (2013) by the Canadian Institute for Health Information (CIHI)<sup>[31]</sup> reported that after caesarian section, hysterectomy is the most common surgery for Canadian women. The age-standardized rates of hysterectomy have wide variation both interprovincially (3-fold) and regionally (4-fold). Rural rates in Canada are 4.64 hysterectomies per 1000 women, which is 46% higher than the urban rate of 3.18 per 1000. Within British Columbia where the average rate is 2.85 per 1000 there is also wide variation from 5.75 per 1000 in the Northern Interior region to 1.37 per 1000 in the city of Vancouver. The overall prevalence of hysterectomy in Canada is 30% between ages 35 and 55 years<sup>[67]</sup> and in the United States approximately 45% of women living to age 70<sup>+</sup> years have had a hysterectomy.<sup>[68]</sup> Lindberg<sup>[69]</sup> reported that 75% of hysterectomies are performed on women younger than 45 years of age.

According to “Nursing Trends” from the Canadian Institute for Health Information (2012),<sup>[52]</sup> the average age of BC RNs was 45.2 years and for LPNs was 43.4 years indicating a significant proportion of these women could be working while undergoing a hysterectomy.

The most frequent indications for hysterectomy in Canada include uterine fibroids (35%), menstrual disorders (19%), genital prolapse (15%), gynecological cancers (15%), endometriosis (8%) and other (8%).<sup>[70]</sup> In contrast, rural area variation statistics show that the rate of hysterectomy for menstrual disorders is double that of urban dwellers and is the primary indication for hysterectomy in that population.<sup>[70]</sup> There are three potential approaches to hysterectomy – laproscopic, vaginal and open abdominal. With the advent of these less invasive approaches, the rate of open approach hysterectomies has steadily decreased<sup>[38]</sup> but reported rates vary between 44%<sup>[71]</sup> to 66%.<sup>[72]</sup> At the University Hospital of Northern British Columbia (UHNBC) in Prince George, BC, an average of 144 open approach hysterectomies out of a total of 200 hysterectomies (72%) are performed annually<sup>[73]</sup> compared to a provincial rate in BC of less than 50%.<sup>[70]</sup>

To perform an open hysterectomy, an incision is made through the skin and the fascia of the abdominal wall. The muscles are retracted and the uterus is exposed and removed. The surgical incision may be vertical, splitting the midline fascia, or transverse, along the 'bikini line', just above the pubis. The orientation of the incision is usually determined by surgeon preference.<sup>[74]</sup>

Many studies have investigated complications following hysterectomy such as post-operative infections and bleeding,<sup>[75]</sup> genito-urinary and gastrointestinal tract injuries,<sup>[76]</sup> fever,<sup>[77]</sup> and low back pain.<sup>[37, 39]</sup> Brandsborg et al.<sup>[78]</sup> reported results of a survey of 1,299 women who had undergone hysterectomy whose post operative pelvic pain persisted in 31.9% at the one year mark. They further noted that pain had not been present prior to surgery in 14.9% of them. Reported risk factors for prolonged chronic pain were preoperative pelvic pain (OR= 3.25; 95% CI 2.40–4.41), previous cesarean delivery (OR, 1.54; CI, 1.06–2.26), pain as the main indication for surgery (OR, 2.98; CI, 1.54–5.77), and pain problems elsewhere (OR, 3.19; CI, 2.29–4.44). No description of the "pain elsewhere" location was given.

## ***Hysterectomy and Back Pain***

One cross-sectional study of 1427 middle-aged Finnish women aged 45-64 years reported that women with hysterectomy had three times the prevalence of back pain compared to their premenopausal counterparts, after adjustment for age. Data were collected by questionnaire and the proportion of each symptom perceived as bothersome (scoring 4 or 5 on a 5 point severity scale) in the past 4 weeks was calculated. The premenopausal group, youngest with a mean age of  $48.5 \pm 2.8$ , was used as the index for comparison with peri-menopausal group (mean age  $50.7 \pm 4.6$ ), post-menopausal group (mean age  $56.6 \pm 4.9$ ) and hysterectomy group (mean age  $54.7 \pm 5.3$ ). They did not differentiate between women taking hormone replacement therapy and those who did not in each group. They did not make a distinction between women who had total hysterectomies including removal of the ovaries and those who did not. Surgical approach was not considered. A significantly higher proportion of the women with hysterectomy (65.6%) had chronic disease compared with 37.8% in the premenopausal reference group. This is likely explained at least in part by the age difference between these two groups. This could impact the proportion of reported back pain in two ways. First, back pain could be a part of the chronic illness thus increasing the proportion on pain medication or second, the chronic disease could mask potential back pain. This was a cross sectional descriptive study and thus no causal connections can be inferred from the results.<sup>[35]</sup>

A five-year randomized control trial of 236 women aged 35-49 using hysterectomy or a levonorgestrel-releasing intrauterine system to treat menorrhagia found an initial decrease in back pain 12 months following treatment in both groups but noted that by the 5 year mark there were significantly higher rates of back pain in the surgical group compared with the conservative treatment group ( $p=0.02$ ).<sup>[36]</sup> They postulated that the cause could be age-related changes in vertebrae possibly associated with impaired ovarian function following menopause. They did not measure ovarian function or bone density of the vertebrae. Hysterectomy approach was determined by the surgeon and was not included in data analysis.

A cross-sectional Swedish study<sup>[79]</sup> of 6917 women aged 50-60, 800 (11.6%) of whom were hysterectomized (the majority between 5 and 10 years before study), reported an odds ratio of 1.37 (1.16-1.62) for self-reported back pain (yes/no) in women who had undergone hysterectomy compared to women who had not undergone hysterectomy. The mean age at surgery was 45.9 years and 96% of the hysterectomies were performed due to excess uterine bleeding

(menorrhagia). They developed a profile of women following hysterectomy that suggested these women were less educated, had a lower age at first birth, higher body weight and higher health care utilization than a comparison group of women without hysterectomy. They found no difference in number of pregnancies, parity and prior use of a birth control pill between groups. The authors postulated that the backache and other symptoms that were more common in the hysterectomy group could be due to personality factors resulting in less resistance to somatic symptoms. They opined that: "This may indicate that intolerance to a bleeding situation before hysterectomy, was the main reason of surgery." Psychosocial factors rather than biologic ones were thought to be at fault, an important reminder that any study of biological factors needs to be interpreted in the context of broader explanatory models such as the psychobiological adaptation model introduced earlier.<sup>[30]</sup>

The MORGEN study<sup>[37]</sup> of 11,428 Dutch women aged 20-59 years (11% with hysterectomy) reported a significant finding of chronic low back pain in women who had undergone abdominal approach hysterectomy (OR 1.47 (95% CI 1.17-1.84)). The authors suggest that hysterectomy may be associated with musculoskeletal pain in general but did not further postulate any mechanisms such as altered trunk muscle function following surgery leading to decreased spinal stability, that could explain this finding. Learman et al.<sup>[38]</sup> conducted a randomized intervention trial and compared outcomes between 68 women with supracervical hysterectomy (SCH) and 67 women with total abdominal approach (TAH) and found no difference between the two approaches in terms of clinical outcomes including new onset back pain in a two-year follow up time. The mean age in both groups was  $41.8 \pm 5.1$  years. The SCH leaves the cervix in place which assists the pelvic floor muscles to provide support for the pelvic organs. Both the SCH and TAH are performed through an abdominal incision so essentially the difference between the approaches would be more likely to impact potential performance of the PFM. This offers support for focusing on the TrA following hysterectomy.

Clarke et al.<sup>[39]</sup> investigated the role of the lithotomy (supine with legs in stirrups) surgical position in the development of postoperative low back pain. They compared 52 women (mean age =43 years) who underwent abdominal hysterectomy in the supine position with 49 counterparts who underwent vaginal hysterectomy in the lithotomy position (mean age=49 years). They found a significant difference in severity of persistent post-operative low back pain at one year between the two groups with the vaginal (lithotomy) group faring better ( $\chi^2 = 10.2$ ,  $df=2$ ,  $p<0.01$ ) than the

abdominal (supine) group offering support for the hypothesis proposed in this thesis. The absence of nerve root tension/leg pain suggested a diagnosis of mechanical LBP. The authors concluded that the lithotomy surgical position does not confer a greater risk of post operative back pain compared to the supine position. However, they were not only comparing position but surgical approach. The supine group had their abdominal wall split during surgery but the lithotomy group had an intact abdominal wall. The authors could not explain the higher rate of backache in the abdominal approach patients and commented that "the muscle splitting surgical approach in the trans-abdominal route cannot be held responsible for the development of post operative low back pain as the abdominal musculature is not compromised during this procedure." They failed to recognize the role that intact abdominal fascia plays in lumbar stabilization. They do suggest the use of a lumbar support belt following surgery and comment that it has been effective in the treatment of post-operative back pain. Indeed, a lumbar/pelvic has been used clinically to provide spinal stability especially when the intrinsic spinal stability system is not functioning properly.

The review of the preceding literature provides evidence of an association between hysterectomy and back pain. What is not clear is the underlying cause(s) of the back pain. The authors propose many theories ranging from demineralization of vertebral bone to poor pain tolerance in women with hysterectomy. One theory that has not been explored is that cutting the abdominal fascia could lead to post-operative pain resulting in altered trunk muscle recruitment patterns both in the short term and long term. This, in turn, could change spinal loading patterns and stability predisposing women to back pain and injury. This theory is the focus of the following dissertation and the investigation of the association between hysterectomy and subsequent back injury, and between hysterectomy and changes in core muscle functions.

The following sections define spinal and core stability, review the current understanding of how pain impacts muscle function, outline the functional anatomy of the trunk (core) muscles and elucidates the mechanism by which the abdominal wall structures (TrA muscle and fascia) in concert with the deep LM and PFM impact spinal stability. A final section presents a critical review of the literature regarding changes in spinal stability leading to low back pain or injury.

### 1.2.3 Spinal Stability

Due to the heavy burden that lumbopelvic pain, low back injury and associated disability place on society in terms of lost productivity, diminished quality of life and high incidence of

recurrence, extensive focus has been placed on understanding the neuromusculoskeletal system of this region and its role in providing spinal stability.<sup>[80-88]</sup> Spinal stability, defined as the potential to resist perturbations that could result in intervertebral displacements,<sup>[89]</sup> is critical from the viewpoint of biomechanical load transfer and in the prevention of low back injuries.<sup>[90]</sup> Crisco and Panjabi described the static stability of the musculoligamentous spine and measured the force required to cause buckling in vitro to be approximately 88 N.<sup>[91, 92]</sup> They noted that this force decreased significantly with back injury. However, in vivo, much higher forces of approximately 6000 N for demanding activities of daily living<sup>[93]</sup> are regularly transmitted through the spine without causing spinal buckling. This is facilitated by the dynamic support afforded by the trunk musculature to the static musculoligamentous system.<sup>[94]</sup> Core stability refers specifically to the ability of these trunk muscles to provide dynamic support to the spine in vivo.

#### 1.2.4 Motor Adaptation to Pain

Muscle function is modifiable with rehabilitation;<sup>[87, 95, 96]</sup> and changes in neuromuscular control of the lumbopelvic region reflect both the biological and psychosocial factors associated with lumbopelvic pain and dysfunction.<sup>[85, 97, 98]</sup> Biological changes include alterations in motor control,<sup>[99]</sup> movement patterns<sup>[100]</sup> and muscle activation<sup>[101]</sup> to a physiological change in the body. Psychosocial factors include fear-avoidance/ kinesiophobia and it has been postulated that back muscle deconditioning has occurred as a consequence of it in a study of patients with persistent low back pain.<sup>[102]</sup> Another study found that pain-related fear was significantly associated with increased lumbar muscle EMG reflecting volitional guarding during movement.<sup>[103]</sup>

Many studies have demonstrated coordinated muscle function in healthy individuals that contrast with altered patterns of muscle activation found in individuals experiencing acute, recurrent or chronic lumbopelvic pain/dysfunction.<sup>[99, 101, 104-108]</sup> Two widely accepted theories have been proposed to explain the effect of pain on muscle function. These are the vicious cycle<sup>[109]</sup> and pain adaptation theories.<sup>[110]</sup>

The vicious cycle or pain-spasm-pain theory propounds that pain leads to increased muscle activation or spasm and that spasm then increases pain through ischemia in the muscle tissue and increased algogenic agents.<sup>[109]</sup> It forms the basis of treatment approaches to conditions such as muscle tension headache, temporomandibular joint dysfunction and chronic low back pain.<sup>[110]</sup> There is experimental evidence that noxious stimulation can reflexively evoke short-duration EMG activity in animal<sup>[111-114]</sup> and human<sup>[115-117]</sup> jaw muscles that supports the first premise

of the theory that pain causes muscle spasm. Other studies have shown increases in submaximal jaw clenching can result in pain in some subjects,<sup>[118, 119]</sup> offering support for the second premise that muscle spasm causes pain. However, despite the popularity of this theory in the clinical community, many studies have found that pain does not always lead to increased muscle activity or spasm.<sup>[120-122]</sup> Other studies found that the increases in muscle activity with painful stimuli were not long-lasting.<sup>[123]</sup> Surface electrodes used in some of the EMG studies have been known to pick up adjacent muscle activity that could account for the finding of increased muscle activity in the target muscle.<sup>[124]</sup> Lund et al.<sup>[110]</sup> found little support for the vicious cycle theory and developed the pain adaptation model to address its shortcomings.

The pain adaptation model proposes a reduction in muscle contraction of muscles that are painful and an increase in the antagonists to the painful muscle. This is accomplished via segmental brainstem or spinal cord mediation (mechanism unknown) to limit movement and protect the musculoskeletal system from further injury.<sup>[110]</sup> The effect of this is slower and smaller movements that limit injury aggravation and thus allow the injured tissue to heal. This theory is based on experimental observations and there is much supporting evidence in the literature.<sup>[110, 120, 122, 125, 126]</sup> In one study, induced pain in isometric knee extensors decreased maximal torque force but did not change the contractile properties of the muscle, lending support to a centrally mediated force inhibition.<sup>[127]</sup> Another study of the effect of experimental muscle pain on the EMG of human jaw-closing muscles showed a significant reduction in EMG amplitudes in those muscles and increased amplitudes in the antagonist muscles.<sup>[128]</sup> The authors felt that the results supported segmental brain stem or spinal cord mediation. EMG studies of the human back muscles during forward bending<sup>[129]</sup> and gait<sup>[130]</sup> following induced pain showed altered patterns of muscle activation with increased activity in the antagonists and reduced activity in the agonists. Similar observations were made during induced pain in the tibialis anterior and gastrocnemius muscles during gait.<sup>[131]</sup>

Despite the supporting literature as noted above, there are published research findings that do not align with the pain adaptation model. One EMG study of experimental pain of the human jaw muscles did not find significant decreases in agonist activity or increases in antagonist activity compared with pain free controls.<sup>[132]</sup> In an analysis of 30 clinical and 3 induced pain studies of trunk muscle recruitment in low back pain, Van Dieën et al.<sup>[120]</sup> noted that neither the vicious cycle theory nor the pain adaptation model adequately predicted the effects of back pain

on trunk muscle activation. To address these inadequacies, Peck et al.<sup>[133]</sup> proposed a unification of the two theories - The Integrated Pain Adaptation Model. In this model, the muscle strategies are unique to each individual and are determined by the anatomical and functional complexity of the movement as well as the multidimensional pain experience of that individual. The goal of a given strategy is to maintain homeostasis while minimizing pain and metabolic cost. Hodges and Tucker<sup>[97]</sup> expand this theory to include the premise that while these adaptations have short-term benefits, there are potential long-term consequences of altered motor patterns in response to pain. They argue that "if it is assumed that movements are performed in an optimal or efficient manner in a nonpain state, departure from this state may not be ideal." For example, trunk muscle splinting could lead to decreased spinal stability which, in turn, can increase the cumulative mechanical load on intervertebral discs,<sup>[134]</sup> which could lead to changes in the disc properties and eventual back pain or injury.<sup>[135]</sup> While pain can provide the stimulus to change the pattern of muscle activity, evidence shows that, in some individuals, this adaptive pattern does not return to normal after the pain or threat of further injury has been eliminated.<sup>[136-138]</sup> The nature of the adaptive patterns of movement in the trunk muscles in response to back pain or injury can be unique to each individual,<sup>[139]</sup> and is maintained across tasks in that individual despite opposite movement demands.<sup>[139]</sup> Hodges and Moseley<sup>[28]</sup> reported a tendency toward diminished activity of the deep stabilizers (TrA and LM) with increased activity of the superficial muscles in the abdomen and back in response to back pain.

Studies of motor adaptation have focused on changes in TrA, LM and PFM muscle recruitment following induced or clinical back pain, groin and pelvic girdle pain. Moseley and Hodges<sup>[126]</sup> used EMG to measure the effect of painful cutaneous stimulation at the low back on TrA and internal oblique (IO) activation with upper extremity movements. They found a gradual and increasing delay of TrA and IO with increased activation of the external obliques during the pain trials. Similarly, Kiesel et al.<sup>[140]</sup> reported reduced muscle thickness change in both TrA and LM following injection of 5% hypertonic saline into the longissimus muscle just lateral to the L4 spinous process. Jansen et al. used RUSI to evaluate TrA and IO in both induced<sup>[141]</sup> and clinical<sup>[142]</sup> groin pain. They found a similar pattern of muscle activation to that described above. Further, in long-standing groin pain, they found diminished resting thickness in the TrA. Arab et al.<sup>[143]</sup> studied differences in PFM function on transabdominal RUSI in women with and without low back pain. They found decreased function of the PFM in the pain group. Beales et al.<sup>[107, 144]</sup> monitored TrA and PFM function in both pain-free individuals and those with chronic pelvic

girdle pain and found that the chronic pain group had motor control changes similar those reported above. What does not appear to have been studied is changes in motor control in response to abdominal pain such as post-surgical incisional pain and how this may impact patterns of muscle activation of the deep stabilizers. The next section highlights the functional anatomy of these deep stabilizers.

### 1.2.5 Functional Anatomy of the Lumbar Stabilization System

When addressing spinal stability, the most commonly investigated deep lumbopelvic muscles are the TrA,<sup>[29, 80-82, 145-148]</sup> LM<sup>[84, 95, 149-155]</sup> and the PFM.<sup>[156-160]</sup> Stabilization of the lumbar spine by these deep muscles is accomplished through two proposed mechanisms: (1) increasing intra-abdominal pressure (IAP)<sup>[161-164]</sup> and (2) resisting translational and rotational forces.<sup>[29]</sup> Hodges et al.<sup>[41]</sup> performed in vivo porcine studies monitoring IAP and the change in relative intervertebral movement of L<sub>3,4</sub> with activation of the TrA (evoked via electrodes threaded through the abdominal wall). They found an increase in IAP, a decrease of L<sub>3,4</sub> motion and an increase in stiffness of L<sub>4</sub> to displacement. They also noted less stiffness in the L<sub>4</sub> vertebrae when a hole was created in the fascia of the abdominal wall that prevented an increase of IAP or when the fascial attachment of TrA was cut that prevented mechanical muscle force transmission. These findings suggest that the TrA provides a mechanical contribution to spinal stability due to its ability to influence IAP and to exert tension through its fascial attachments to the thoracolumbar fascia.

The PFM, the only transverse load bearing muscle group in the body, have also been shown to be part of the deep stability system of the trunk and spine.<sup>[165]</sup> Along with their role in bowel and bladder continence and elimination, pelvic organ support, and sexual arousal, electromyography (EMG) studies have shown that they contribute to trunk stability<sup>[160]</sup> synergistically with the TrA<sup>[159, 166]</sup> through the lower portion of the thoracolumbar fascia.<sup>[167]</sup> The PFM respond in a manner similar to the TrA and LM to trunk perturbations,<sup>[29, 84, 168]</sup> and are tonically active in seated and standing activities.<sup>[169-171]</sup> There is also evidence that the PFM contribute to the control of IAP,<sup>[105, 172, 173]</sup> and increase sacroiliac joint stiffness (in vitro) through their posterior fascial attachments,<sup>[174]</sup> lending credence to the argument that they are essential to postural control by means of a mechanism similar to that described above for the TrA. Richardson et al.<sup>[175]</sup> report that co-activation of the PFM with the LM has been observed clinically, but no studies have been found that confirm this observation. However, Capson et al.<sup>[176]</sup> have reported

that changes in lumbar posture from hypo-lordotic to hyper-lordotic impact the resting PFM activity on EMG. An increase in PFM activity was noted in hypo-lordotic postures. A recent study by Arab et al.<sup>[143]</sup> found a significant difference in PFM function in women with LBP compared to those without LBP ( $P=0.04$ , 95% CI of difference: 0.002-0.27). A pilot pre-test-post-test study of women with LBP concurrent with incontinence found improvement in both conditions following a course of pelvic floor rehabilitation.<sup>[177]</sup>

Unlike the TrA or PFM, the LM do not have a role in modulating IAP but there is evidence (in vitro) that the segmental fibers of the LM contribute to segmental intervertebral stiffness<sup>[90]</sup> due to its location. MacDonald et al.<sup>[178]</sup> indicate that there is strong evidence that the deep LM can control intervertebral shear and torsion without generating torque. This means that LM has the potential to provide a strategy to control intervertebral motion without restricting range of motion. They cite a biomechanical in vitro study by Wilke et al.<sup>[179]</sup> wherein the effects of different muscle groups acting in different directions on the stability of a single motion segment were assessed. Wilke et al.<sup>[179]</sup> concluded that the strongest influence on stiffness was LM, which accounted for more than 2/3 of the segmental stiffness.

In the following section, the summary of the literature will focus on understanding the functional anatomy of the deep muscles of the lumbopelvic region, specifically the TrA, LM and PFM muscles.

### ***Transversus Abdominis***

The TrA muscle originates from the inner surface of the lower six costal cartilages, the thoracolumbar fascia, the anterior two thirds of the iliac crest and the lateral third of the inguinal ligament and inserts anteriorly into the linea alba and pubis.<sup>[180]</sup> In the ideally functioning system, TrA is activated prior to initiation of limb or trunk movement.<sup>[83]</sup> Specifically, in anticipation of a predictable force or in response to perturbations, TrA exhibits early, tonic, co-activation with LM and the PFM, regardless of the direction of the force.<sup>[29, 84, 145, 146, 181, 182]</sup> Voluntary activation of the TrA has been assessed clinically with the abdominal drawing in maneuver (ADIM) where an increase in thickness has been observed on both RUSI and MRI during performance of the ADIM.<sup>[183, 184]</sup> Automatic activation of the TrA has been evaluated both with the active straight leg raise test (ASLR)<sup>[184, 185]</sup> and isometric low load tasks with lower limb suspension in slings.<sup>[148]</sup>

Latency in onset of the TrA during the ADIM as well as reduced muscle thickness change from rest to contracted states have been observed in individuals suffering from lumbopelvic pain. Kiesel et al.<sup>[140]</sup> found that induced spinal pain decreased the TrA thickness ratios during ADIM in normal controls. Others have noted delayed and diminished voluntary and automatic TrA contraction in LPP cohorts.<sup>[29, 106, 147, 148, 186, 187]</sup> For example, Ferreira et al.<sup>[148]</sup> recorded fine wire EMG activity simultaneously with RUSI imaging to demonstrate that individuals with low back pain have less TrA activity (EMG) and smaller increases in thickness during isometric low load tasks with legs suspended (RUSI). Similarly, Hides et al.<sup>[186]</sup> examined elite cricketers with low back pain and noted a reduced thickness change with ADIM on MRI.

### ***Lumbar Multifidus***

The lumbar multifidus (LM) originates from the posterior aspect of the sacrum, aponeurosis of the erector spinae, posterosuperior iliac spines, sacroiliac ligaments and mamillary processes of the lumbar vertebrae.<sup>[180]</sup> The deep multifidus, which is thought to control segmental motion, consists of multiple fascicles that run across only two spinal levels and insert on the lamina, mamillary process and zygapophyseal joint capsule.<sup>[178]</sup> The superficial LM spans between two and five spinal levels. The common clinical belief underpinning rehabilitation practice was that the deep LM acted tonically like TrA, and that the superficial LM acted phasically more like the superficial abdominal muscles.<sup>[188]</sup> MacDonald et al.<sup>[178]</sup> challenged this notion in a literature review and found evidence that deep and superficial LM both have the capacity for phasic and tonic contraction and this varies with demands of spinal control. For example, Saunders et al.<sup>[189]</sup> hypothesized that there would be a difference in recruitment between deep and superficial muscles, and found that while TrA was tonically active during the gait cycle, the LM was recruited in a phasic manner at heel strike in running and walking.

Like the TrA, changes in the neurophysiological characteristics of the LM occur with spinal pain or injury. Increased latency in lumbar muscle onset has been reported for populations with chronic LBP<sup>[190-193]</sup> and sciatica<sup>[194]</sup> which can persist after resolution of pain.<sup>[149]</sup> MacDonald et al.<sup>[149]</sup> report a change in motor recruitment patterns in individuals between episodes of LBP. They raise the possibility that this abnormal pattern of muscle control may explain the propensity for recurrence of back pain. This decrease in muscle activity could contribute to the changes in cross-sectional area of the deep stabilizers that has been reported. As early as three days following onset of a first episode of acute LBP, the cross-sectional area of the MF at the site of the injury can

decrease rapidly without spontaneous recovery.<sup>[137, 152]</sup> Conflicting findings regarding MF size following injury have been reported. Hides et al.<sup>[152]</sup> noted segmental MF wasting on the side ipsilateral to the pain or injury whereas Kiesel et al.<sup>[195]</sup> found no statistically significant difference in MF size or symmetry in individuals with acute LBP. The difference may be that Hides et al were examining individuals with a first episode of acute LBP whereas Kiesel et al.'s sample included individuals with acute and chronic back pain. Another study that included individuals with chronic LBP found generalized atrophy in the MF but an increase in the cross-sectional area on the symptomatic side.<sup>[196]</sup> Chronicity may explain the differences in MF muscle thickness changes in these studies.

### ***Pelvic Floor Muscles***

The PFM are divided into three layers. The superficial layer includes the bulbospongiosus, ischiocavernosus and superficial transverse perineal muscles as well as the external anal sphincter. The middle layer includes the intrinsic urethral sphincter, deep transverse perineal, compressor urethrae and the urethrovaginal sphincter. The deep layer includes the levator ani and ischiococcygeus.<sup>[197]</sup> The right and left levator ani run horizontally from the internal surface of pubis along the obturator internus fascia to the coccyx. Medially the two sides of the muscle join in the midline raphe. Anteriorly there is a u-shaped defect known as the urogenital hiatus through which the urethra and vagina pass. There are three loops of fibres in the levator ani: the puborectalis forms a sling around the distal end of the gastrointestinal tract; the pubococcygeus runs from the pubis to the coccyx; and the iliococcygeus originates on the inner side of the ischium and the posterior part of the tendinous arch of the obturator fascia and inserts onto the coccyx. The levator ani supports the pelvic viscera and keeps the anus and vagina closed. It resists IAP during straining such as coughing or sneezing and prevents evacuation of digestive contents at inopportune times. The ischiococcygeus muscle lies over the sacrospinous ligament and forms the posterior part of the deep PFM. It originates on the ischial spine inserts onto the lateral margins of sacrum and coccyx and functions in a similar manner to the levator ani.

There is evidence of deficient or delayed PFM activity and poor endurance in response to coughing, sneezing, voluntary contraction, ASLR and postural perturbations in study participants who have reported lumbopelvic pain.<sup>[99, 105, 107, 169, 198-201]</sup> Beales et al.<sup>[107]</sup> noted altered motor control patterns with the ASLR in study participants with chronic LBP. They found that lifting the leg on the affected side of the body produced bracing through the abdominal wall that was associated

with an increase in IAP and depression of the pelvic floor compared with the other side.<sup>[107]</sup> Smith et al.<sup>[202]</sup> found a delay in response of the PFM with upper limb movements in incontinent women whereas the PFM was the first to be activated with upper limb movements in continent women. The authors suggest that these findings would be expected to have negative consequences for lumbopelvic stability.

In summary, because of the synergistic roles of the TrA, LM and PFM in maintaining lumbar stability, it is important to assess the impact of interruption of the abdominal fascia and related muscular attachments on the function of all three muscle groups. Kiesel et al.<sup>[140]</sup> noted a decrease in TrA contracted thickness with induced spinal pain during the ADIM and Ferreira et al.<sup>[148]</sup> noted reduced TrA thickness ultrasound and changes in automatic control (EMG) in individuals with low back pain. Likewise Hides et al.<sup>[186]</sup> found ipsilateral loss of TrA muscle thickness in elite cricketers with unilateral low back pain. The results are not as clear for the LM during back pain with Hides et al.<sup>[152]</sup> finding segmental LM wasting (decreased cross-sectional area in individuals with acute back pain. Wasting was limited to the injured segment and the mechanism was proposed by Hides et al. to be due to perceived pain via a ling loop reflex that targeted the level of pathology to protect the damaged tissue. Kiesel et al.<sup>[140]</sup> also found a reduction of resting and contracted thickness change in lumbar multifidus during induced back pain. Stokes et al.<sup>[196]</sup> found increased LM cross sectional area ipsilateral to radicular symptoms in recent (<18 months) (or chronic (>18 months) CT Scans. This selective change could reflect an adaptive response by the muscle to maximize lumbar stability. Thus different responses are seen in response to differing pathologies and tasks as predicted by the pain adaptation models discussed earlier in this chapter. So while changes to the lumbar stability system with back pain have been and continue to be well-studied, what has not been evaluated in vivo is the effect of insult to the abdominal wall on the muscle thickness of the TrA, LM and PFM in resting and contracted states. To address this gap, ultrasound imaging will be used to study potential changes in the muscle morphology of the TrA, LM and PFM, in resting and contracted states, before and after hysterectomy.

### 1.3 Conclusions

Lumbopelvic pain is a prevalent and costly health issue in the western world<sup>[203]</sup> with a high incidence of recurrence (70% within one year)<sup>[204]</sup> and a tendency toward chronicity.<sup>[205]</sup> LBP has been associated with altered motor control<sup>[10, 107]</sup> and changes in muscle morphology.<sup>[148, 206-208]</sup>

Nurses, care aides and licensed practical nurses experience high risks of work-related low back injury due, in large part, to their heavy workload.<sup>[209, 210]</sup> Identifying risks that contribute to back injury and opportunities for rehabilitation to reduce risks and disability is beneficial. With the average age of these healthcare workers in their mid forties, it is possible that a significant proportion of them could be undergoing hysterectomy during their working life. If abdominal hysterectomy is a risk factor for subsequent back injury, secondary rehabilitative and work-modification prevention strategies could be employed. If a link between surgical insult to the abdominal wall and subsequent diminished lumbar stability can be established, and the mechanism identified, intervention could be provided. It seems logical if individuals at risk can be identified, appropriate intervention such as core muscle rehabilitation could reduce the risk of back injury.

This thesis proposes that the link between back injury and hysterectomy could be alternation in muscle activation patterns post-surgically resulting in changes in spinal stability and mechanical loading related to reduced function of the deep stabilization system including the TrA, LM and PFM. The thesis seeks to provide evidence of this link through two research approaches – one a population-based epidemiological study and the other a targeted, clinical measurement study. The population-based, epidemiological analysis relied on health data records to investigate the hypothesized association between hysterectomy and back injury risk among a cohort of healthcare workers as a group at high risk for back injury. The clinical measurement study relied on tests of muscle function that are standardized and feasible to perform in a clinical setting among women with and without hysterectomy, to facilitate the transfer of knowledge from the lab to the clinic.

## 2. **Administrative Database Analysis of Association between Abdominal Hysterectomy and Low Back Injury among Healthcare Workers**

Frontline female healthcare workers are at a higher risk of back injury than their male counterparts and represent an industry with higher incidence of work-related low back injury. This chapter begins with an outline of back injury rates in the healthcare sector followed by the rationale for hypothesizing a potential increase in back injury risk following abdominal approach hysterectomy. This chapter describes a population-based approach to investigating this potential risk using data housed at Population Data BC and stewarded by the Ministry of Health in British Columbia. A novel method of occupational cohort extraction is described along with associated limitations for its use in this application.

### 2.1 **Introduction**

Low back injury is the most common job-related health problem among frontline healthcare workers such as Registered Nurses (RNs), Licensed Practical Nurses (LPNs) and Care Aides (CAs).<sup>[12]</sup> WorkSafeBC statistical reports show that workers in the healthcare sector have a higher rate of back injury than the all-sectors rate and this rate is remaining stable despite a declining injury rate in other sectors.<sup>[211]</sup> The majority (~90%) of these frontline positions are staffed with female workers<sup>[212]</sup> and Alamgir et al.<sup>[53]</sup> have reported that these workers have an increased risk of musculoskeletal injuries (rate ratio = 1.43, 95% CI 1.11-1.85) compared to their male counterparts. Risk factors for back injury in this population include the physical demands associated with lifting, carrying, pushing and pulling forces of greater than 25 lbs<sup>[213]</sup>, repetition, and awkward positions such as bending or twisting<sup>[57, 58]</sup>. The 2005 National Survey of the Work and Health of Nurses (NSHWN)<sup>[214]</sup> showed that 85% of LPNs and 76% of RNs had lifting and transferring patients as part of their regular work. Marras et al.<sup>[12]</sup> noted that patient handlers were especially susceptible to low back disability and Eriksen et al.<sup>[57]</sup> found that frequent mechanical exposures were significant predictors of intense or disabling low back injury in Care Aides. In a recent systematic review, Yassi and Lockhart<sup>[7]</sup> reported risk estimates for back injury ranging from 1.2 to 5.5 for healthcare workers performing nursing activities.

The physiological mechanism that provides stability and prevents injury to the back during dynamic activities requiring force transmission (lifting, pushing/pulling, twisting), is that

of core muscle activation.<sup>[94]</sup> The core muscles are oriented in a myofascial ring that spans the circumference of the trunk and provides stability during load transfers through the trunk. As the load is transferred, the core muscles activate, tensioning the ring, thus preventing shearing forces in the lumbar spine.<sup>[24]</sup> Functional deficits have been found in these structures in individuals with low back injury.<sup>[80, 107, 147, 215]</sup> Identifying individuals with poor core muscle function/stability, who could be at risk for low back injury, would help with targeting injury prevention and rehabilitation strategies. Therefore, studying potential risk factors such as surgical interruption of the core muscle system which would interfere with their ability to play a protective role is worthwhile.

Abdominal hysterectomy, a common surgery in women aged 30 to 55 years of age (prevalence in Canada of 30%),<sup>[216]</sup> involves a compromise of the abdominal myofascial ring when the surgeon cuts into the abdomen to expose the uterus. One study ostensibly comparing surgical position, supine vs. lithotomy, but also comparing vaginal and abdominal approach to hysterectomy, found increased back pain that did not resolve in individuals who had the abdominal approach.<sup>[39]</sup> The MORGEN study<sup>[37]</sup> also noted a significant incidence of low back pain following abdominal hysterectomy (see section 1.2.2 for full details). Brown and McGill's<sup>[43]</sup> study of rats and Salgado et al.'s study of rabbits<sup>[217]</sup> demonstrated a reduced force transmission through the abdominal muscles once their aponeurosis had been cut and repaired. The Sprague-Dawley rat used in Brown and McGill's study has been shown to be a valid model for human abdominal wall muscle function as it has identical muscles with similar contractile and force generating properties.<sup>[42]</sup>

To evaluate the hypothesis that abdominal hysterectomy is associated with subsequent low back injury, a population-based administrative database study was conducted, taking advantage of existing, linked data on medical services and workers' compensation claims for back injury. This novel hypothesis is supported by personal physiotherapy clinical experience both in rehabilitation practice and return-to-work disability management of an association between hysterectomy and low back injury. A surgical insult to the abdominal myofascial ring that contains the muscles and surrounding fascia of the lateral abdominal wall, that are important contributors to lumbar stability, could result in reduced function, putting the low back at increased risk of injury.

To control for confounding factors associated with occupational physical demands, the risk of low back injury associated with hysterectomy status was adjusted for occupation (RN, LPN or CA), type of healthcare facility (Acute Care, Long Term Care, Community Care), Health Authority and urban/rural geographic location. Care Aides and LPNs have higher rates of musculoskeletal injuries (including back injuries) than nurses as a result of differences in physical demands.<sup>[50]</sup> Blue<sup>[218]</sup> reports that work location (as a result of heavier work) impacts back injury rates. Staffing levels also impact job demands<sup>[209, 219]</sup> and overtime hours, as well as access to health services are known to vary by region in British Columbia.<sup>[220]</sup> Hysterectomy rates vary between Health Authorities in British Columbia and by urban/rural dwelling ranging from 5.75 surgeries per 1,000 women in the Northern Interior (primarily rural) to 1.37 in Vancouver, BC (urban).<sup>[31]</sup> Several studies have shown that risk of work related low back injury varies with work location and job duties as well.<sup>[6, 65, 221, 222]</sup> While exact work location and duties of each healthcare worker, such as specific ward or patient population, was not available, general locations including Acute Care, Long Term Care and Community Care were provided along with job title as the best surrogate measures of workload and physical demand measures available in the administrative data.

Demographic factors such as age were also included in the analysis as potential confounding variables. Although age is associated with hysterectomy,<sup>[68]</sup> the association with risk of back injury is more contradictory. Ando et al.<sup>[223]</sup> found no significant associations between age, duration of employment, and body mass index (BMI) for risk of musculoskeletal injury. Menzel et al.,<sup>[224]</sup> in a survey of nursing personnel, also found no increased risk of back injury with increasing age. In contrast, the 2006 Canadian Nurses Association report<sup>[20]</sup> found that trends in injury-related absenteeism increased in Canadian nurses over 45 years of age. Despite the conflicting evidence, age is often a risk factor for health outcomes and was therefore included in the analysis investigating the association between hysterectomy and back injury.

## **2.2 Methods**

### **2.2.1 Data Sources**

Administrative health databases have been widely used in research studies in Canada<sup>[225-232]</sup>. In British Columbia, Population Data BC, which is housed at the University of British Columbia, maintains and links provincial health data and, with approval from the Ministry of

Health and other data stewards, extracts and provides linked data to health researchers for approved projects. This data resource provides almost 25 years of health data on physician contacts (outpatient), hospitalizations and workers' compensation claims. Linkage with the Ministry of Health registry file provides data on residency in British Columbia over time and a neighborhood-level socioeconomic indicator based on census data.

For this study, the health data provided for research purposes included the universal Medical Services Plan (MSP) registry<sup>[46]</sup> for yearly follow-up of residency in the province and for socio-demographic data on age, geographic location of residence during follow-up, and socioeconomic status; health records including outpatient services for physicians, specialists, and other practitioners<sup>[47]</sup> and for identification of prior back injury history; hospital discharge records for hysterectomy status<sup>[48]</sup>; and WorkSafeBC (WSBC – the provincial workers' compensation system)<sup>[49]</sup> for short-term disability claims (at least one day of wage loss) for identification of work related back injury (both prior history and new claims during follow-up). Health data included service date and diagnosis codes using the International Classification of Diseases, Revision 9<sup>[233]</sup> (ICD-9) and Revision 10 (ICD-10). Procedure codes included the Canadian Classification of Diagnostic, Therapeutic and Surgical Procedures (CCP) for data prior to 2001 and Canadian Classification of Health Interventions (CCI) for 2001 and later.

Personal Health Numbers used for linkage purposes were removed from the linked database and replaced with a unique study identifier prior to provision of data access to the researchers by Population Data BC. This project was approved by the University of British Columbia's Behavioural Research Ethics Board (Certificate #H10-01684) and was governed by a research agreement between the researchers and the data stewards (Project #11-005).

### 2.2.2 Study Cohort

Using methodology developed by Cherry et al.,<sup>[234]</sup> a cohort of frontline female direct care workers was extracted by Population Data BC programmers using Classification Unit (CU) codes in the WSBC claims database. Initially, all claims with CU codes for Acute Care (766001), Long Term Care (766011) and Community Care (766006) were extracted. Then, Standard Occupation Classification (SOC) codes<sup>[235]</sup> (D112, D233, D312) were used to identify nurses (RN), licensed practical nurses (LPN) and care aides (CA) respectively in the data beginning in 1997. For data before 1997, Occupational Classification Manual (OCM) codes<sup>[236]</sup> (3131, 3134, 3135) were used to identify RNs, LPNs and CAs. This formed the basis of a population-based, longitudinal workforce

sample of front line healthcare workers with detailed occupation and industry of employment information, albeit defined by work disability (for any reason) over a 25-year data period. The claim at the time of cohort enumeration was used solely for identification of a population of healthcare workers. These cohort members were then linked to the medical services plan registry and health databases for defining entry into the cohort, follow-up, as well as exposure and outcome status. If the claim at the time of cohort enumeration was for a low-back injury it would also have been used for identification of work related low back injury prior to the start of follow-up for exclusion or for identification of the outcome of interest during follow-up.

### ***Inclusion and Exclusion Criteria***

To be included in the research cohort, a female healthcare worker must have been a British Columbia resident for at least five years, as identified in the medical services registry, prior to entering the cohort in 1996 or later and have no evidence of prior back injury during this five-year period in the medical services, hospitalization or workers' compensation data files.

Healthcare workers with a history of back injury identified in the MSP, hospital discharge records or WSBC files in the five years prior to their start date were excluded. Previous research by Cherkin<sup>[225]</sup> identified 66 ICD-9 codes related to mechanical low back diagnoses and these were adopted, along with their ICD-10 counterparts, as exclusion criteria. This list expands on the codes used by Koehoorn et al.<sup>[237]</sup> for the identification of work-related low back injury as it includes degenerative conditions such as spinal stenosis and spondylolisthesis. The codes were modified for use with the MSP data as these records only contain three digit codes. Women with hysterectomy prior to cohort start date were also excluded having been identified using CCP codes in the hospital discharge records, in the range of 80.2 to 80.69 for the years from 1986 to 2001 and CCI codes 1.RM.89\*A and 1.RM.91\*A, where the \* represents the surgical approach and can be any of (A,C,D,L) for 2001 and later. "A" refers to a combined laparoscopic and vaginal approach; "C" is for vaginal approach; "D" is for laporoscopic approach and "L" is for the open abdominal approach. All records of the 315 women who underwent a cancer-related hysterectomy identified by cancer related ICD-9 and ICD-10 diagnosis codes for relevant cancers during the follow-up period were also removed from the cohort as were individuals undergoing hysterectomies using vaginal or laporoscopic approaches. Included ICD-9 codes were 179, 179.0, 180.8, 180.9, 182.0, 182.1, 183.0, 183.3, 183.8, 184.0, 184.2 and 184.4. Included ICD-10 codes were C519, C530, C538, C539, C541, C548, C549, C560, C561, C569, and C5700.

### 2.2.3 Study Design

A retrospective cohort study was carried out using the following steps. First, the cohort of female frontline healthcare workers was extracted from the WorkSafeBC compensation claims records and deterministically linked with health data at Population Data BC as outlined in the previous section. Since WSBC and the hospital discharge databases have records from 1985 forward but the MSP databases only have diagnosis codes from 1991 forward, the earliest cohort start date was April 1, 1996 (MSP and hospital files run from April 1 to March 31) ensuring at least five years of previous history for application of exclusionary criteria. Individuals could enter the cohort at any point during the follow-up period once a five-year medical history was established.

Once a participant was confirmed as a frontline healthcare worker and there was no additional information to indicate that she had switched occupations or industries based on occupational history data in the workers' compensation claim data, the worker was assumed to be a healthcare worker for the duration of follow-up. Similarly, since job title and work location was determined by SOC/OCM and CU codes at the time of the WorkSafeBC claim, the individual was considered to remain in those occupations and locations unless a new claim offered evidence to the contrary. If a cohort member was no longer a resident of BC after 1996, as indicated by the yearly medical registry file, or they moved out of a healthcare occupation after entry in the cohort, as indicated by the claim or medical services records, they were lost to follow up.

Two models were developed: Model 1 investigated the relationship between abdominal hysterectomy status (yes versus no) on the incidence of work-related low back injury; Model 2 investigated the incidence of any back injury (work-related and non work-related). These two models were focused on the relationship between abdominal hysterectomy and the onset of new back injury.

### 2.2.4 Outcome Definition

#### ***Model 1 - Work-Related Low Back Injury***

This outcome of interest was defined as an accepted workers' compensation claim (dichotomous yes or no) identified by a low back-related ICD-9 diagnosis code that resulted in at least one day of work absence. Previous work by Cherkin<sup>[225]</sup> and Koehoorn et al.<sup>[237]</sup> was used to identify ICD-9 codes for "degeneration or displacement of discs, or intervertebral disc disorders; spinal stenosis, neuritis or radiculitis; lumbago, sciatica, backache, strains and sprains and other

unspecified symptoms of the back" and these were used for identification of the study outcome in the WorkSafeBC records. When analyzing the possible outcomes that would relate to weakened core musculature from a hysterectomy surgery, claims related to sacral ligaments and spinal stenosis were not considered to be relevant and excluded from the list. Included ICD-9 codes are shown in table 2-1. Claims included both short-term (time-loss) as well as long-term (permanent) disability claims.

**Table 2-1 ICD-9 Codes and Descriptors**

ICD-9 Code	Description
722.5	Degeneration of lumbar or lumbosacral intervertebral disc
722.6	Degeneration of intervertebral disc site unspecified
722.7	Intervertebral disc disorder with myelopathy
722.9	Other and unspecified disc disorder
724.2	Lumbago
724.3	Sciatica
724.5	Backache Unspecified
739.3	Nonallopathic lesions of lumbar region not elsewhere specified
847.2	Lumbar sprain
847.9	Sprain of unspecified site of back

### 2.2.5 Any Back Injury

In addition to work-related low back injuries as outlined above, "any back injury" was defined in the MSP and hospital discharge databases using the codes listed above. However, it should be noted that MSP ICD-9 codes are only coded to three digits. So, while 847.2, for example, indicates *lumbar* strain in the WorkSafeBC data, the 847 code in the MSP data indicates back strain without the location identifier. As a result, thoracic and cervical strains could be included in the outcome definition for any back injury.

In both models above, the outcome was the first occurrence of back injury during follow-up in individuals with no history of back injury for a minimum of five years prior to start of follow-up.

### 2.2.6 Analysis Plan

#### *Model 1 - Cohort Follow Up for Work-related Back Injury*

Age restrictions (18-65 years, representing the typical working age population) at time of entry into the cohort or the end of follow-up ensured that only time at risk for *work-related* low

back injury was included in the analysis for Model 1. For example, if a worker was 24 years old when she incurred a work related injury in 2006, she could only enter the cohort in 2000. Likewise for a worker who entered the cohort in 1996 at age 56, she would only be followed until 2005 when she reached 65 years of age.

Workers were followed until the occurrence of either a work-related low back injury as indicated by a workers' compensation claim, loss to follow-up or the end of the study, whichever occurred first.

#### *Model 2 - Cohort Follow Up for Any Back Injury*

In this model, age was restricted in a similar way to Model 1 for two reasons. The first was for consistency when comparing the two groups and the other was that the oldest person to have a hysterectomy in this cohort was less than 60 years old. Therefore, the maximum follow up age in the exposed group would be 65 years old, so it made sense to truncate the follow up in the unexposed group at a similar age.

The cohort was followed until the occurrence of either a work-related low back injury as indicated by a workers' compensation claim, a back-related visit to a physician as indicated in the MSP billing records, a hospitalization for a back injury, or loss to follow-up or the end of the study, whichever occurred first.

#### ***Models 1 & 2 Analysis***

For both models, follow-up time was attributed by hysterectomy status (no for 'exposure' for follow-up time prior to hysterectomy surgery date or for those with no hysterectomy during follow-up; and yes for 'exposure' from surgery date forward for those with a hysterectomy during follow-up. Follow-up was censored five years post hysterectomy as injuries occurring beyond this period were not considered temporally related to hysterectomy, because other possible contributors to back injury increase as time progresses.

#### **2.2.7 Analytic Approach**

Using the linked research database, incidence density rates of work related back injury by hysterectomy status from 1996 forward were calculated using the following formula: #new cases during follow-up period/sum of person-time at risk for each individual in the population. The rate

ratio was derived through a comparison of the incidence densities in the exposed versus the unexposed populations.

This design allowed individuals to contribute time to each group as appropriate. For instance, when an individual began the cohort in 1996, she contributed time until her hysterectomy date (provided no work related low back injury was incurred after start date and prior to hysterectomy for Model 1 or any back injury after start date and prior to hysterectomy for Model 2) and then entered the hysterectomy group and began contributing time to that group. Rates were stratified for comparison by geographic region (5 health authorities for delivery of healthcare services, and residence in a urban versus rural area) as well as occupation group (RN, LPN, CA) and work location (Acute Care, Long-term Care, Community Care).

The Kaplan-Meier approach was used to calculate the probability of back injury at the time it occurred. The denominator is the population at risk at the time of each event. Survival curves were developed using PROC LIFETEST in SAS® Version 9.3 (SAS Institute, Cary, NC, USA). SAS is available for use within the Secure Research Environment (SRE) at Population Data BC.

Survival analysis, using the SAS software's PROC PHREG for Cox proportional hazard regression modeling ( $\alpha=.05$ ), was employed to model time until event (work-related low back injury for Model 1 or any back injury for Model 2) while adjusting for age, geographic location characteristics, occupation group and work location. The proportional hazards assumption was confirmed using Schoenfeld residual plots.<sup>[238]</sup> The whole population at risk was used to define the baseline risk over time. This baseline risk can be increased or decreased by the addition of covariates to the model. SAS uses a forward selection method that starts with nothing in the model and then adds in significant covariates until the model can no longer be improved through the addition of more covariates. Covariates included age, occupation, type of healthcare, health authority, and urban/rural geographic location.

## **2.3 Results**

### **2.3.1 Model 1 - Incidence of Work Related Low Back Injury**

The initial data extract included records for 37,057 female front line healthcare workers. Application of the exclusion criteria reduced the cohort size by 18,289 (49.35%) healthcare workers for prior back injury; 3,025 (8.16%) for prior, non-abdominal approach or cancer related hysterectomy and 6,673 (18.01%) for not meeting the continuous residency requirement whereby

individuals had to have lived in BC for 5 years prior to the start of follow-up in order to accurately assess their eligibility for inclusion in the cohort. This resulted in a final study cohort of 9,070 (24.48% of the extracted cohort) healthcare workers (Figure 2-1) with no evidence of a prior history of low back injury or hysterectomy based on at least five years of data/residency prior to the start of follow-up.

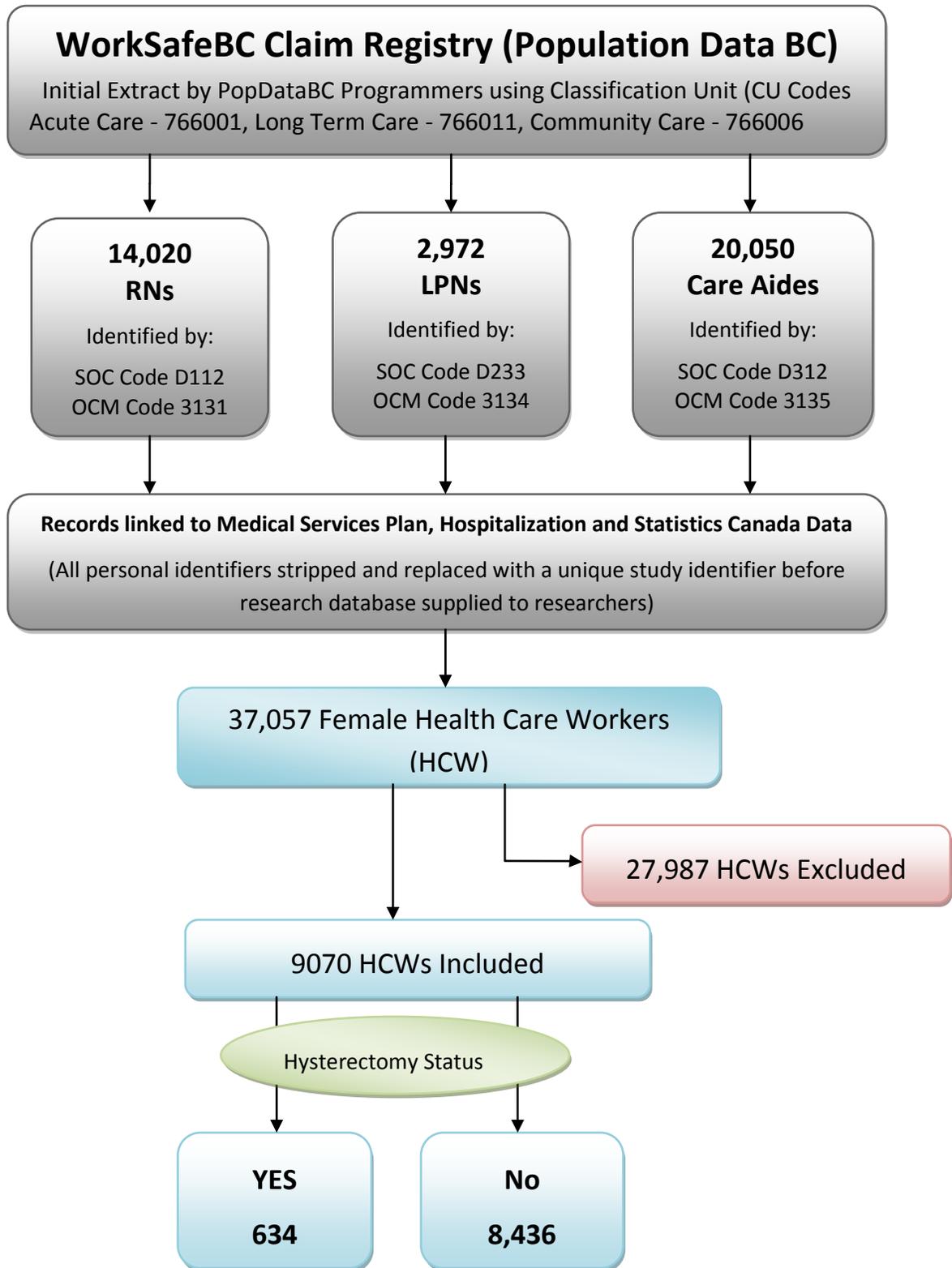


Figure 2-1 Flow chart from data extraction to final sample with exposure status.

As shown in Table 2-1, the average age of the final analytic sample at start of follow-up was 38.5 years, slightly younger than the overall population of healthcare workers initially extracted from the workers' compensation claims data. Occupation frequency as determined from the WorkSafeBC SOC and OCM codes on the claim file showed that Care Aides made up the largest proportion at 54.1%, with Registered Nurses making up 37.9% and Licensed Practical Nurses 8.0% of the extract. Statistics Canada reports that in 2003 the proportions of front line healthcare workers in Canada were 52% Registered Nurses, 39% Care Aides and 10% Licensed Practical Nurses, but they note that these proportions have changed since 1987 and continue to change.<sup>[239]</sup> Occupational proportions in the final analytic sample were slightly different at 46.5% CAs, 43.9% RNs and 9.5% LPNs; but consistent with the overall distribution of occupations in the healthcare work force. The majority of healthcare workers were represented by the Fraser Health Authority, the largest health authority by population and workforce size in the province of British Columbia.

**Table 2-2 Occupational proportions in initial extract, excluded and final sample.**

	Total Population <sup>1</sup> (n=37057)	Excluded (n=27987)	Included (n=9070)
Average Age(At Entry)	40.01	40.49	38.5
SD	11.49	11.41	11.61
Job Types (%)			
RN	14,020 (37.8)	10,039 (35.9)	3,981 (43.9)
LPN	2,972 (8.0)	2,107 (7.5)	865 (9.5)
CA	20,050 (54.1)	15,833 (56.6)	4,217 (46.5)
Missing/Multiple <sup>2</sup>	15 (0.0)	8 (0.0)	7 (0.1)
Health Authority (%)			
1 – Interior	6,905 (18.6)	5,282 (18.9)	1,623 (17.9)
2 – Fraser	13203 (35.6)	9,931 (35.5)	3,272 (36.1)
3 – Vancouver Coastal	6198 (16.7)	4,495 (16.1)	1,703 (18.8)
4 – Vancouver Island	8425 (22.7)	6,472 (23.1)	1,953 (21.5)
5 – Northern	1621 (4.4)	1,194 (4.3)	427 (4.7)
9 – Provincial Health	510 (1.4)	419 (1.5)	91 (1.0)
Missing	195 (0.5)	194 (0.7)	1 (0.0)
Work Location (%)			
Acute	19,590 (52.9)	14,672 (59.4)	4,918 (54.2)
Long Term Care	1,874 (5.7)	1,434 (5.1)	440 (4.8)
Community	11,293 (34.5)	8,586 (30.7)	2,707 (29.8)
Missing	4,300 (11.6)	3,296 (11.8)	1,004 (11.1)

<sup>1</sup> Extracted from workers' compensation claims data for healthcare workers in British Columbia

<sup>2</sup> Multiple refers to individuals who worked in more than one capacity (i.e. LPN then RN)

Abbreviations: SD, standard deviation.

Among the 37,057 healthcare workers initially identified from workers' compensation data, there were 6,142 hysterectomized women representing an overall period prevalence of 16.6%. Within the analytic sample of 9,070 included healthcare workers, there were 634 hysterectomies for an overall prevalence of 6.9% during the period of the study. Both of these measures differ from the 30% prevalence previously noted in the introduction. This is likely the result of a

healthy, employed cohort spanning a wider age range of 18 to 65 years compared to the 35 to 55 year age range used for the population based estimates of the prevalence of hysterectomy. The excluded sample of 27,987 included 5508 women with hysterectomies (19.7%) for which back injury preceded hysterectomy. This also helps to explain the low rate of hysterectomy in the included research sample.

In the no hysterectomy exposure group (i.e. no hysterectomy or prior to hysterectomy), 2,561 workers went on to work related low back injury, producing an incidence density rate of 3.02 claims per 100 person-years. In the hysterectomy group, 61 workers went on to work related low back injury within a five-year time frame for an incidence density rate of 2.89 claims per 100 person-years. Back injuries among workers post hysterectomy included 28 Care Aides (46%), 10 LPNs (16%) and 23 RNs (38%) who were equally distributed among the provincial health authorities, providing no indication of a higher risk group by occupation or geographic location. Rate ratios indicated no elevated risk of work-related back injury by hysterectomy status: RR=0.92, (95%CI 0.72-1.20) at five years of follow-up. Stratification for comparison by occupation, work location, geographic region and socioeconomic status did not reveal elevated risks of work-related low back injury associated with hysterectomy. The one exception was an increased rate ratio for LPNs (1.27), although the 95% confidence interval included '1' (95% CI 0.44-2.13 ). (Table 2-2) The Kaplan-Meier survival curves for time to back injury showed no significant differences between the unexposed and exposed groups.

**Table 2-3 Incidence density rate ratios for association between hysterectomy and work-related low back injury, including by covariates.**

	Work-related Back Injury Hyst+	Person Years	Work-related Back Injury Hyst-	Person Years	Rate Ratio (95% CI)
Incidence Density	61	2,113	2,561	84,938	0.92 (0.72-1.20)
<i>By Covariate</i>					
<b>Job Title</b>					
LPN	9	195	295	8,114	1.27 (0.44-2.13)
RN	22	938	896	38,560	1.01 (0.59-1.44)
CA	22	1,055	1052	40,059	0.79 (0.46-1.13)
<b>Work Location</b>					
Acute	30	1,142	1249	46,958	0.99 (0.63-1.35)
Community	5	131	179	3,955	0.84 (0.11-1.61)
Long Term	18	671	815	25,214	0.83 (0.45-1.22)
<b>Health Authority</b>					
1 – Interior	12	495	447	15,212	0.82 (0.36-1.30)
2 – Fraser	18	765	790	31,587	0.94 (0.51-1.38)
3 – Vancouver Coastal	5	214	418	16,523	0.92 (0.12-1.75)
4 – Vancouver Island	15	589	469	18,747	1.02 (0.50-1.55)
5 – Northern	3	114	100	4,117	1.08 (0.12-2.36)

The unadjusted Cox Proportional Hazard Ratio for the effect of hysterectomy (yes versus no) on work-related low back injury risk was 0.98 (95% CI 0.74-1.30). Adjusting for covariates outlined above, the adjusted Hazard Ratio for the risk of work-related low back injury associated with hysterectomy was calculated to be 0.95 (95% CI 0.78-1.09). With a hazard ratio of 0.97 (95% CI 0.97-0.98), increasing age in this cohort appeared to offer a very slight but protective effect for back injury. Type of Care Facility was the only other risk factor for work related low back injury with Long Term Care (HR = 2.21, 95% CI 1.74 - 2.36) and Community Care (HR=1.44, 95% CI 1.32 to 1.57) having an increased risk of work-related back injury compared to Acute Care. Geographic risk factors (Health Authority and rural/urban) showed no elevated risk of injury.

### 2.3.2 Model 2 - Incidence of Any Back Injury

Using the same methods as described in section 2.3.1 above, the cohort was followed forward until the occurrence of any back injury. This included work related injuries as described in the preceding section along with back-related physician visits in the MSP file or hospitalizations in the DAD file.

In the no hysterectomy exposure group, 6775 workers had a back injury, producing an incidence density rate of 13.7 back injuries per 100 person-years. In the hysterectomy group, 125 workers went on to a back injury within a five-year time frame for an incidence density rate of 13.8

back injuries per 100 person-years. Stratification by covariates (Table 2-3) showed an increased injury ratio for hysterectomy among LPNs, and for healthcare workers in both the large urban centre of Vancouver Coastal and the most northern/rural region of the province of, although the 95% confidence intervals for all of these increased ratios included '1'. Working in the Interior and Vancouver Island Health Authorities (both a mix of urban and rural locations) showed a reduced risk of back injury associated with hysterectomy, with 95% confidence intervals around the estimates that excluded '1'.

**Table 2-4 Results for association between hysterectomy and any back injury, including by covariates.**

	Any Back Injury Hyst+	Person Years	Any Back Injury Hyst-	Person Years	Rate Ratio (95% CI)
Unadjusted (5 year)	125	907	6,775	49,626	1.01 (0.83-1.19)
<i>By Covariate</i>					
<b>Job Title</b>					
LPN	15	61	689	4,413	1.57 (0.78-2.39)
RN	40	434	2822	22,976	0.75 (0.52-0.99)
CA	70	612	3262	23,185	0.81 (0.62-1.01)
<b>Work Location</b>					
Acute	59	456	3546	27,743	1.01 (0.75-1.27)
Community	11	71	363	2,327	0.99 (0.41-1.60)
Long Term	37	218	2133	9,487	0.76 (0.51-1.01)
<b>Health Authority</b>					
1 - Interior	17	179	1259	8,506	0.64 (0.34-0.95)
2 - Fraser	46	323	2435	17,845	1.04 (0.74-1.35)
3 - Vancouver Coastal	17	108	1261	9,574	1.20 (0.63-1.77)
4 - Vancouver Island	38	246	1445	6,908	0.74 (0.50-0.98)
5 - Northern	7	39	314	2,433	1.39 (0.37-2.45)

The unadjusted Cox Proportional Hazard Ratio for the effect of hysterectomy (yes versus no) on any back injury risk was 0.86 (95% CI 0.72,1.02). Adjusting for covariates outlined above, the adjusted hazard ratio for the risk of any low back injury associated with hysterectomy remained below 1 at 0.83, although the 95% confidence interval now excluded '1' (0.70, 0.97). Among all of the covariates, being a RN (HR=0.83; 95% CI 0.79, 0.88) was also protective against back injury compared to the CA and LPN designations.

## 2.4 Discussion

In summary, neither the model for work-related low back injury nor the model for any back injury demonstrated evidence of a positive association with hysterectomy. In fact, a protective effect of hysterectomy on low back injury was seen in the "any back injury" model. This was contrary to the stated hypothesis of this study. Reasons for this finding could include changes in activities of daily living following hysterectomy such as not returning to work, working part time or in less physically demanding work, changing employment, and reducing participation in sports or other activities. Support for this comes from a study by Ceausu et al.<sup>[79]</sup> in Sweden. They developed a health profile of women using a sample of 6917 women from Lund, Sweden, 800 (11.6%) of whom had undergone hysterectomy. Using both questionnaires and laboratory tests

they found that full time work was negatively associated with hysterectomy for women (OR=0.76; 0.62,0.93, p=0.007).

Previous research has shown a relationship between inefficient stability of the lumbar spine by the transversus abdominis muscle and fascia with low back pain/injury<sup>[29]</sup> and that the risk of future back injury in some populations can be reduced with a program of core strength exercises.<sup>[240]</sup> Animal studies have shown that force transmission across the abdominal aponeurosis is reduced following surgical insult and repair.<sup>[45, 217]</sup> However, the inherent limitations and methodological approach used with administrative health data may have exerted a conservative bias on the data and the ability to identify a relationship between hysterectomy and back injury among a occupational group of women at increased risk of injury. These issues are summarized in the following sections.

#### **2.4.1 Strengths and Limitations of Administrative Database Studies**

The large size and inclusiveness of the BC healthcare databases allow researchers access to patterns of routine clinical care at low cost. Records are generated when an encounter with the health system occurs. Biases related to information collected using survey methods such as selection and recall bias are minimized with the reliance on administrative data but these data have been collected for billing and resource utilization purposes rather than to address a research question. While they provide objective, detailed, comprehensive health and exposure data for the target population, there are limited data on unmeasured confounders for personal attributes such as body mass index<sup>[21]</sup> and health behaviours such as sedentary lifestyle<sup>[17]</sup> and smoking.<sup>[18]</sup> Database errors have been found to occur due to physician misdiagnosis (8%) or data entry mistakes (22%).<sup>[229]</sup> This could result in misclassification of individuals when applying exclusion criteria allowing individuals with prior back injury into the cohort and excluding others who do not have a prior history of back problems. This could dilute the sample thus exerting a conservative bias.

#### **2.4.2 Limitations of Cohort Enumeration, Inclusion/Exclusion and Personal Characteristics**

The definition of an occupational cohort by work disability at one point in time may also introduce some bias into the study. It does not capture the segment of the population without claims and this population may differ in significant ways from the claimant population. Previous work by Koehoorn et al.<sup>[241]</sup> showed that the claimant population differed from the non-claimant

population in terms of healthcare service usage. The claimants used more services both before and after their claims for musculoskeletal injuries such as back injuries. This means that those with a work-related back injury may have been more likely to have been excluded for prior history of back injury perhaps exerting a conservative bias on the risk of back injury following hysterectomy. This may also translate into a missing segment of the population of individuals who do not visit their physician frequently or directly access allied or alternative care providers without obtaining a physician referral. There could be a lower rate of back problems in this group (without claims) providing a lower comparison rate thus reducing the possibility of a type 2 error. Additionally, the study outcome, work related low back injury identified by a claim in the WorkSafeBC files, could miss workers who did not file a claim or who did not have a time-loss claim or those who sought medical attention for a non-compensable injury. This may have resulted in the inclusion of workers in the comparison group who had a back injury not captured in the workers compensation database, exerting a conservative bias on the estimates and limiting the ability to detect differences.

Other limitations include the use of MSP coding for exclusion of those with a prior back injury. The three digit diagnostic codes in the MSP database do not specify the spinal level involved. As a result, individuals with prior musculoskeletal strain or sprain in the MSP data, regardless of the spinal location, and no evidence of *low* back injury from the hospitalization or workers' compensation data, would have been excluded from the cohort. As there is evidence to suggest a high-level of comorbidity between neck and low-back musculoskeletal injuries<sup>[242]</sup> the exclusion of those with strains and sprains in the MSP data regardless of location (44% of exclusions) was likely a conservative approach that could underestimate the actual association.

Using MSP coding for identification of cases would also impact the power of the study to identify risks of back injury. Individuals who visited their physicians for cervical and thoracic spine injuries would also be included as cases when injuries to these areas are not impacted by trunk muscle function. However, if the distribution of the cases related to injuries in this area was equivalent in both the hysterectomy and non-hysterectomy groups, this bias would be minimized.

For individuals included in the research cohorts, there were varied sources of information on continued employment in the healthcare sector as evidenced by their occupation/industry codes in their claim history (if applicable) and/or a healthcare employer paid premium in the yearly medical services registry. As a result, the association between hysterectomy and back injury

in a group of workers hypothesized to be exposed to physical demands that exacerbate or trigger issues related to the core musculature may not have held if a significant portion of healthcare workers, especially those with hysterectomy, exited the healthcare work force. Also, it could not be ascertained if a worker with a back injury returned to modified job duties (graduated, light-duty, alternative work) or if workers with a hysterectomy underwent core muscle rehabilitation post surgery. That is, if individuals with hysterectomy were more likely to return to modified duties post surgery or undergo core strengthening, this may have reduced their risk of work-related or any low-back injury to that of the baseline population risk. Similarly, workers with a hysterectomy may have chosen to move to less physically demanding jobs post surgery reducing the risk of injury associated with core musculature. Detailed information on work and employment histories was not available using the study methods.

Further, Engkvist et al.<sup>[6]</sup> studied risk for over-exertion back injuries in nurses and found the highest relative risks associated with work unit (orthopedics RR=5.2, 95% CI = 2.7-10.2), type of work activity (lift/transfer RR=2.7, 95% CI = 1.6 - 4.5) and hours worked (full time RR = 2.4, 95% CI = 1.6 - 3.6). Information about these factors was not available in the data, only occupation group and type of care facility, which may have been reasonable surrogate measures for physical demands. Typically, in the healthcare sector, Care Aides perform the heaviest physical work. Also, individuals employed in Long Term Care facilities usually provide service for a more dependent patient population than those in Acute or Community settings. This study did not observe differences in the risk of low back injury by hysterectomy among occupational groups or type of facility. Surrogate measures of Occupation and Facility Type may not capture variability of the physical job demands at the individual level.

Finally, the protective effect of age could be a function of excluding all workers with previous back injuries resulting in a healthy worker effect. Since the greatest reported risk of future back injury is prior back injury,<sup>[243]</sup> exclusion of individuals with a back injury left a group of workers who could have developed effective strategies to maintain a healthy back and avoid injury. They could also be individuals who work through pain and/or avoid physician contact.

## **2.5 Conclusions and Implications**

Using this method of cohort extraction and analysis, this study found that among front line healthcare workers with a previous work-related injury claim, those who subsequently

underwent hysterectomy demonstrated no greater risk of work-related back injury time-loss than those who did not. Conversely hysterectomy exerted a protective effect on risk of back injury when all back injuries - both workers' compensation and non-compensation - were considered. These results may not generalize to the general population or hysterectomy might not be a risk factor for back injury. Alternate explanations of this result include:

- a) hysterectomy does not decrease abdominal strength/function and therefore would not impact the risk of back injury.
- b) reduced abdominal muscle strength/function does not increase the risk of back injury.
- c) individuals with hysterectomy exit the workforce, change jobs or return to modified duties following surgery thus reducing their risk of injury. They may also limit their regular activities of daily living thus reducing back injury risk.

The next logical step in light of the current study is to evaluate this myofascial stability system before and after hysterectomy. The next chapter presents an evaluation of the lumbar stability system over time in a non-surgical population of women to establish a baseline for comparison of a group of patients before and after hysterectomy.

### **3. Test-retest Reliability of Transversus Abdominis, Multifidus and Pelvic Floor Muscles at Rest and Under Various Loading Conditions in Healthy Women without Hysterectomy**

Abdominal hysterectomy disrupts muscle function with an incision into the midline fascial attachment. During healing, pain may inhibit use of these muscles and muscle strength might be lost. Previously published test-retest reliability estimates for muscle thickness measurements of the transversus abdominis, pelvic floor and low back muscles have been limited to intervals between 2 and 14 days. This chapter describes an investigation to determine if muscle thickness in the lumbar multifidus (LM) and transversus abdominis (TrA) muscles as measured with rehabilitative ultrasound imaging (RUSI) remains stable over one to three months and if pelvic floor muscle contraction and its response to loading strategies are consistent from one time to the next. The data collected includes measures from muscles at rest, and during three muscle contraction tests in healthy women, aged 35 to 55, without hysterectomy or recent (6 months) history of back injury or abdominal surgery. Pelvic floor measures were taken at rest and when contracted, as well as during lower extremity loading. Data collected in this investigation will also be used for comparison purposes with women who are undergoing abdominal hysterectomy (see Chapter 4).

#### **3.1 Introduction & Background**

Rehabilitative ultrasound imaging (RUSI) is becoming increasingly popular in physiotherapy research and practice to evaluate and guide the rehabilitation of the function of the deep trunk stabilizers and pelvic floor muscles. These deep stabilizers, Transversus Abdominis (TrA) and Lumbar Multifidus (LM), have been shown to assist with segmental spinal stabilization [25, 27, 80, 181] and, working together, play a role in prevention of recurrence of back pain. [244-246] In the clinic, RUSI is an effective method of biofeedback for contraction of these muscles. [247, 248] Research to date has included investigations of differences between populations such as those with and without low back pain, [148, 149, 195, 208, 249-253] variation by personal characteristics such as gender, [254] age, [255, 256] body mass index, [254, 257] parity, [258, 259] and efficacy of treatment with repeated measures. [153, 260]

### 3.1.1 Ultrasound Imaging of the Deep Stabilization System

Brightness-mode (B-Mode) RUSI is used in both research and clinical settings to quantify muscle morphology and activation of the deep stabilizers. The validity of measures obtained using TrA at rest, during sub-maximal contraction using the abdominal drawing-in maneuver (ADIM) and the active straight leg raise (ASLR) as well as the LM at rest and during the contralateral arm lift (CAL) has been investigated through comparison with electromyography (EMG) [148, 250, 261-263] and magnetic resonance imaging (MRI). [264, 265]

Fine wire or needle EMG (fwEMG) is considered to be the gold standard for measuring muscle activity. [250, 261] It detects myoelectric activity in response to motor nerve excitation. [266] Reported limitations of this method include cross talk from nearby muscles and issues with calculation of absolute EMG amplitudes using maximum voluntary contraction as many patients are unwilling or unable to perform MVCs. [120, 267, 268] Other drawbacks include sampling error related to the small portion of the muscle being recorded [262, 267] as well as displacement, deformation and fracture of the wire electrodes during muscle contraction. [269]

Criterion validity of B-mode RUSI compared to EMG has been evaluated for TrA and LM with mixed results. There are five studies investigating the relationship between TrA muscle thickness change using B-mode RUSI and muscle activity measured by fwEMG [148, 250, 261-263] and one that compares thickness change of LM captured with B-Mode RUSI with fwEMG. [270] Conclusions from these studies vary from stating that changes in muscle thicknesses are good indirect measures of muscle activity [148, 263] to suggestion of a weak or inconclusive relationship between abdominal muscle thickness change as a measure of muscular activity. [261] Criticisms of the study methods utilized include small sample size (3-14 participants) and varied test protocols including tasks used, subject positioning, sampling rate, and sampling site. Only two studies of the abdominal muscles used clinically relevant tests such as the ADIM and ASLR. Correlations with fwEMG for Whittaker et al.'s [261] recent study were  $r=0.35\pm 0.11$  for the TrA thickness measured during the ADIM and  $r=0.28\pm 0.09$  for the ASLR. They noted that there were statistically significant relationships in the TrA measures but that the coefficient of determination was small indicating that the change did not account for much of the variability in the small sample of 7 individuals. [261] In contrast, McMeeken et al. [263] reported  $R^2=0.87$ ,  $p<.0005$  in a study of asymptomatic participants. In another study of asymptomatic participants, Kiesel et al. [270]

compared EMG amplitude to muscle thickness of LM, and reported a high correlation between the methods ( $r=0.79, P<.001$ ) for tests producing 19-34% of maximal voluntary contraction such as the contra-lateral arm lift (CAL) using a weight calibrated to the individual's mass. Overall, as noted by Hodges et al.,<sup>[262]</sup> for tests eliciting submaximal muscle contraction, such as the ones in this study, ultrasound is a viable tool for measurement of muscle activity of the deep stabilizing muscles.

The gold standard for measures of human muscle morphology is MRI.<sup>[271]</sup> Two studies have compared measures of the deep stabilizers taken using B-mode RUSI with MRI. One measured the LM at rest and found no significant difference between resting measures taken with MRI and RUSI ( $F=0.42, p>0.05$ ),<sup>[265]</sup> the other measured TrA at rest and during the ADIM reporting correlations between muscle thickness measures obtained using MRI and those obtained with RUSI of 0.84 to 0.95.<sup>[272]</sup> Both studies used small numbers of young, healthy individuals. Studies of other skeletal muscles have reported agreement ranging from 0.22 to 0.90 between the two methods.<sup>[273-276]</sup> The lower values were explained by several of the investigators as being related to difficulty with imaging the same portion of the muscle due to differences in imaging planes and positioning.<sup>[273, 276]</sup> Despite these issues, many published papers comment that the validity of RUSI for measuring muscle thickness is adequate based on level of agreement between measurement methods.<sup>[254, 257, 277-279]</sup> A systematic review of the validity of RUSI to measure trunk muscle size and activation concluded that it was valid to use RUSI both for measuring trunk muscle size and activation during most sub-maximal contractions.<sup>[264]</sup>

Tests commonly used to evaluate muscle function with RUSI include the CAL for lumbar multifidus<sup>[270, 280-282]</sup>, the abdominal drawing-in maneuver (ADIM) for voluntary activation of the TrA<sup>[140, 249, 263, 278, 283-285]</sup> and the active straight leg raise (ASLR) to measure the automatic function of that muscle.<sup>[99, 141, 253, 261, 286]</sup> Reliability estimates for B-mode RUSI measurement of TrA and LM in a variety of circumstances such as seated and standing rest,<sup>[287-289]</sup> respiration,<sup>[290]</sup> four-point kneeling<sup>[249]</sup> and during lower limb loading tasks<sup>[250, 291]</sup> have been published. Table 3-1, adapted from Hebert et al.,<sup>[292]</sup> summarizes the intrarater reliability and precision estimates for studies that have used B-Mode ultrasound measures of muscle thickness using the ADIM, ASLR and CAL along with rest (supine, crook/hook lying and prone) conditions. Inter-rater reliability and precision estimates are not presented as all testing in this study was performed by one examiner, the principal investigator.

**Table 3-1 B-Mode RUSI intrarater reliability results by test.**

Citation	N/ Status	Muscle/ Condition	Reliability Estimate		Precision Estimate	
			Within Day	Between Day	Within Day	Between Day
Teyhen et al. <sup>[284]</sup> 2005	9/LBP	TrA Rest	ICC <sub>3,1</sub> (CI <sub>95</sub> ) 0.93(0.75-0.99)		SEM (mm) TrA=0.31	Between Day
Hides et al. <sup>[293]</sup> 2007	19/A	TrA Hook-lying rest	ICC <sub>3,4</sub> (CI <sub>95</sub> ) 0.62 (0.32-0.85)	ICC <sub>3,6</sub> (CI <sub>95</sub> ) 0.85 (0.42-0.98);	SEM (mm) 0.247	SEM (mm) 0.089
		ADIM	0.80 (0.56-.093)	0.84 (0.52-0.96)	0.224	0.176
Kiesel et al. <sup>[195]</sup> (2007)	15 NS	TrA Hook-lying rest	ICC <sub>3,3</sub> (CI <sub>95</sub> ) 0.98 (0.91-0.99)		SEM, MDC <sub>95</sub> 0.1 mm, 0.3 mm	
		ADIM	0.97 (0.91-0.98)		0.2 mm, 0.6 mm	
		Percent Change	0.96 (0.91, 0.99)		6.26%, 17.34%.	
		LM (L4/5) Prone Rest	ICC <sub>3,3</sub> (CI <sub>95</sub> ) 0.99(0.97-0.99)		0.71 mm, 1.9 mm	
		CAL	0.98 (0.92-0.99)		0.9 mm, 2.5 mm	
		Percent Change	0.98(0.96-0.99)		2.96%, 8.19%.	
McMeeken et al. <sup>[263]</sup> (2004)	13/A	TrA Hook-lying rest		ICC <sub>7,7</sub> 0.99 (0.96-1.00)		No Information
Rankin <sup>[256]</sup> et al. (2006)	10/A	TrA Hook-lying rest	ICC <sub>7,7</sub> (CI <sub>95</sub> ) 0.98-.99 (0.85-1.0)	ICC <sub>7,7</sub> (CI <sub>95</sub> ) 0.96-.99 (0.85-1.0)	No Information	No Information
Van et al. <sup>[279]</sup>	6/A	LM Prone Rest	ICC <sub>1,1</sub> = 0.97-0.98		SEM (mm) 3.1-3.2	
Wong et al. <sup>[282]</sup> (2013)	27/ A/LBP	LM Prone Rest	ICC <sub>3,2</sub> (CI <sub>95</sub> ) 0.99 (0.99-1.0)	ICC <sub>3,2</sub> (CI <sub>95</sub> ) 0.93 (0.85-0.97)	MDC <sub>95</sub> , Rel. MDC <sub>95</sub> 0.7 mm, 2.7%	MDC <sub>95</sub> , Rel. MDC <sub>95</sub> 3.0 mm, 11.6%
		CAL	0.99 (0.99-1.0)	0.97(0.92-0.99)	0.9 mm, 2.7%	2.2 mm, 6.7%
		Percent Change	0.99 (0.97-0.99)	0.80 (0.61-0.91)	3.8%, 14.3%	13.2%, 46.6%
Roddey et al. <sup>[294]</sup> (2007)	70/A	TrA Hook-lying Rest	ICC <sub>2,1</sub> (CI <sub>95</sub> ) R=0.83; L=0.93		SEM (mm) R= 0.03, 0.02	
		ADIM	R=0.81; L=0.92		R=0.09L=0.04	
Brizzolara et al. <sup>[295]</sup> (2015)	15/A	TrA Percent Change from Supine rest to ASLR		ICC <sub>3,3</sub> (CI <sub>95</sub> ) R=0.71, L=0.52		SEM R=27.4%,L=21.14% MDC <sub>95</sub> (CI <sub>95</sub> ) R=63.9% (0.13-0.90%); L=49.3% (0.43-0.84%)
Koppenhaver et al. <sup>[286]</sup> (2009)	30 LBP	TrA Hook-lying rest	ICC <sub>3,2</sub> (CI <sub>95</sub> ) 0.96 (0.91-0.98)	ICC <sub>3,2</sub> (CI <sub>95</sub> ) 0.93 (0.85-0.97)	SEM, MDC 0.2 mm, 0.5 mm	SEM, MDC 0.2 mm, 0.7mm
		ADIM	0.97 (0.94-0.99)	0.87 (0.74-0.94)	0.3 mm, 0.7 mm	0.5 mm. 1.3 mm
		% Change	0.94 (0.87-0.97)	0.73 (0.43-0.87)	9.8%, 27.1%	19.2%, 53.3%
		Supine Rest	0.98 (0.95-0.99)	0.94 (0.87-0.97)	0.1 mm, 0.4 mm	0.2 mm, 0.6 mm
		ASLR	0.96 (0.92-0.98)	0.93 (0.86-0.97)	0.3 mm, 0.8 mm	0.4 mm, 1.1 mm
		%Change	0.92 (0.84-0.96)	0.73 (0.43-0.87)	9.2%, 25.4%	12.3%, 34.1%
		LM Prone Rest	0.97 (0.94-0.99)	0.98 (0.95-0.99)	1.0 mm, 2.8 mm	0.9 mm, 2.5 mm
		CAL	0.99 (0.98-1.00)	0.97 (0.94-0.99)	0.6 mm, 1.6 mm	1.1 mm, 3.1 mm
		%Change	0.78 (0.53-0.89)	0.79 (0.56-0.90)	4.0%, 11.0%	4.0%, 11.0%

Citation	N/ Status	Muscle/ Condition	Reliability Estimate		Precision Estimate	
Schrank et al. <sup>[296]</sup> (2011)	20/A	LM Prone Rest	ICC <sub>3,1</sub> (CI <sub>95</sub> ) ER 0.99 (0.986-0.997) NRs 0.96-0.98 (0.93-0.995)		SEM 0.41 mm 0.43-1.07 mm	
Gnat et al. <sup>[297]</sup> (2012)	10/A	TrA Hook-lying rest ADIM %Change		ICC <sub>2,1</sub> (CI <sub>95</sub> ) 0.97 (0.95-0.99) 0.84 (0.60-0.94)		SEM, MDC 0.22 mm, 0.60 mm 7.28%, 20.18%
Whittaker et al. (2013)	18 A/ LBP	TrA Rest -unspecified	ICC <sub>3,3</sub> (CI <sub>95</sub> ) LBP= 0.98 (0.95,0.99) A=0.92(0.95,0.99)	ICC <sub>3,3</sub> (CI <sub>95</sub> ) LBP=0.96 (0.81,0.99) A=0.97(0.86,0.99)	SEM, MDC 0.2, 0.4 0.2, 0.4	SEM, MDC 0.4, 1.1 0.3, 0.9
Linek et al. (2015)	39 A	TrA Supine Rest  ASLR  %Change		ICC <sub>3,3</sub> R=0.95, L=0.95  R=0.95, L=0.95  R=0.91, L=0.81		SEM, MDC R=0.20, 0.57 L=0.19, 0.54 R=0.24, 0.67 L=0.21,0.59 R=6.51, 18.0 L=7.99, 22.1

\*Adapted from Hebert et al.<sup>[292]</sup>

Abbreviations : TrA, transversus abdominis; LM, lumbar multifidus; ADIM, abdominal drawing-in maneuver; ASLR, active straight leg raise, CAL, contralateral arm lift; ICC, interclass correlation coefficient; LBP, low back pain, A, asymptomatic; NS, not stated; SEM, standard error of measurement; MDC, minimum discernible change, L, left; R, right; CV, coefficient of variation; CI, confidence interval; ER, experienced rater; NR, novice rater.

Portney and Watkins<sup>[298]</sup> opine that while there are no standard values for acceptable reliability, values closer to 1.00 represent stronger reliability. They suggest that values above 0.75 are indicative of good reliability and state that for clinical measures, reliability should exceed 0.90 to ensure reasonable validity. The minimal research standards for reliability coefficients for group comparisons is 0.70.<sup>[299]</sup> Overall, as can be seen in Table 3-1, for individual muscle measurements, all reliability ranges are greater than 0.90 with only one range below 0.70. Derived percent change measures are lower but still exceed the minimum except for Brizzolara's ICC<sub>3,3</sub> = 0.52 for the left sided TrA. Derived measures include more than one source of error as they are the ratio of two measures (rest and contracted). Reliability for novice raters (ICC<sub>3,1</sub> = 0.96-0.98 (0.93-0.995)) was lower than for experienced raters (ICC<sub>3,1</sub> = 0.99 (0.986-0.997)). None of the reliability studies analyzed female muscles only but Rankin's study<sup>[256]</sup> found that while males have significantly larger lateral abdominal muscles than females, once muscle size was normalized for body mass, TrA thickness did not differ between the genders.

Intra/inter rater and intra/inter session reliability has been established<sup>[245, 250, 251, 279, 286, 300]</sup> but the longest times between sessions has been only one to two weeks (TrA)<sup>[245, 251, 256, 263, 293, 297, 301]</sup> Most treatment focused on these muscles takes place over longer periods. Mannion et al.<sup>[302]</sup> measured TrA in individuals with chronic low back pain before and following a 9-week program

of therapeutic spinal stabilization exercises. In a randomized control trial of three treatment protocols, Vasseljen et al.<sup>[303]</sup> measured TrA at an 8 week interval to compare outcomes in chronic low back pain patients. In an exploratory study of the relationship between fear avoidance and activation of TrA in patients with low back pain, Unsgaard et al.<sup>[304]</sup> measured on two occasions, 8 weeks apart. In the protocol for the prevention of low back pain in the military (POLM) RCT, LM testing was planned before and after a 12-week intervention period.<sup>[305]</sup> No studies to date have evaluated the stability of muscle measurements over these longer intervals. Additionally, as the next study evaluates change in muscle thickness of the TrA and LM muscles following hysterectomy, stability of a longer intersession period is needed to evaluate recovery. Following hysterectomy, individuals may return to driving, which requires lumbopelvic stability to operate the brake, after 3-4 weeks; return to work often occurs at 6-8 weeks in lighter jobs and up to 3 months after surgery in heavier jobs (see Chapter 4 for full details).

### 3.1.2 Ultrasound of the Pelvic Floor Muscles

A correct pelvic floor muscle (PFM) contraction is described by Bø et al.<sup>[306]</sup> as a concentric, cranial/ventral lift and squeeze around the urethra resulting in urethral closure, PFM stabilization and resistance to downward movement. When evaluating pelvic floor function using transabdominal RUSI, change in bladder base position from its resting position is an indicator of PFM function.<sup>[99, 100, 307]</sup> Voluntary muscle contraction is evaluated by asking participants to contract the pelvic floor by performing a Kegel maneuver<sup>[308]</sup>, which consists of drawing in and lifting the pelvic floor muscles.<sup>[100, 201, 285, 307, 309]</sup> Whittaker et al.<sup>[310]</sup> notes that bladder base position change can be affected by competing forces of intra-abdominal pressure (IAP), PFM elevation and inherent myofascial laxity, and that this can be a limitation of this technique. For instance, a woman could have a strong pelvic floor contraction but forces associated with IAP could match or exceed this contraction resulting in either no change or a descent of the bladder base. To address this limitation, a second test, an ASLR, has been used in several studies to measure the effect of IAP on the bladder base.<sup>[99, 105, 201, 310]</sup> The ASLR is performed without a concurrent voluntary contraction of the pelvic floor muscles. If the bladder base does not change position, the conclusion is that there is no net effect of IAP. If the bladder base descends, it is indicative of increased susceptibility to IAP.

Sherburn et al.<sup>[309]</sup> studied the validity of transabdominal ultrasound imaging of displacement of the posterior bladder wall as a reflection of pelvic floor muscle contraction.

Correct pelvic floor contraction was confirmed on digital palpation (the gold standard for assessment of PFM function)<sup>[311]</sup> for both sagittal and transverse images but there was no relationship between displacement and digital strength grading (Spearman correlation coefficients were  $r=-0.13$  for the sagittal and  $r=0.21$  for the transverse images). Average inter-rater reliability ICCs for sagittal and transverse plane bladder base displacement measures were between 0.86 and 0.88 (95%CI 0.68 to 0.97) and intersession, intrarater ICCs up to 5 days apart were between 0.81 and 0.89 (95% CI 0.51 to 0.96) for bladder base displacement on transverse and sagittal images. One limitation identified is the lack of a bony landmark to use as a reference point making it difficult to quantify the movement of the bladder base. However, the bladder base displacement observed with proper pelvic floor muscle contraction is easy to identify and easily distinguishable from incorrect technique.<sup>[309]</sup> Thus, in day-to-day clinical practice a non-invasive screening test for pelvic floor function as demonstrated by bladder base displacement (yes/no) would be appropriate, and evaluating the consistency of this screening test over time would contribute to demonstrating the value of RUSI. To grade the muscles, more invasive techniques such as manometry or digital palpation are necessary.<sup>[312]</sup>

In summary, the reliability of the ADIM, ASLR, CAL and voluntary pelvic floor muscle contraction has been established over short test-retest intervals, but not over longer intervals. The purpose of the present investigation was so establish the intrarater/intersession reliability of the RUSI muscle thickness measurements for the TrA and LM and of the adequacy of the pelvic floor contractions during these tasks over intervals of 4, 8 and 12 weeks; these intervals corresponding to common rehabilitation intervention durations in the literature. Ultimately, the intent is to establish reliability of the RUSI measurements over a 3 month period. The reliability and associated minimum detectable change values from this study can be used when measuring a group of women before and after open approach hysterectomy.

### **3.2 Methods**

This repeated measures study took place at the University of Northern British Columbia (UNBC) Community Care Facility in Prince George and required each participant to attend four regularly spaced RUSI assessments over a three month period. Participants were asked to carry on with their usual activities between visits. Intakes were staggered over a 14 month period from September 2012 to December 2013.

### 3.2.1 Participant Recruitment

Participants were recruited in Prince George, BC from posters placed at public buildings such as the University of Northern British Columbia (UNBC), Prince George Regional Hospital, Prince George Library and at women's gatherings along with a website hosted by UNBC. The posters and website contained information about the study and requirements for participation. Interested participants contacted the Principal Investigator whose contact details were provided on the poster and website. A telephone interview was conducted to determine eligibility, and solicit informed consent. Interested individuals, who met the inclusion criteria, were scheduled for an initial data collection session. Inclusion criteria stated that only non-hysterectomized women between 35 and 55 with no back pain for at least six months would be admitted into the study. Further, any women with prior incidence of back pain would need to score at Grade 1 or less on the back pain questionnaire developed by Van Korff<sup>(33)</sup> which has been used to distinguish between back pain as part of a lifetime prevalence and disabling back pain.

### 3.2.2 Ethical Considerations

This study was granted ethics approval from the University of British Columbia - Clinical Research Ethics Board (H12-00382) as well as the Research Ethics Board of the University of Northern British Columbia (E2012.0215.024.00). An expedited review of the study was provided by Northern Health so that recruitment posters could be placed at the University Hospital of Northern British Columbia. All participants gave written informed consent prior to data collection.

### 3.2.3 Examiner

All imaging was performed by the principal investigator (LL) who is a physiotherapist with over 30 years of clinical experience. Prior to the study, the examiner completed a four day residency in RUSI with Dr. Jackie Whittaker in White Rock, BC and successfully completed an online course in musculoskeletal ultrasound imaging from the Burwin Institute of Diagnostic Medical Ultrasound in Canada. Additionally, she attended a two-day clinical musculo-skeletal ultrasound imaging course from Ultrasonix in Richmond, BC. Following this training, the examiner had hands-on practice using the study protocol to capture images with 10 volunteers who were not eligible for the study (too young, had back pain or had undergone hysterectomy).

To determine examiner preparedness prior to beginning the present study, intrarater reliability was assessed as follows. Three anonymized images were randomly selected from each of the ten training volunteers and measured using Image J software on two occasions 7 days apart and the intraclass correlation (ICC) was calculated at 0.94 (95% CI: .90-.99) indicating high reliability for Transversus Abdominis using the ADIM.

### 3.2.4 Ultrasound Imaging Protocol

Upon arrival at the first appointment, demographic information was obtained including age, height, weight, activity level, number of pregnancies, job title and education level. RUSI static B-Mode images were captured using an M-Turbo ultrasound machine (Sonosite, Inc, Bothell, WA) and a 60 mm, 2 to 5 MHz curvilinear transducer (figure 3-1). Transducer orientation was done following the radiological standard with the indicator pointing to the right when capturing images in the transverse plane (transversus abdominis and bladder base) and cranially when in the sagittal plane (lumbar multifidus and sagittal suprapubic measurements).



**Figure 3-1 Sonosite M-Turbo ultrasound imaging unit and 60 mm, 2-5 MHz curvilinear transducer.**

The examiner sat to the right of the participant who was lying on the plinth and used a two-handed grip to limit transducer motion as outlined by Whittaker et al.,<sup>[314, 315]</sup> and maintained a consistent pressure as recommended by Ishida et al.<sup>[316]</sup> A research assistant sat on the left side of the participant and operated the ultrasound machine upon verbal commands from the examiner. This allowed the examiner to focus on maintaining a consistent pressure on the transducer during maneuvers and to keep the transducer from tilting mediolaterally or cranial-

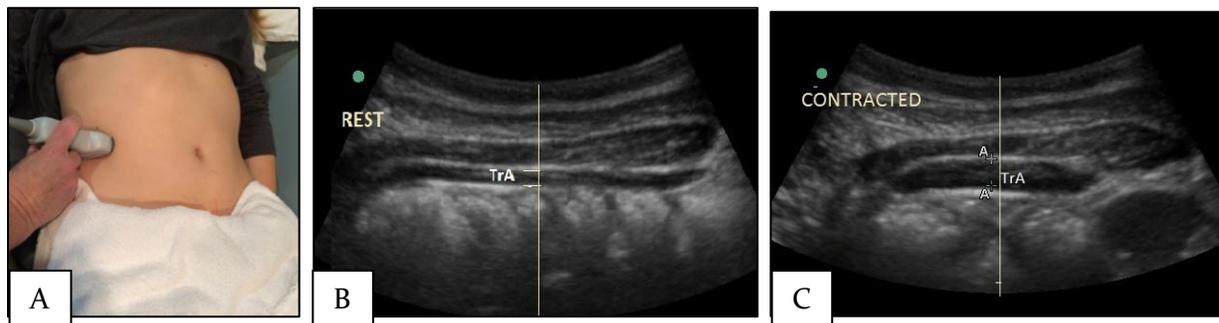
caudally and from rotating clockwise or counter clockwise. This was facilitated by using a two handed grip with the examiner's arms supported on the plinth.

To ensure that the pelvic floor muscles could be visualized, the participants needed sufficient fluid in the bladder and a standardized bladder-filling protocol was used.<sup>[310]</sup> They were asked to empty their bladders one hour before the scheduled appointment and then immediately drink 500 ml of water and not to void again until after the test. Kordi et al.<sup>[317]</sup> found that resting thickness of the TrA decreased from 23 to 27% immediately after eating, so participants were asked not to eat during the one hour immediately prior to testing.

Images of the transversus abdominis, bladder base and lumbar multifidus muscles were obtained from each participant using the following protocols.

### ***Transversus Abdominis (TrA)***

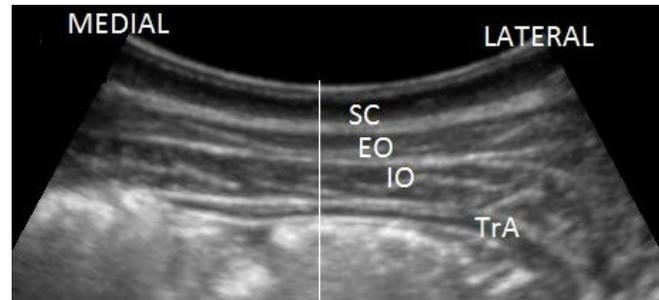
Images of the right TrA were acquired at rest as well as during the Abdominal Drawing-In Maneuver (ADIM) and the Active Straight Leg Raise (ASLR) tests. The ADIM elicits volitional contraction of the TrA whereas the ASLR elicits an automatic response of the TrA in response to this loading task.<sup>[286]</sup> To obtain the images, the transducer was positioned along the mid-axillary line midway between the right iliac crest and the inferior border of the rib cage as outlined by Teyhen et al.<sup>[284]</sup> and shown in figure 3-2.



**Figure 3-2 a. Ultrasound probe placement for rest, ADIM and ASLR images of the lateral abdominal wall; b. TrA at rest. C. TrA contracted. Vertical lines are the reference lines for measuring and crosshatches indicate the muscle borders.**

The middle of the muscle belly was centered in the middle of the ultrasound screen<sup>[286]</sup> and the transducer was adjusted at a slightly oblique angle to ensure that the fascial layers above and below the TrA were in a horizontal orientation.<sup>[318]</sup> Visualization of the image was optimized by adjusting the near gain to clarify the muscle/fascia borders and the depth was adjusted to

ensure that the superficial musculature of the lateral abdominal wall filled 40 to 50% of the display.<sup>[319]</sup> (figure 3-3).



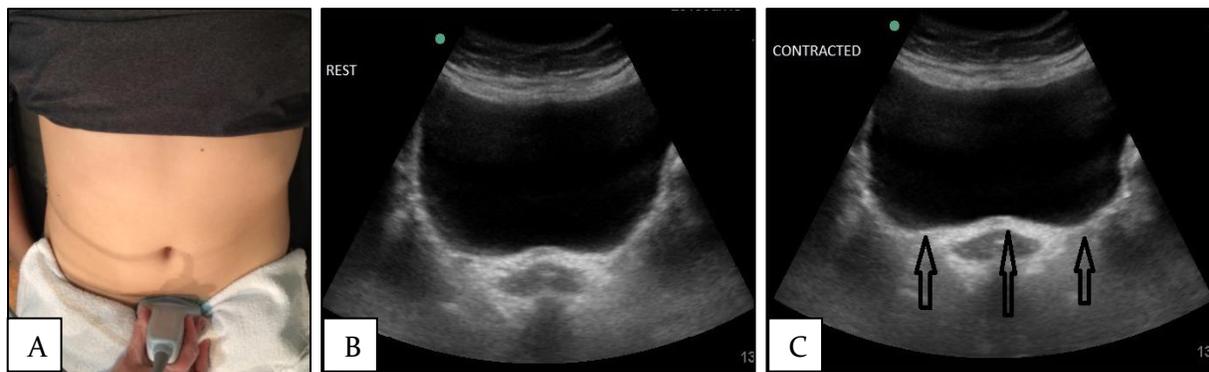
**Figure 3-3 Transverse RUSI image of the lateral abdominal wall. SC=subcutaneous tissue; EO=external oblique; IO=internal oblique; TrA transversus abdominis.**

To capture images of the ADIM, the participant was positioned in supine hook-lying.<sup>[187, 254, 320]</sup> To control for the effects of respiration on the abdominal wall, all images were captured at end expiration.<sup>[288, 315, 320]</sup> Following image capture of the muscle at rest, participants were instructed to take a breath in and out, and to hold the breath out while they contracted their abdominals by gently pulling in the lower abdomen and avoiding spinal movement.<sup>[187]</sup> The participant was asked to relax fully after each contraction to allow the muscle to return to the resting state. The participant practiced until a consistency in performance was established - usually 3 to 5 times.<sup>[195]</sup> On subsequent visits, a reminder of the specific task was given with one practice before image capture. Three images at rest and contracted were captured for measurement offline at a later time. The three thickness measurements were averaged per Koppenhaver et al.<sup>[321]</sup>

For the ASLR, the participant was positioned in supine with the legs straight. Following capture of images at rest in this position, she was asked to take a breath and after breathing out to lift her left leg<sup>[321]</sup> about 20 cm without bending her knee as described by Koppenhaver et al.<sup>[321]</sup> This distance was standardized by attaching a ruler to a tripod at the correct height. The tripod was placed on the left side of the patient extending over the plinth beside the lower end of the participant's shin. The participant was instructed to lift her leg until her shin touched the ruler. One practice was done prior to image capture on all visits and the participant was asked to relax fully after each ASLR. The image was captured with the leg at maximum excursion. This routine was performed three times and measured offline as above.

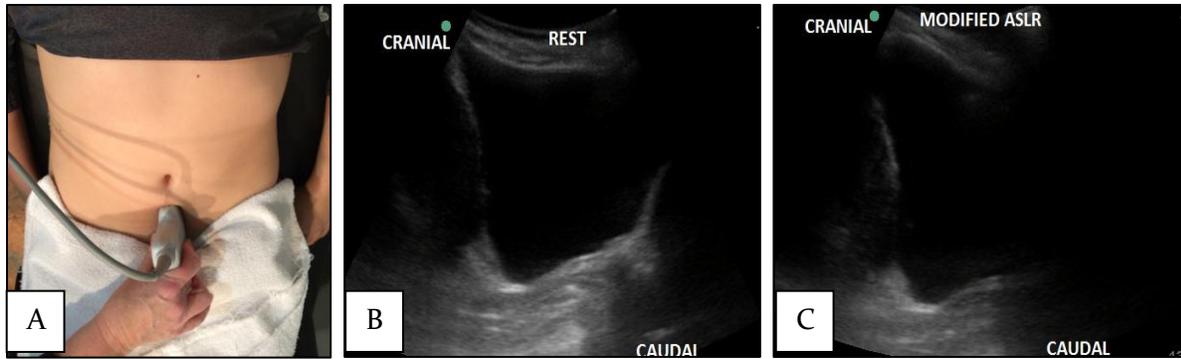
### ***Pelvic Floor Muscles***

The participant was placed in supine hook-lying with the legs supported by a bolster and the lumbar spine flat against the plinth. Images were captured trans-abdominally with the ultrasound transducer placed transversely just above the pubic symphysis.<sup>[34]</sup> The transducer was aimed at the base of the bladder resulting in an angle of approximately 60 degrees cephalad from vertical. Depth was adjusted so that the bladder base was in the bottom third of the image (figure 3-4). Participants were asked to perform a Kegel exercise at the end of a normal breath out. If the participant did not know how to perform a Kegel exercise, a prompt to close their rear passage and bring the contraction forward into the vagina was given. Three images were captured at rest and at maximal bladder base lift.



**Figure 3-4 A. Ultrasound probe placement for transverse bladder base images. B. Bladder base at rest. C. Bladder base elevated.**

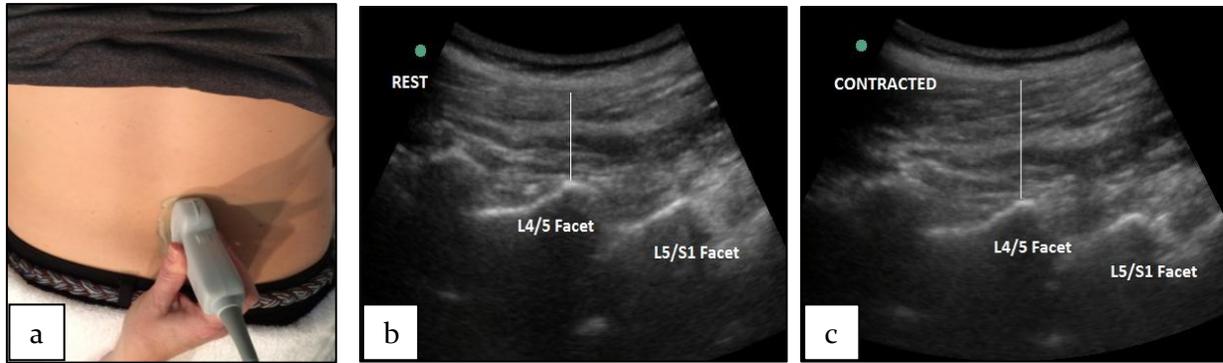
A sagittal image was obtained by placing the transducer in a sagittal orientation in the mid-line of the abdomen just above the pubic symphysis as shown in figure 3-5. An angle of approximately 60 degrees from vertical towards the head was required to get a clear image of the bladder and bladder base. The participant was asked to perform a modified ASLR of the left leg (from the hooklying position) to evaluate pelvic floor descent which is an indicator of increased intra-abdominal pressure.<sup>[99]</sup> The left leg was chosen as it was the leg used in the ASLR and the examiner was seated on the right so lifting the left leg eliminated the risk of jarring the examiners arm and thus the ultrasound transducer.



**Figure 3-5 A.** Ultrasound probe placement for sagittal bladder base images. **B.** Bladder base at rest. **C.** Bladder base descent during modified ASLR indicating increased intra-abdominal pressure.

### ***Lumbar Multifidus***

Participants were placed in prone over pillows, which supported the trunk. An inclinometer, placed longitudinally from the L4 spinous process to the median sacral crest ensured that the lumbo-sacral angle was less than 10 degrees.<sup>[195, 270, 280, 322, 323]</sup> The left upper extremity was abducted to 120° and the elbow was bent at a 90° angle. A weight standardized to the participant's body weight was placed in the left hand as outlined by Kiesel et al.<sup>[270]</sup> For individuals with body weight less than 68.2 kg, a 0.68 weight was used. For those with body weights between 68.2 and 90.9 kg a 0.9 kg weight was used. For body mass greater than 90.9, a 1.36 weight was used. Using the technique delineated by Kiesel et al.,<sup>[270]</sup> the transducer was placed first over the L4 spinous process and then moved laterally right and tilted slightly medially to visualize the L4/5 facet joint, LM and thoracolumbar fascia as in figure 3-6. Following one practice on each visit, images of the right LM were captured at rest and contracted at the end of expiration of a normal breath. The participant was asked to relax fully between contractions. Three images were captured for each state, measured offline at a later date and averaged for each maneuver as recommended in the literature<sup>[321, 323]</sup>.



**Figure 3-6 A. Ultrasound probe placement for measurement of lumbar multifidus(LM). Measurement is done from the tip of the facet to the plane between the subcutaneous tissue and the LM muscle as shown by the vertical line. B. LM At rest. C. LM contracted during a standardized contralateral arm lift.**

### 3.2.5 Measurements

The images were measured offline using Image J software v1.46r (National Institutes of Health, Bethesda, MD) on a different date than image collection. TrA thickness measurements were made between the hyperechoic fascial lines that demarcate the superficial and deep borders of the muscle<sup>[187, 195, 253, 320]</sup>(figure 3.3) Measurements were made up to the muscle-fascia boundaries, so fascial thickness is not included in the resulting measures.

Using trans-abdominal ultrasound there is no bony landmark from which to measure bladder displacement and therefore it can only be expressed relative to a mobile starting point.<sup>[309]</sup> Issues such as rate of bladder filling make standardizing bladder base displacement measurements difficult.<sup>[310]</sup> Therefore, these images were assessed as having an elevation of the bladder base or not (Yes/No) rather than quantitatively. (figure 3.4) Similarly, descent of the bladder base with ASLR exertion was also a dichotomous measure. (figure 3.5) Images at rest followed by contraction were compared to see if there was an elevation or descent of the bladder base in response to the testing condition.

LM measures were taken between the tip of the L4-5 facet to the plane between subcutaneous tissue and MF muscle (inner boundary of the fascia) as described by Stokes<sup>[322]</sup> and utilized in numerous studies<sup>[140, 195, 270, 280, 281, 286]</sup> (figure 3.6).

In each scenario, the three images of the muscles taken at each activation state (rest/contracted) were averaged and that value was used in the analyses.<sup>[321]</sup> For the percent

change values, three ratios were calculated using the individual pairs of values for rest and contracted measurements and then averaged.

### 3.2.6 Data Analysis

Statistical analyses were conducted using IBM SPSS for Windows, Version 22.0 software (IBM Corp, Armonk, NY). Descriptive statistics including the mean, range and standard deviation for each testing occasion were estimated to summarize the data.

Data from 30 participants for 4 time points (baseline, 4, 8 and 12 weeks) resulting in 3 measurement intervals (4, 8 and 12 weeks) and 4 measurement conditions (hook-lying rest, ADIM, supine rest and ASLR) for TrA as well as 2 measurement conditions (prone rest and contralateral arm lift) for lumbar multifidus were included for analysis. The dependent measures for the two muscles were the resting thickness, contracted thickness and percent change. Percent change was calculated using the formula  $(\text{thickness}_{\text{contracted}} - \text{thickness}_{\text{rest}}) / \text{thickness}_{\text{rest}}$ . Three individual ratios were calculated and averaged for each session.

Intrarater test-retest reliability estimates using Shrout and Fleiss<sup>[324]</sup> type 3,1 intraclass correlations (ICCs) with 95% confidence intervals were calculated for each of the dependent measures for three intervals, 4 weeks, 8 weeks and 12 weeks. The standard error of measurement (SEM), a measure of response stability,<sup>[298]</sup> under each condition was used to quantify the measurement error in the same units as the original measurement<sup>[325]</sup> using the formula:

$$SEM = s_{x \text{ pooled}} \sqrt{1 - ICC}. \text{ (} s_{x \text{ pooled}} \text{ is the weighted average of the individual sample variances.)}$$

Minimal detectable change (MDC) reflects the minimal within person change in thickness or percent thickness that can be interpreted with 95% confidence as a true change above measurement error.<sup>[292]</sup> It was calculated using the formula  $MDC_{95} = 1.96 \times \sqrt{2} \times SEM$ . To allow comparisons with other reliability studies, the relative  $MDC_{95}$  was derived by dividing the  $MDC_{95}$  by its corresponding mean muscle thickness or mean percent thickness change.<sup>[282]</sup>

Intrarater test-retest reliability for the pelvic floor nominal data was calculated using the kappa statistic which is a chance corrected measure of agreement. This utilized the formula  $P_c = \frac{\sum f_c}{N}$  here  $P_c$  stands for the proportion of agreements expected by chance and  $\sum f_c$  stands for total row times total column and  $N$  stands for the total observations.

Repeated measures analysis of variances (ANOVA) were done for the dependent variables to determine if there were significant differences between the measures at the different time intervals. Measures for testing occasions 2, 3 and 4 were contrasted with testing occasion 1. This was done to measure the change over the increasing time periods of 4 to 12 weeks. This also provides a comparison for the hysterectomy group in the next study who were measured initially before surgery and then three times after to evaluate if the muscles returned to the initial state over those time periods. Post hoc testing was done using the Bonferroni adjustment with  $\alpha=.05$ . Covariate analysis (repeated measures ANCOVA) included age, parity, previous back injury, activity level and BMI.

According to Field,<sup>[326]</sup> there is no counterpart for repeated measures ANOVA for binary data. Therefore the data from the pelvic floor is summarized descriptively by reporting frequencies of each response; specifically examining whether there was consistency across measurement times with respect to the participants' ability to contract the pelvic floor muscles (PFM) by elevating the bladder base. For the ASLR test, bladder descent was noted if it occurred the majority of three trials on each occasion. Correlation analyses, based on Spearman's rho ( $r_s$ ) and Cramer's V ( $\phi_c$ ) for nonparametric data, were used to examine the relationship between the frequency of bladder base movement (elevation or descent) over the four visits and age, BMI, prior back injury, parity and activity level.

### **3.3 Results**

A total of 32 healthy women participated. One woman dropped out after the first session and another's scans were unreadable due to a thick abdominal adipose apron necessitating an image depth (>15 cm) that made it difficult to discern the abdominal muscle boundaries.

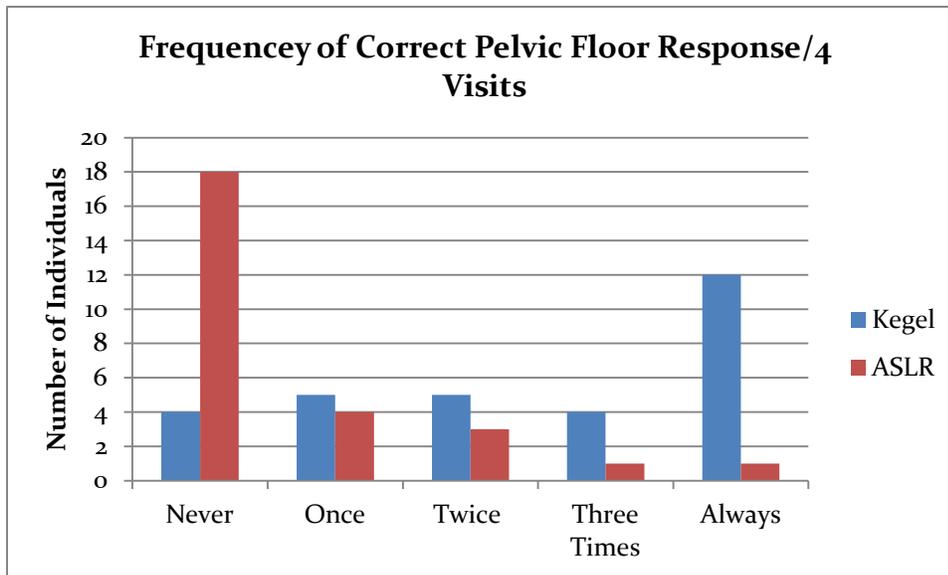
The average age of the remaining 30 participants was  $42.9 \pm 5.7$ , (range 35-54) with a body mass index of  $25.9 \pm 5.5$  (range 19.8 - 41.6). Nine participants reported that they did not participate in any form of regular exercise. Of the remaining 21 individuals, 18 reported a strenuous exercise regimen 3 to 4 times per week (e.g., cross-fit, bootcamp) while 3 individuals indicated a more moderate regimen (e.g., regular walks, tennis). Eighty percent reported some form of post-secondary education; all had completed high school. All lived in middle class neighborhoods and most worked in the health and education fields. Median parity was 2, with 33% of participants being nulliparous. Fifty-seven percent reported a past history of back pain or injury requiring time off work and/or treatment from a health professional.

The means and standard deviations for the measurements at rest and contracted as well as for the percent change between rest and contracted for each muscle were very similar at all time points. Most were biggest at baseline except for the LM during CAL and percent change (Table 3.2).

**Table 3-2 Descriptive statistics for the muscle thickness measurements in each of the rest, contracted and percent change conditions for each of the muscles on the 4 testing occasions.**

Measurement	Initial	Week 4	Week 8	Week 12
	Mean±SD (Min-Max)	Mean±SD (Min-Max)	Mean±SD (Min-Max)	Mean±SD (Min-Max)
<b>TrA</b>				
Hook-lying Rest (mm)	3.1±0.9 (1.6-5.2)	3.1±0.8 (1.8-5.1)	3.0±0.9 (1.6-4.8)	3.1±0.8 (1.4-4.8)
ADIM (mm)	4.9±1.3 (2.0-7.3)	4.7±1.1 (2.6-6.5)	4.6±1.3 (2.4-7.0)	4.7±1.4 (2.5-6.9)
% change rest vs ADIM (%)	56.1±23.9(12-112)	53.01±26.3 (.06-101)	57.9±28.8 (.10-125)	53.8±24.4 (2-104)
<b>TrA</b>				
Supine Rest (mm)	3.0±0.8 (1.8-5.1)	3.0±0.9 (1.7-5.0)	3.1±0.9 (1.7-4.9)	3.1±1.0(1.4-5.3)
ASLR (mm)	3.9±1.0 (1.7-5.6)	3.8±0.9 (2.2-5.5)	3.7±1.1 (1.7-5.8)	3.8±1.2 (1.4-6.0)
% change rest vs ASLR (%)	26.4±19.6 (-.02-69)	23.0±15.4 (0-53)	22.8±16.2 (-0.3-54)	24.2±16.8 (.01-77)
<b>LM</b>				
Prone Rest(mm)	28.6±5.3 (20.2-39.0)	28.4±4.5 (20.9-38.4)	27.9±4.8 (21.2-41.0)	28.2±4.8 (21.1-39.7)
CAL (mm)	33.6±5.9 (25.0-45.2)	33.8±5.1 (25.4-46.5)	33.6±5.1 (25.3-46.5)	33.3±5.4 (23.6-47.0)
% change rest vs CAL (%)	18.2±7.3 (8-31)	19.6±8.5 (7-36)	21.0±7.3 (8-35)	18.7±7.4 (7-36)

Abbreviations: TrA, transversus abdominis; LM, lumbar multifidus; ADIM, abdominal drawing in maneuver; ASLR, active straight leg raise; CAL, contralateral arm lift; mm, millimetres



**Figure 3-7 Frequency of correct pelvic floor muscle responses over the 4 testing occasions combined. Elevation of the pelvic floor during a Kegel contraction. No descent of the bladder base during active straight leg raise contraction.**

For pelvic floor contraction as measured by elevation of bladder base on transabdominal ultrasound, 4 individuals (13% of sample) never demonstrated the ability to elevate the bladder base and 12 (40%) were able to contract it on every occasion. Five (16%) were able to contract it on one occasion only, 5 (16%) on two occasions and 4 (13%) on three occasions.(figure 3-7A) Descent of the bladder base during ASLR was evident in all but 4 of the participants with 60% consistently demonstrating bladder base descent over the four trials.(figure 3-7B) There was some variability during the three trials for five of the participants (i.e. a descent was observed only on one or two of the trials on that testing occasion). Analysis of the association with the variables age, BMI, and parity showed no significance in predicting the ability to contract the pelvic floor nor bladder base descent. Higher activity level was significantly associated with bladder base descent on ASLR with a correlation of 0.44 ( $p < 0.05$ ).

**Table 3-3 Correlation of frequency of bladder base displacement by covariate.**

Covariate	Voluntary Contraction PFM	Bladder Base Descent w/ASLR
Age	$r_s=0.22, p=0.25$	$r_s=0.08, p=0.68$
Body Mass Index	$r_s=-0.36, p=0.54$	$r_s=-0.23, p=0.22$
Parity	$r_s=0.12, p=0.54$	$r_s=-0.21, p=0.28$
Activity Level	$r_s=0.17, p=0.37$	$r_s=0.44, p=0.02^*$
Prior Back Injury (Yes/No)	$\phi_c=0.31, p=0.58$	$\phi_c=0.39, p=0.34$

*Abbreviations: ASLR, active straight leg raise; PFM Pelvic Floor Muscles*

### 3.3.1 Reliability

#### ***Intrarater, Intrasession Estimates***

Intrarater intra-session reliability estimates ( $ICC_{3,3}$ ) for measurement of the three images captured for each condition on each occasion were not statistically different as the confidence intervals overlapped. Therefore, only the initial visit estimates are presented in Table 3-4. They ranged from  $ICC_{3,3} = 0.94$  to 0.99 on all testing occasions.

**Table 3-4 Initial visit intra-session intrarater reliability for the average measurement of three acquired images for each measure.**

Measure	Mean±SD (*)	ICC <sub>3,3</sub> (95% CI)	SEM (*)	MDC <sub>95</sub> (*)	Relative MDC <sub>95</sub>
<b>TrA</b>					
Rest (hook-lying)	3.1±0.9	0.98 (0.96,0.99)	0.13	0.35	11.3%
Contracted (ADIM)	4.9±1.3	0.97 (0.94,0.99)	0.23	0.62	12.7%
% change	56.1±23.9	0.91 (0.81,0.97)	7.2	19.9	35.4%
<b>TrA</b>					
Rest (supine)	3.0±0.8	0.97 (0.91,0.98)	0.14	0.38	12.7%
Contracted (ASLR)	3.9±1.0	0.96 (0.91,0.98)	0.20	0.55	14.1%
% change	26.4±19.6	0.77 (0.45,0.98)	9.4	26.1	98.7%
<b>LM</b>					
Rest (prone)	28.6±5.3	0.99 (0.99-1.00)	0.53	1.47	4.8%
Contracted (CAL)	33.6±5.9	0.99 (0.99-1.00)	0.59	1.64	4.9%
% change	18.2±7.3	0.89(0.73,0.95)	2.4	6.7	36.9%

Abbreviations: TrA, transversus abdominis; LM, lumbar multifidus; ADIM, abdominal drawing in maneuver; ASLR, active straight leg raise; CAL, contralateral arm lift

\*Values in millimeters except % change

The reliability estimates for the average of three values of percent thickness change were lower and ranged between 0.77 and 0.91 for each session. Standard error of measurement was less than 0.3 mm for the measurements of transversus abdominis at rest and contracted and less than 0.6 mm for the lumbar multifidus at rest and contracted. Percent change SEMs were between 2.4% and 9.4% and the MDC values were between 6.7% and 26.1%.

### ***Intrarater, Intersession Estimates***

Test-retest reliability estimates were calculated for three intervals, initial to 4 weeks, to 8 weeks and to 12 weeks. Depending on the muscle (TrA or LM) and muscle condition (rest/contracted), the ICC<sub>3,1</sub> for comparing the average of three thickness measurements between occasions ranged between 0.72 to 0.90. All met or exceeded the minimal standard of .70 for research<sup>[299]</sup> but only one measure at one time (TrA Rest initial to week 8) demonstrated a high enough estimate to be considered sufficient for monitoring individual scores in the clinic. Reliability estimates for the three percent thickness change measurements ranged from 0.48 to 0.69 which did not meet the minimal standard noted above. (Table 3-5).

**Table 3-5 Test-retest reliability estimates for 3 intervals; Initial to 4, or to 8, or to 12 weeks.**

Measure	Initial/Week 4		Initial/Week 8		Initial/Week 12	
	Mean±SD (mm*) <sup>†</sup>	ICC <sub>3,1</sub> (95% CI)*	Mean±SD (mm*) <sup>†</sup>	ICC <sub>3,1</sub> (95% CI)*	Mean±SD (mm*) <sup>†</sup>	ICC <sub>3,1</sub> (95% CI)*
<b>TrA</b>						
Rest (hook-lying)	3.1±0.8	0.89 (0.79,0.94)	3.1±0.9	0.86 (0.72,0.93)	3.1±0.9	0.87 (0.75,0.94)
Contracted (ADIM)	4.8±1.2	0.82 (0.71,0.90)	4.7±1.3	0.81 (0.64,0.90)	4.8±1.3	0.80 (0.62,0.90)
% change	54.6 ±25.1	0.69 (0.48,0.82)	57.0 ±26.45	0.68 (0.44,0.80)	55.0 ±24.0	0.64 (0.37,0.81)
<b>TrA</b>						
Rest (supine)	3.1±0.8	0.87 (0.74,0.93)	3.1±0.8	0.90 (0.80,0.95)	3.1±0.8	0.87 (0.75,0.94)
Contracted (ASLR)	3.9±0.9	0.76 (0.65,0.87)	3.8±1.1	0.78 (0.59,0.89)	3.9±1.1	0.75 (0.54,0.88)
% change	24.7±17.6	0.55 (0.24,0.76)	24.6±17.9	0.48 (0.14,0.71)	25.3±18.1	0.54 (0.23,0.75)
<b>LM</b>						
Rest (prone)	28.5±4.9	0.83 (0.72,0.90)	28.2±5.1	0.83 (0.67,0.91)	28.4±5.1	0.75 (0.54,0.87)
Contracted (CAL)	33.7±5.5	0.80 (0.69,0.89)	33.6±5.5	0.80 (0.62,0.90)	33.5±5.6	0.72 (0.49,0.86)
% change	18.8±7.7	0.69 (0.45,0.84)	19.4±7.1	0.65 (0.27,0.83)	18.3±7.8	0.58 (0.28,0.78)

Abbreviations: ICC, intraclass correlation, TrA, transversus abdominis; LM, lumbar multifidus; ADIM, abdominal drawing in maneuver; ASLR, active straight leg raise; CAL, contralateral arm lift

\*Values in millimeters except percent change

<sup>†</sup>Pooled over 2 testing occasions

The intrarater intersession standard error of measurement (SEM) over three time periods (initial to 4 weeks, to 8 weeks and to 12 weeks) ranged between 0.28 mm and 0.59 mm for measurements in both sets of conditions for the TrA and between 1.1 mm and 2.99 mm for measurements of LM (Table 3-6). Minimal detectable changes (MDC<sub>95</sub>) for TrA thickness ranged from 0.72 mm to 1.64 mm and for the LM ranged between 5.62 mm to 8.3 mm. Overall, these values increased slightly over subsequent visits but the largest between-visit difference for TrA thickness was 0.26 mm and 1.44 for LM. Relative MDC<sub>95</sub> percentages varied from 19.7% to 38.6% for the muscle thickness measurements over the three time intervals and from 70.9% to 145.4% for the percent change measures.

**Table 3-6 Intrarater, intersession error and precision estimates.**

Measure	SEM (mm*)			MDC <sub>95</sub> (mm*)			Relative MDC <sub>95</sub> (%)		
	4 wk	8 wk	12 wk	4 wk	8 wk	12 wk	4 wk	8 wk	12 wk
<b>TrA</b>									
Rest (Hook-ly)	0.28	0.32	0.31	0.77	0.90	0.86	24.6	29.3	27.8
ADIM	0.51	0.55	0.59	1.42	1.54	1.64	29.6	32.4	34.1
% Change	14.0	14.9	14.4	38.7	41.5	39.9	70.9	72.8	72.6
<b>TrA</b>									
Rest (Supine)	0.30	0.26	0.30	0.82	0.72	0.82	26.9	23.1	26.4
ASLR	0.45	0.50	0.54	1.24	1.38	1.50	31.7	36.3	38.6
% Change	11.8	12.9	12.3	32.7	35.8	34.0	132.5	145.4	134.5
<b>LM</b>									
Rest	2.03	2.09	2.54	5.62	6.87	7.0	19.7	20.5	24.8
CAL	2.46	2.48	2.99	6.82	6.86	8.3	20.2	20.4	24.7
%Change	4.3	4.2	5.0	12.0	11.6	13.9	63.6	59.8	76.0

Abbreviations: SEM, standard error of measurement, MDC<sub>95</sub>, minimal detectable change with 95% confidence, TrA, transversus abdominis; LM, lumbar multifidus; ADIM, abdominal drawing in maneuver; ASLR, active straight leg raise; CAL, contralateral arm lift

\*Values in millimeters except percent change

Kappa coefficients for the intrarater intersession reliability for the two bladder base measures varied between 0.37 and 0.46 for the elevation and between 0.44 and 0.71 for the descent, depending on the intervals (Table 3-7). It is interesting to note that the kappa coefficients increased over time for bladder base descent.

**Table 3-7 Cohen's Kappa for intrarater intersession reliability measures.**

Measure	4 week	8 week	12 week
Kegel - Bladder Base Elevation	0.37	0.46	0.41
ASLR - Bladder Base Descent	0.44	0.66	0.71

Abbreviations: ASLR, active straight leg raise

### **Repeated Measures ANOVA**

Repeated measures ANOVAs for each of the conditions indicated no significant differences between four testing occasions for the muscle thickness measurement of the TrA in hook lying at rest ( $F=1.09$ ,  $p=0.36$ ), contracted during the ADIM ( $F=1.81$ ,  $p=0.15$ ), in supine at rest ( $F=1.06$ ,  $p=0.33$ ), and contracted during the ASLR ( $F=1.30$ ,  $p=0.27$ ). Similarly, no significant differences between the four testing occasions were observed for the percent thickness change in the TrA during the ADIM ( $F=1.01$ ,  $p=0.394$ ), or during the ASLR ( $F=0.62$ ,  $p=0.61$ ). There were also no significant differences between the four testing occasions in the thickness of the LM at rest ( $F=0.729$ ,  $p=0.537$ ), or contracted during the CAL ( $F=0.210$ ,  $p=0.840$ ), nor for the percent thickness change during a CAL ( $F=1.97$ ,  $p=0.13$ ). Only the CAL data did not satisfy the assumption of sphericity and in that case the Greenhouse-Geisser adjustment was used.

Repeated measures ANCOVA showed a significant relationship between BMI and TrA thickness in hook-lying ( $F=3.46$ ,  $p=.02$ ) and supine ( $F=3.35$ ,  $p=0.02$ ) at rest. Examination of the correlation coefficients indicated a negative relationship (hooklying rest  $r=-0.41$ ,  $p=0.02$ ; supine rest  $r=-0.42$ ,  $p=0.02$ ). A significant relationship was also noted between age and LM thickness prone at rest ( $F=3.18$ ,  $p=0.03$ ) with older individuals having thinner muscles ( $r=-0.39$ ,  $p=.03$ ) but not for the other covariates (parity, previous back injury) or conditions examined (Table 3-8).

**Table 3-8 Repeated measures analysis of covariance by condition.**

Measure	BMI	Age	PBI	Parity	Activity Level
<b>TrA</b>					
Rest (hook-lying)	$F=3.46$ , $p=0.02^*$	$F=0.10$ , $p=0.94$	$F=0.12$ , $p=0.49$	$F=0.03$ , $p=0.83$	$F=0.79$ , $p=0.50$
Contracted (ADIM)	$F=0.24$ , $p=0.86$	$F=0.75$ , $p=0.53$	$F=1.02$ , $p=0.39$	$F=0.54$ , $p=0.66$	$F=0.97$ , $p=0.41$
% change	$F=1.20$ , $p=0.12$	$F=2.08$ , $p=0.11$	$F=0.27$ , $p=0.85$	$F=0.86$ , $p=0.47$	$F=0.79$ , $p=0.51$
<b>TrA</b>					
Rest (supine)	$F=3.35$ , $p=0.02^*$	$F=1.06$ , $p=0.36$	$F=1.63$ , $p=0.22$	$F=1.62$ , $p=0.22$	$F=0.00$ , $p=1.00$
Contracted (ASLR)	$F=1.25$ , $p=0.30$	$F=0.80$ , $p=0.50$	$F=0.75$ , $p=0.52$	$F=0.70$ , $p=0.56$	$F=0.14$ , $p=0.94$
% change	$F=0.70$ , $p=0.55$	$F=1.08$ , $p=0.36$	$F=0.39$ , $p=0.76$	$F=0.68$ , $p=0.57$	$F=0.17$ , $p=0.95$
<b>LM</b>					
Rest (prone)	$F=1.77$ , $p=0.16$	$F=3.18$ , $p=0.03^*$	$F=0.39$ , $p=0.76$	$F=0.71$ , $p=0.55$	$F=0.44$ , $p=0.73$
Contracted (CAL)	$F=0.78$ , $p=0.51$	$F=1.81$ , $p=0.15$	$F=1.09$ , $p=0.36$	$F=0.69$ , $p=0.56$	$F=0.33$ , $p=0.81$
% change	$F=1.48$ , $p=0.23$	$F=0.95$ , $p=0.42$	$F=0.63$ , $p=0.60$	$F=0.38$ , $p=0.77$	$F=0.19$ , $p=0.90$

Abbreviations: BMI, body mass index, PBI, prior back injury TrA, transversus abdominis; LM, lumbar multifidus; ADIM, abdominal drawing in maneuver; ASLR, active straight leg raise; CAL, contralateral arm lift

\*significant at  $p<.05$

## 3.4 Discussion

This study examined the stability of RUSI measurements over time of tests commonly used to assess trunk and pelvic floor muscles associated with back pain.<sup>[99, 149, 244, 249, 253, 321, 327, 328]</sup>

RUSI measurements for TrA and LM were found to be reliable for assessing muscle thickness over longer periods of time, of relevance for assessing the impact of the effects of hysterectomy on muscle morphology in future studies. Muscle measurements were obtained using RUSI to quantify TrA and LM muscle thickness at rest and during sub-maximal contractions and the percent change from one state to the other. Dependent variables for pelvic floor contraction were limited to bladder base elevation (yes/no) during a Kegel exercise and bladder base descent postulated to be due to intra-abdominal pressure (yes/no) during a ASLR task.

### 3.4.1 Reliability Measures

Most of the test/retest reliability research has been performed over intervals of only one to three days,<sup>[270, 280, 282, 286, 321]</sup> with a few being done over periods of one<sup>[261, 263, 286]</sup> to two weeks.<sup>[245]</sup> To

the best of my knowledge, this is the first study that looks at stability of measurements for intersession intervals longer than two weeks. A repeated measures ANOVA reported no significant differences for any of the dependent muscle thickness variables obtained under different conditions measured at 4, 8 and 12 week intervals. Reliability is dependent on the errors due to the rater, the instrument, the sample, the test protocol and the analysis design.

Repeated measures of the individual muscle thickness measurements at rest or during a contraction showed good intrarater reliability for all testing intervals. Portney and Watkins<sup>[298]</sup> indicate that there are no standard values for acceptable reliability using the ICC; they offer a general guideline that ICCs greater than 0.75 represent good reliability, 0.50 to 0.75 represent moderate reliability and those less than 0.50 represent poor reliability. The minimal research standard proposed by Aaronson is 0.70.<sup>[299]</sup> With the exception of the ASLR ( $ICC_{3,1}=0.75-0.78$ ) and the LM measures for rest and contracted at the 12 week interval ( $ICC_{3,1}=0.75, 0.72$ ) which were still adequate by the latter standard, the other intraclass correlations were all above 0.80 even for the longest 12 weeks interval. Test-retest ICCs for derived measures of percent thickness change over the three intervals were moderate ranging from 0.48 to 0.55 for the ASLR, 0.58 to 0.69 for the CAL and 0.64 to 0.69 for the ADIM. Lower ICC values for the derived measures is consistent with other studies as noted in table 3-1 given that errors at rest and during contraction contribute to reduce reliability. However, the findings in the current study are lower than most previously reported possibly because of the longer intervals and the use of older subjects examined in the present study.

### ***Transversus Abdominis***

Both TrA percent thickness change measures were lower than the minimal research standard. Brown and McGill<sup>[329]</sup> postulated that error in the estimation of thickness change could be related to the lateral slide that occurs when the TrA contracts. They stated that as the TrA shortens, the site being measured on the muscle moves to a new location within or outside of the image. Therefore the use of a standardized location to measure the image may result in measurement of a different section of the muscle. They found that accounting for shortening by adjusting measurement position on the image resulted in a significantly higher percent change thickness (73.0% vs.42.5%). In this study, every effort was made to keep the muscle centered in the image by adjusting the transducer position laterally if there was a slide in the muscle position. Nevertheless, some error could have occurred from this change in position.

Lariviere et al.<sup>[184]</sup> noted that the ASLR is a task that involves automatic recruitment of the TrA, thereby eliminating error related to motor learning and more similar to use of the TrA in activities of daily living. Their study using M-mode ultrasound concluded that, in spite of this, the ASLR was less effective than the ADIM for TrA recruitment. Additionally, it was noted that the performance of the ASLR varied widely between repetitions in many participants. This is consistent with observations in the current study but even more so when comparing measurements over the different time intervals. Since the ASLR was performed after the ADIM and the participants were taught to contract the TrA during the ADIM at the initial visit, there may have been some transfer of motor learning from the voluntary ADIM task to the automatic ASLR task. In fact, at the first muscle measurement session, some of the participants inquired if they should be voluntarily activating the TrA prior to performing the task. Therefore, this variation in training effect between participants and testing occasions could contribute to issues in reliability.

Due to the laminar nature of the abdominal wall muscles, contraction of one muscle layer can impact its neighbor.<sup>[329]</sup> For instance, as the internal oblique (IO) shortens and thickens, it can reduce the ability of the TrA to contract. During a task such as the ASLR, if the IO contracts preferentially as was the case with several participants in this study, a reduction in TrA thickness can be noted. This would contribute to the wider variance in the ASLR measures. Brizzolara et al.<sup>[295]</sup> found between day (2-4 days) reliabilities for the percent change from rest to contracted of 0.52 to 0.71. Koppenhaver et al.<sup>[286]</sup> reported between day (1-3 days) measures of 0.73 for this condition. Linek et al.<sup>[301]</sup> reported between day ICCs, for percent change from measures taken 1 week apart, of 0.81 to 0.91 in a group of adolescents. It should be noted however that all three of the aforementioned studies used measures, averaged over multiple days ( $ICC_{3,3}/ICC_{3,2}$ ) when calculating their ICCs. Using mean scores increases reliability estimates as means are better estimates of true scores thus reducing error variance. In this study, the ICC model and form used was 3,1 for evaluating muscle thickness measurement stability over a period of time. This could account for much of the difference in reliability estimates.

The ASLR has been performed differently across some studies and this could also impact reliability estimates. Several study protocols have had the individual raise their lower limb by 5 cm from the plinth either with a delimiter<sup>[261]</sup> or by demonstration.<sup>[99, 253, 295]</sup> Linek et al.,<sup>[301]</sup> in their study which employed an adolescent population had the individual raise their leg until the hip

was at 30 degrees of flexion. Depending on individual leg length, this could introduce a wide variation in how high the leg was lifted. In the case of adolescents, the limbs could be shorter than adults resulting in a higher leg lift. The present study used the test as described by Mens et al.<sup>[330]</sup> and utilized by Koppenhaver et al.<sup>[286]</sup> where the individual raises their leg 20 cm from the plinth. A delimiter at 20 cm was added to standardize the test protocol.

In addition to the issues outlined above, differences in participant demographics between studies could also contribute to differences in reliability estimates. The population in this study was all female, older and included women with higher BMI scores than other studies.

Comparison of measures between 4, 8 and 12 weeks intervals showed little variation. In fact, in both the published studies and this study, the largest difference seems to be when comparing within day to between day measures. Increasing the time interval does not appear to change the reliability estimate. Similarly the precision estimates were stable over the three time periods.

The standard error of measurement (SEM) estimates for TrA thickness, which ranged from 0.28 and 0.54 mm and between 11.8% and 14.9%, were similar to published values reported by Koppenhaver et al.<sup>[286]</sup> They used the mean of two measures to produce SEM estimates for measurements taken 1-3 days apart which ranged between 0.2 mm and 0.5 mm and 12% to 19.2% for the three conditions of rest, ADIM and ASLR with corresponding percent change measures. Linek et al.<sup>[301]</sup> used the mean of three measures with an intersession period of 7 days and reported a SEM of 0.20 mm at rest and 0.22 mm when contracted for the ASLR. For ADIM, Mannion et al.<sup>[245]</sup> reported slightly higher intersession (7-14 days) SEMs of 0.4 mm for crook-lying rest and 0.58-0.65 mm for ADIM when using a foam block belted around the participant to hold the transducer. Calculation of the SEM was based on ICC values produced using the two-way, mixed effects model similar to this study but the mean muscle thickness in each condition and the corresponding standard deviation (rest =4.0 mm, 1.0 mm; contracted=5.5 mm, 1.4 mm) was higher than in this sample. The inclusion of both genders in that study would have increased the average muscle size as men tend to have thicker abdominal muscles.<sup>[257]</sup>

This study found  $MDC_{95}$  for resting values that were lower than those reported by Mannion et al.<sup>[245]</sup>(1.1) in hooklying and Hodges et al.<sup>[262]</sup>(1.0) semi-reclined in chair with hips flexed to 30° and slightly higher than Critchley et al.<sup>[249]</sup> at 0.6 in 4-point kneeling. Values for intersession measures of 4, 8 and 12 weeks for hook lying rest, supine rest, ADIM and ASLR were

slightly higher than the 3 day intersession  $MDC_{95}$  values reported by Koppenhaver et al.<sup>[286]</sup> However, the percent change  $MDC_{95}$  for ADIM was lower in this study (38.7-41.0%) than the 53.3% between day estimate in that study. Percent change  $MDC_{95}$  value for the ASLR was the same as Koppenhaver et al.'s despite a lower ICC estimate. This was due to a lower variance in this study (sd=17.6%) compared to Koppenhaver et al.'s (sd=36.7%) which may relate to differences in the composition of the research sample.

### ***Lumbar Multifidus***

Similar to the TrA results, the LM muscle thickness measurement intraclass correlations were all above the minimum value of 0.70 but lower than those reported by Wong et al.<sup>[282]</sup> and Koppenhaver et al.<sup>[286]</sup> for the L4/5 intrarater between day ICCs. For the percent change measures, calculated estimates were in the moderate range. SEMs ranged between 2.03 mm and 2.99mm for the three time intervals and between 5.0% and 5.5% for the percent change variable. The between day relative  $MDC_{95}$  of 19.7 to 24.8% for this study was higher than the between day values reported by Koppenhaver et al.<sup>[286]</sup> (7.2 to 8.1%) as well as Wong et al.<sup>[282]</sup> (6.7-11.6.0%) for the L4/5 lumbar multifidus. The difference is likely related to their use of the ICCs reliability estimate corresponding to averaging measurements by combining visits as explained for the TrA above. The reported % change relative  $MDC_{95}$  of 72.2-83% fell between Wong's estimate of 46.6% and Koppenhaver's at 98%. The  $MDC_{95}$  of between 14.0% and 15.2% in this study would nevertheless make monitoring thickness change following intervention difficult due to the high proportion of error variance.

### ***Covariate Analysis***

In previous studies, factors such as gender,<sup>[254, 257]</sup> age,<sup>[256, 257]</sup> parity,<sup>[258, 259]</sup> previous back pain/injury<sup>[208, 249, 252, 331]</sup> and BMI<sup>[254, 257]</sup> were found to be significant predictors of muscle size and function. In this study, with gender as a constant, a negative relationship was noted between BMI and TrA muscle thickness (higher BMI, smaller TrA) and only for the hook lying rest, supine rest and ADIM percent change variables. These results are similar to Mannion et al. (2008)<sup>[245]</sup> who found that BMI explained 20% of the variance in muscle size at rest and during ADIM with a significant negative correlation with the contraction ratio. In contrast, previous research by Springer et al.<sup>[254]</sup> had found a positive correlation ( $r \geq .66$ ) between BMI and muscle size. These studies differed from this one by gender composition and age group: 22 to 62 for Mannion and 18

to 45 for Springer; both included males and females in the analysis of BMI. Neither study included anyone with a BMI over 31 whereas the participants in this study included 7/30 individuals with BMI over 31.

Like Mannion et al.<sup>[257]</sup> and Rankin et al.<sup>[256]</sup> who both found differences related to age such that muscle thickness showed a low negative correlation with age, this study showed similar results for the LM but not for the TrA. This is likely due to the truncation of the age sample which included no participants below age 35 or above age 55. In this data, no association between prior back injury/pain and muscle size was found. This study sample had been pain free for at least six months prior to study start. Critchley et al.<sup>[249]</sup> had noted a smaller increase in abdominal hollowing TrA thickness in chronic pain patients versus controls who had been pain-free (self-report) for the previous 2 years. They also noted no differences in TrA thickness by age, parity, level of exercise or prior abdominal surgery for minor procedures. This is consistent with the findings reported here.

### ***Pelvic Floor Muscles***

Cohen's kappa intersession reliability coefficients were between 0.37 and 0.46 for bladder base elevation using the Kegel voluntary contraction and between 0.44 and 0.71 for bladder base descent with the ASLR. Landis and Koch<sup>[332]</sup> suggest that values of kappa greater than 0.80 represent excellent agreement; 0.40-0.60 moderate agreement and less than 0.40 poor to fair agreement. Portney and Watkins<sup>[298]</sup> note that the ICC has been shown to be equivalent to measures of nominal agreement such as Cohen's kappa and indeed when the data was analyzed using the ICC<sub>3,1</sub> model, the values only differed at the third decimal place. This allows interpretation of the values noted above in a similar way to the continuous data for the TrA and LM. It should be noted that only the ASLR bladder base descent measure for the 12 week interval was higher than the minimal value suggested by Aaronson et al.<sup>[299]</sup>

The ASLR has been shown to cause bladder base descent when there is an altered motor control strategy as evidenced by reduced TrA contraction during the ASLR. O'Sullivan et al.<sup>[99]</sup> and Beales et al.<sup>[107, 144, 333]</sup> using nasogastric catheters with lumens situated in the esophagus and abdomen recorded an increase in intra-abdominal pressure due to splinting of the diaphragm and abdominal wall muscles resulting in descent of the bladder base. Whittaker<sup>[334]</sup> also noted a smaller increase in TrA thickness during the ASLR associated with bladder base descent postulating an increase in IAP as the mediating factor. In this study, there was a non-significant

negative correlation between percent change ASLR and frequency of bladder base descent but this was limited by the nature of the data collection (yes/no on each testing occasion). When performing transabdominal RUSI to assess bladder base position change during ASLR, the resulting IAP can push the abdomen outward moving the transducer away from the structures of interest leading the investigator to an erroneous finding of bladder base descent. In this study, a two handed grip as previously described was used to maintain transducer position during the ASLR while the research assistant operated the controls. Our results were consistent with the published studies above.

Voluntary pelvic floor contraction, as shown by elevation of the bladder base on RUSI, varied from one testing event to the next and some individuals who were able to lift the pelvic floor on one occasion were unable to demonstrate the maneuver on the subsequent testing occasion. Some of the variability could be due to a practice effect after being taught to contract on the first session but does not explain the lack of ability on subsequent testing after a successful contraction on the previous occasion.

Transabdominal RUSI has been shown to have strong correlation with findings from transperoneal ultrasound<sup>[335]</sup> but there are limitations related to this technology. Transabdominal ultrasound does not distinguish between a lack of lift related to hyper-tonicity as opposed to PFM weakness.<sup>[336]</sup> Thompson and Sherburn<sup>[337]</sup> noted that other limitations of RUSI include lack of information regarding the presence of pain or specific morphological defects and suggest that "2D ultrasound is best done in conjunction with digital assessment". Thompson et al.<sup>[201]</sup> noted descent of the bladder neck when attempting a PFM in 17% to 40% of pre menopausal women, aged 20 to 50 years participating in their study of pelvic floor function in continent women. They also found that incontinent women have a higher likelihood of pelvic floor descent when attempting to contract the pelvic floor.<sup>[105]</sup> In the current study, 13% of participants were never able to elevate the bladder base over the four testing sessions and 40% were always able to do it. The rest were able to do it sometimes but not always.

Many factors such as incontinence,<sup>[307, 338]</sup> vaginal birth,<sup>[339, 340]</sup> muscle trauma and tears<sup>[341]</sup> during the birth process and pelvic instability<sup>[342]</sup> could influence the voluntary contraction and/or automatic responses of the pelvic floor muscles as evidenced by changes in the bladder base position. Information regarding these potential confounders was not elicited from participants but might not have influenced the results as Beales et al.<sup>[333]</sup> noted that even among healthy subjects, motor control strategies for these tasks vary widely.

In summary, while the reliability coefficients for pelvic floor muscle measurements in this study proved to be lower than other studies, and less than optimal, their lower reliability may still be adequate in some situations. For example falsely misreading an ECG indicating a need for heart surgery is a significant problem, but measurement of thickness change to track the effect of a rehabilitation program does not have as serious consequences. Clinically, showing a patient a trend towards improvement even with suboptimal reliability may help keep them invested in the training process. Such applications may warrant further investigation.

### 3.4.2 Study Limitations

The use of a convenience sample that included a higher proportion of health-conscious, educated women than the population at large as well as using a single examiner limits generalizability to other examiners and populations.

The inclusion of individuals with a high BMI could affect image quality and, in fact, one set of images had to be discarded due to difficulties with image capture and measurement. That individual had a thick adipose apron around her abdomen. However, in the individual's with higher BMI's, image quality was sufficient for accurate measurement. Re-measurement of these images showed little variation from the original measures. This could be due to body shape and adipose tissue distribution with abdominal fat that was not thick enough to affect image quality. Also, as a practicing clinician who works primarily with middle-aged women, I have learned to adjust the far gain to capture good images with larger women.

For the longer intervals of 8 and 12 weeks, intervening tests at 4 and 8 weeks could have caused an overestimation of the reliability estimates due to practice at the intervening visits. As can be seen from the testing protocol in Appendix D little coaching was done after the first visit which should minimize this effect.

In some studies,<sup>[282, 314]</sup> transparencies have been used to landmark the transducer location but given the number of transducer locations used in the current study this could have been cumbersome. For the lateral abdominal wall, with this female population, often the transducer position only fit at one location due to the close proximity of the 12th rib to the iliac crest. Once the muscle was centered in the image, there was reasonable certainty of it being in the correct location. For the pelvic floor, the transducer was placed just above the pubic symphysis in the midline with the bladder centered in the image. This location was easily reproducible. Poor

reliability is more likely related to the wide variation in motor control strategies for the pelvic floor tasks. Also, while a standard bladder filling protocol was used, bladders appeared more full on some testing occasions than others. For LM, landmarking the lumbar vertebrae is straightforward and could be confirmed by moving the transducer along the sagittal plane to visualize the sacrum and transverse process of L5 which is quite blunted. The L4/5 facet joint was centered in the image. The consistent reliability observed over wide time interval supports that it is possible to achieve adequate reliability without relying on transparencies to ensure reproducible probe placement.

With regard to pelvic measures, information regarding trauma or tearing during childbirth as well as incontinence, pelvic instability, menopause could have been helpful and to explain the variation with performance between visits. But as noted above, there is a wide variation in muscle control strategies in normal subjects. Digital palpation as recommended by Thomson and Sherburn<sup>[337]</sup> could have confirmed resting bladder base position which would distinguish between individuals who have no change in bladder base position with attempted contraction due to hypotonicity and hypertonicity. Also pelvic organ prolapse could have been assessed with such an investigation. However, given the invasive nature of digital palpation, recruiting volunteers may have been more difficult. Further, if the intended use of RUSI to assess bladder base is to document the effect of core stabilization efforts not directly related to pelvic floor pathology then this invasive test would not be justified.

### **3.5 Conclusions and Implications**

The results of this study support the use of RUSI to measure ADIM, ASLR and CAL for comparison purposes before and after interventions as the average of three rest and contracted thickness measurements showed sufficient stability over long-term testing intervals between occasions in 'healthy' participants. However, the wide variation in motor control strategies for pelvic floor function as evidenced by change in bladder base position over subsequent visits, make this a less reliable measure. Transperineal RUSI, which facilitates the use of a bony landmark for measurement, or digital palpation might be a more reliable approach albeit significantly more invasive. Averages of three percent change thickness measures, especially for the ASLR task did not prove to be sufficiently reliable measures over the three intervals to recommend their use for clinical or research applications.

### 3.6 Summary and Novelty

This study examined a group of women over a three month period, the longest intersession period that has been researched to date. Good reliability for muscle thickness measurements between sessions was found indicating that the ADIM, ASLR and CAL are effective measures of muscle morphology and function over time. However, the derived measures of percent thickness change were less reliable. It should be noted that while the reliability coefficients were lower than previous between day studies, which reported ICC<sub>3,3</sub> (averaged measurements between sessions) ICC<sub>3,1</sub> values observed in the present study for single measurements were similar for 4, 8 and 12 week intervals. This indicates that the use of these tests over the longer periods is not significantly impacted by the effects of time. The thickness measurements were adequate to capture likely and clinically meaningful changes as part of intervention studies focusing on improving the functioning of the muscles studied. The minimal detectable change estimates showed that the thickness measurements would be sensitive to an increase in muscle thickness of approximately 1.0 mm in resting states and 1.7 mm in contracted states for the TrA and to 6 - 8 mm in the LM. The corresponding values for the percent change variables in the TrA were quite high requiring a contraction ratio to exceed 50% of the initial ratio making these measures less sensitive to change over time. Evaluation of pelvic floor muscle function as evidenced by changes in bladder base position might be better done using transperineal RUSI or digital palpation compared to the method used in the present study which demonstrated suboptimal reliability.

#### **4. Monitoring of Transversus Abdominis, Multifidus and Pelvic Floor Muscles at Rest and Under Various Loading Conditions in a Case Series of Women Aged 35 to 55 before and after Undergoing Abdominal Hysterectomy**

This chapter describes a pilot study to determine if muscle thickness in the lumbar multifidus (LM) and transversus abdominis (TrA) muscles as measured with rehabilitative ultrasound imaging (RUSI) changes following open approach hysterectomy in a series of 9 women. Changes in pelvic floor muscle contraction and loading strategies as well as perceived recovery and readiness to return to work were investigated. Muscle thickness was measured at rest, and during the ADIM, ASLR and CAL tests. Pelvic floor function was assessed by evaluating change in bladder base position in response to voluntary contraction and lower extremity loading. Health-related post-surgical quality of life with regard to potential physical, psychological and functional impairment along with pain and changes in visceral function and sleep was measured with the Abdominal Surgery Impact Scale. Stage of readiness to return to work and/or ability to continue once back at work following hysterectomy was addressed with the Readiness for Return-to-Work (RRTW) scale.

##### **4.1 Introduction & Background**

Low back pain (LBP) is a major health burden with a lifetime prevalence of non-specific LBP of 60-70% in industrialized countries.<sup>[343]</sup> LBP has a high rate of recurrence with up to 26% of individuals experiencing a subsequent episode within three months following the initial episode and 70% reporting recurrence within one year.<sup>[204]</sup> It is associated with substantial healthcare costs and negatively impacts quality of life.<sup>[344]</sup> Given the prevalence of this condition, risk factors that can be identified and potentially modified with treatment, are worthwhile investigating. The Women's Health and Aging Study,<sup>[40]</sup> a large cohort study of older, community dwelling, disabled women, found an increased likelihood of self-reported LBP in women who had undergone surgical menopause. (Surgical menopause is a type of induced menopause resulting from removal of the gonads). The authors noted that they did not ask participants about the type of surgical approach. They suggested post-operative rehabilitation of the lumbopelvic muscular stability system should be investigated as a preventive measure.

#### 4.1.1 Lumbo-Pelvic Stabilization

Dynamic lumbopelvic stability provided by active muscle contraction helps to protect the lumbar spine from injury in loading situations.<sup>[345-347]</sup> Coordinated trunk muscle function plays a critical role in the control of spinal motion and stability.<sup>[25, 27, 90, 179]</sup> Changes in motor control<sup>[99]</sup> movement patterns<sup>[100]</sup> and muscle activation<sup>[101]</sup> of these deep stabilizers have been reported in the literature in individuals experiencing acute, recurrent or chronic lumbopelvic pain/dysfunction.<sup>[99, 101, 104-108]</sup> The pain adaptation model proposes a reduction in muscle contraction of muscles that are painful and an increase in the antagonists to the painful muscle.<sup>[110]</sup> The effect of this is slower and smaller movements that limit injury aggravation and thus allow the injured tissue to heal. This theory is based on experimental observations and there is much supporting evidence in the literature.<sup>[110, 120, 122, 125, 126]</sup> Hodges and Tucker<sup>[97]</sup> point out that while these adaptations have short-term benefits, there are potential long-term consequences of altered motor patterns in response to pain. While pain provides the stimulus to change a given pattern of muscle activity, the muscle recruitment pattern does not return to normal once the pain stops.<sup>[136-138]</sup> These adaptive patterns are unique to each individual,<sup>[139]</sup> however, Hodges and Moseley<sup>[28]</sup> reported a tendency toward diminished activity of the deep stabilizers (TrA and LM) with increased activity of the superficial muscles in the abdomen and back in response to back pain.

RUSI has been shown to be a valid and reliable instrument for measuring the morphology and function of these abdominal,<sup>[187, 250, 272, 286, 291-293, 348, 349]</sup> low back<sup>[265, 282, 286, 292, 321, 323, 349]</sup> and pelvic floor muscles.<sup>[307, 309]</sup> Common sub-maximal testing includes the abdominal drawing in maneuver (ADIM) to assess voluntary contraction of the TrA, active straight leg raise (ASLR) to assess automatic control of the TrA, the contra-lateral arm lift (CAL) for multifidus function, Kegel exercise to assess pelvic floor lift and the ASLR to measure ability of the pelvic floor to mitigate increases in intra-abdominal pressure with lower limb loading.

Altered patterns of muscle contraction of these deep spinal stabilizers have been noted on both EMG and RUSI in individuals with chronic and recurring low back pain<sup>[81, 99, 148, 181, 208, 350]</sup> including reduced thickness measurements<sup>[140, 186, 253]</sup> and delayed<sup>[29, 106, 147, 148, 178]</sup> contraction as well as muscle atrophy.<sup>[152, 215, 331, 351, 352]</sup> For the TrA, tasks such as the ADIM and the ASLR have highlighted these changes in a low back injured population.<sup>[81, 106, 141, 142, 181, 187, 208, 253]</sup> TrA have been postulated to work synergistically with LM to achieve lumbar stability<sup>[283, 353]</sup> by tensioning the

thoracolumbar fascia<sup>[354, 355]</sup> and by changes in IAP<sup>[356]</sup> Delayed onset of TrA has been found in patients with LBP compared to asymptomatic individuals.<sup>[148, 291]</sup> Hides et al.<sup>[244]</sup> found that in terms of ability to perform a good contraction, a significant positive relationship existed between the two muscles. To evaluate TrA, a clinical muscle test using a pressure biofeedback unit which was placed under the abdomen with the patient in prone was proposed. A good TrA contraction was considered to have occurred if a reduction of 3-6 mm Hg was recorded.<sup>[188]</sup> Manual palpation of an isometric contraction of LM rated the contraction as good, poor or unable. The odds of a good contraction of LM was 4.5 times higher (OR=2.59, 95%CI 1.07- 6.29) for patients who demonstrated good contraction of TrA. Similarly, the PFM also show evidence of deficient activity and decreased endurance in individuals with low back pain.<sup>[99, 199, 200]</sup>

The mechanism through which the deep stabilizers affect postural control was investigated by Hodges et al.<sup>[41]</sup> using a porcine model. Intra-abdominal pressure (IAP) along with intervertebral motion at L3 and L4 and stiffness to displacement of the L4 vertebrae was monitored during TrA and diaphragm contraction. They found that contraction of these muscles created an increase in IAP which correlated with a decrease in L<sub>3,4</sub> motion along with increased stiffness of L<sub>4</sub>. This effect was diminished when a hole in the abdominal wall prevented increasing IAP or when the fascial attachment of the muscle was cut. This suggests that the TrA and diaphragm muscles assist with spinal stability due to their ability to increase IAP and tension the thoracolumbar fascia which surrounds the trunk. The PFM may contribute to postural control using a similar mechanism to that described above for the diaphragm and TrA muscles as their contraction contributes to raising the IAP.<sup>[160, 172, 173]</sup> Previous research<sup>[159, 173, 357]</sup> has shown synergistic contraction of the PFM and TrA when performing stability exercises and Hodges et al.<sup>[168]</sup> concluded that the PFM contribute to both postural and respiratory activity. LM does not increase IAP but rather provides local segmental control of the lumbar spine through its intersegmental attachments. Given the synergistic action of these three muscle groups in the provision of spinal stability, and the finding that in individuals with low back pain, there is a reduced cross-sectional area of both LM and TrA, it is reasonable to wonder if changes in TrA function related to abdominal surgery could impact LM as well.

Brown et al.<sup>[43]</sup> further tested force generation of the TrA in the Sprague-Dawley rat, a proven model representation of the human abdominal wall,<sup>[42]</sup> once the aponeurosis was cut finding reduced tension in the muscles. This concept of altered patterns of movement in the deep

stabilizers has been widely tested in individuals with current or previous back pain and injury with conclusive evidence that LBP can be related to reduced function in the TrA and pelvic floor muscles in addition to the LM.<sup>[358-360]</sup> The impact of surgical breach of the abdominal fascia during routine abdominal surgery on function of the deep stabilizers in humans has yet to be assessed. Muscle thickness changes before and after abdominal hysterectomy were investigated in this study as it is a common, planned surgery which breaches the abdominal fascia.

#### 4.1.2 Hysterectomy

The Health Indicators Report (2010) by the Canadian Institute for Health Information (CIHI)<sup>[70]</sup> reported that after caesarian section, hysterectomy was the most common surgery for Canadian women. It is the most common surgery in women over 35 years of age. A focus on hysterectomy rather than caesarian section was chosen due to the changes to the abdominal and pelvic floor muscles as well as the abdominal fascia that occur during pregnancy.<sup>[34, 361, 362]</sup> The most common indications for hysterectomy in Canada include uterine fibroids (35%), menstrual disorders (19%), genital prolapse (15%) gynecological cancers (15%), endometriosis (8%) and other (8%). Rural variation statistics show that the rate of hysterectomy for menorrhagia is double that of urban dwellers and menorrhagia is the primary indication for hysterectomy in the rural population. Age standardized rates of hysterectomy in 2012 showed a wide variation across provinces with Saskatchewan being the highest at 4.69/1000 and British Columbia (BC) being the lowest at 2.85/1000. The four-fold regional variation within BC ranged from lowest (1.37/1000) in Vancouver to highest (5.75/1000) in the Northern Interior health region.<sup>[31]</sup>

There are three potential approaches to hysterectomy - laparoscopic, vaginal and open abdominal. With the advent of the less invasive laparoscopic and vaginal approaches, rates of open hysterectomy have steadily declined but in 2011, approximately 72% of the 200 hysterectomies performed at the University Hospital of Northern British Columbia were open approach.<sup>[73]</sup> Open approach hysterectomy through breaching of the abdominal fascia is the most likely surgical approach to affect the function of the stabilizing muscles of the spine. A study of hysterectomy approach in the Vancouver Coastal/Providence Healthcare regions in BC in 2014 showed that 47.7% of hysterectomies were performed using open approach by 2011.<sup>[363]</sup> A US study showed an increasing likelihood for open approach for individuals with increasing BMI with a longer surgery time required with obese individuals as well.<sup>[364]</sup>

To perform an open hysterectomy, the surgeon makes a vertical or transverse incision through the aponeurosis of the lower abdomen just above the pubis<sup>[45, 74]</sup> interrupting the proximal attachment of the TrA. CT studies of the impact of upper abdominal surgical approaches on the anterolateral trunk and back musculature have found post-operative atrophy of the TrA in some cases.<sup>[365, 366]</sup> Causes of muscular atrophy have been postulated to include denervation,<sup>[365]</sup> pain,<sup>[152]</sup> poor vascularization<sup>[367]</sup> and kinesiophobia.<sup>[368]</sup> This repeated measures study will evaluate the impact of open approach hysterectomy using rehabilitative ultrasound imaging (RUSI) to measure the thickness of muscles at rest and during submaximal contraction prior to and at 4, 8 and 12 weeks after hysterectomy. Further, subjective information regarding pain levels and readiness to return to work were gathered from participants to see if they were related to the potential changes in muscle thickness.

This study aims to evaluate the impact of surgical interruption to the human abdominal fascia on trunk stability, through changes in resting and contracted muscle thickness in response to post-operative pain, specifically for planned open-approach hysterectomies. The working hypotheses were that resting and contracted TrA and LM muscle thickness would decrease following surgery along with values on the derived percent change measures. It was further hypothesized that some of these conditions would persist to the 12 week post-surgical interval. This interval was chosen as most women would have returned to full work and leisure activities by that point in time.<sup>[369]</sup>

A case series research design was chosen as a first step toward examining this novel hypothesis. The testing protocol, assessed in the previous chapter, was found to be consistent over the proposed time of 12 weeks. However, no previous work had been done on women undergoing hysterectomy so a case series was undertaken to help to refine the proposed hypothesis and approach before considering a larger study. Case series help to develop procedures such as recruitment strategies and testing protocols to inform the design of future clinical studies. However, as a descriptive design, no statistical inferences to the general population are made from the case series results.

## 4.2 Methods

This prospective descriptive case series involved measurement of the transversus abdominis (TrA), lumbar multifidus (LM) and pelvic floor muscles (PFM) with rehabilitative

ultrasound imaging (RUSI) in women before and after open approach hysterectomy. Images were taken at rest and during contractions elicited by the following clinically relevant maneuvers - the Abdominal Drawing-in Maneuver (ADIM), Active Straight Leg Raise (ASLR), Contralateral Arm Lift (CAL) as well as during voluntary contraction of the PFM. This study took place at the University of Northern British Columbia (UNBC) Community Care facility in Prince George, BC. Intakes were staggered over a 16 month period from September 2012 to December 2013. Initial scans were taken within 1 week prior to surgery with follow up scans at 4, 8, and 12 weeks post-surgery.

#### 4.2.1 Participant Recruitment

A total of 10 women scheduled to undergo an open hysterectomy were recruited in Prince George, BC from gynecologists' offices, posters placed in public buildings and by word of mouth. One gynecologist's office consulted with their patients and then provided a list to the principal investigator of those individuals who were willing to be contacted. Volunteers underwent a telephone interview to determine eligibility and willingness to participate. Inclusion criteria allowed women, scheduled for open hysterectomy who were between 35 and 55 years of age with no current back pain. Women undergoing hysterectomy for cancer or suspected cancer were excluded from the study. The prevalence of cancer related hysterectomies is about 15%.<sup>[70]</sup> Women with a previous history of back pain had to score at Grade 1 or less on the back pain questionnaire developed by Van Korff<sup>[33]</sup> which has been used to distinguish between back pain as part of a lifetime prevalence and disabling back pain.

#### 4.2.2 Ethical Considerations

This study was granted ethics approval from the University of British Columbia - Clinical Research Ethics Board as well as the Research Ethics Board of the University of Northern British Columbia where the study was carried out. An expedited review of the study was provided by the Northern Health Authority so that recruitment posters could be placed at the University Hospital of Northern British Columbia. All participants gave written informed consent prior to data collection. Participants were compensated \$15.00 per visit to pay for parking/transportation.

#### 4.2.3 Examiner

All imaging was performed by the principal investigator (LL) who is a physiotherapist with over 30 years of clinical experience. Full qualifications for RUSI can be found in Chapter 3, Section 3.2.3.

#### 4.2.4 Procedures

This case series study used a repeated-measures design involving four visits, one before surgery and three following the procedure at 4, 8 and 12 weeks. The initial visit took place within 1 week prior to surgery and the first post-surgical visit was scheduled for 4 weeks post surgery to allow for wound healing after this major surgery. Individuals typically remain in hospital for up to 5 days following abdominal hysterectomy.<sup>[370]</sup> Also after hysterectomy, individuals are restricted from driving for a minimum of 3 weeks, until they can tolerate the seat belt across the abdomen and safely perform an emergency stop.<sup>[371]</sup> To perform an emergency stop, the individual must be able to transfer loads effectively through the pelvis. This was deemed a prerequisite prior to requesting that participants perform the ASLR. The 8 week post-surgical interval coincided with usual return to work times following abdominal hysterectomy to light/medium demands jobs<sup>[369, 372]</sup> and the 12 week interval was the maximum time for return to heavy material handling work and all pre-surgical activities.<sup>[369, 372]</sup>

#### *Data Collection - Self Report*

At the initial visit participants signed consent forms and completed self-report measures including a demographic information sheet which included age, height, weight, regular exercise (yes/no) with description, parity, job title, previous history of back pain or injury (yes/no) description of, and time since, last episode, as well as reason for hysterectomy.

#### **Abdominal Surgery Impact Scale**

To evaluate subjective impressions of recovery, on the second visit (the first post-surgical visit), participants completed the Abdominal Surgery Impact Scale (ASIS)<sup>[373]</sup>. The ASIS is a 7-point Likert scale designed to measure short-term post-surgical health-related quality of life and includes 18 items, within 6 domains. These domains include: physical function; functional impairment; pain; visceral function; sleep and psychological function with a total possible score between 18 and 126 with the higher scores indicating better recovery. Reliability coefficients for

each subscale were 0.55 for visceral function; 0.80 sleep and psychological function ; 0.81 pain; 0.83 physical impairment; and 0.90 functional impairment. All but the visceral function domain met the reliability benchmarks of  $>.70$  for research.<sup>[299]</sup>

### **Readiness for Return to Work Scale**

On the third visit, eight weeks post surgery, participants completed the Readiness for Return-to-Work (RRTW) Scale<sup>[374]</sup> which had been developed by Franche et al.<sup>[374]</sup> as a staging tool for readiness for work in individuals off work on a compensated absence into four readiness for change factors - pre-contemplation; contemplation; prepared for action - self evaluative and prepared for action - behavioral. For individuals who had returned to work, two factors impacted potential durability: uncertain maintenance and proactive maintenance. The instrument is set up so that individuals either complete the 13 items for individuals not currently working or the 9 items for those who are working. Each stage is scored by taking the mean of all items creating that factor. A higher score on a particular factor indicates higher levels of beliefs on that factor. The authors noted that during the return to work, high levels of both types of maintenance, proactive and uncertain, were associated with poorer physical health, increased functional disability, and increased fear-avoidance, and particularly so for uncertain maintenance. Higher levels of uncertain maintenance also associated with higher pain levels and more negative mental health states. Reliability for this instrument has been shown to be between 0.65 and 0.75 for the off-work subscales and between 0.67 and 0.82 for the maintenance subscales.<sup>[374]</sup>

### ***Data Collection - Muscle Thickness***

RUSI static images were captured using an M-Turbo ultrasound machine (Sonosite, Inc, Bothell, WA) and a 60 mm, 2 to 5 MHz curvilinear transducer. All images were captured by one examiner with qualifications as per Chapter 3.2.3 Examiner. Images of the Transversus Abdominis, Lumbar Multifidus at rest and under loading conditions including ADIM, ASLR and CAL were obtained from each participant using the protocols outlined in Chapter 3.2.4 Ultrasound Imaging Protocol. Three images were obtained and averaged for each of the nine conditions on each testing occasion. Specifically, the nine conditions include, hook-lying rest, ADIM, percent change rest to ADIM, supine rest, ASLR, percent change rest to ASLR for the TrA and prone rest, CAL, percent change rest to CAL for the LM. Measurements are reported in mm for the rest and contracted conditions. Pelvic floor muscle function by observed change in bladder base position

was evaluated using the Kegel voluntary contraction and the ASLR as per the procedure outlined in Chapter 3.2.4. Elevation of the bladder base on a Kegel exercise met the criteria for a correct response. A correct response to the ASLR was the absence of bladder base descent during that maneuver. Responses were scored as yes/no for correct/incorrect response. The same RUSI measurement protocol was used on the second, third and fourth visits. Images were measured offline using Image J software V1.46r (National Institutes of Health Bethesda, MD) as per the protocol described in Section 3.2.5 Measurements in Chapter 3.

#### 4.2.5 Data Analysis

As a case series, each individual women's results were examined individually and collectively using descriptive statistics and plotting on graphs. To explore the potential for using these data in a future effectiveness trial, selected between group comparisons were examined statistically, recognizing there was likely insufficient power to detect differences. Statistical analyses were conducted using IBM SPSS for Windows, Version 22.0 software (IBM Corp, Armonk, NY). Descriptive statistics including the mean, range and standard deviation for each testing occasion were applied to summarize the data. The Abdominal Surgery Impact Scale and the Readiness to Return to Work Scale were scored and reported. Pearson product moment correlations were done to compare the self report data with muscle thickness difference scores calculated by subtracting the thickness value on the subsequent visit from that obtained on the initial visit. ASIS results were correlated with the 4 week difference scores and the RRTW with the 8 week scores. The data from the pelvic floor measures is summarized as proportions of correct responses at each of the 4 testing occasions.

Data from this case series was compared with data from the group of healthy women (no hysterectomy) in chapter 3 on whom the RUSI measurement protocol had been tested and error terms established. A MANOVA including all TrA and LM resting, contracted and derived measurements at baseline was done to determine if there was a difference between the initial muscle thickness measurements between groups. Reliability of the measures had been calculated using data from the comparison group by the principal investigator. The reliability for each of the measures is fully outlined in Chapter 3. The minimal detectable change (MDC), calculated using the comparison group values (see Chapter 3, Table 3-5), was compared to the magnitude of difference between sequential measures for each condition for each interval (4, 8 and 12 weeks) to ensure that the difference observed was more than simply a manifestation of measurement error.

Repeated measures analysis of variance (RM-ANOVA) was completed for each condition using time as the independent variable and muscle thickness measures as the dependent variable. Assumptions for RM-ANOVA include normality, homogeneity of variance (if more than one group) and sphericity. Since there is only one group being tested, homogeneity of variance is not relevant. There was no significant departure from normality in the data as measured by the Kolmogorov-Smirnov test except for the ADIM measurements in week 8 where there was one outlier leading to a positive test of 0.304,  $p=0.016$ . In cases where the assumption of sphericity was violated, the Greenhouse-Geisser corrected tests were reported. Effect size for repeated measures ANOVA (omega squared) was calculated using the formula:

$$\omega^2 = \frac{\left[\frac{k-1}{nk} (MS_M - MS_R)\right]}{MS_R + \frac{MS_B - MS_R}{k} + \left[\frac{k-1}{nk} (MS_M - MS_R)\right]} \text{ (Field, 2013, p. 566)}$$

Omega squared was chosen as, for small samples, it is an unbiased estimator of the true population value of effect size. Partial eta squared, the default SPSS output value, tends to overestimate effect size in repeated measures ANOVA applications.<sup>[326, 375]</sup> Omega squared uses measures of the population variance whereas eta squared measures the sample variance.<sup>[375]</sup> Therefore omega squared values will always be less than eta squared values calculated on the same data.<sup>[376]</sup> Kirk<sup>[377]</sup> suggests three benchmarks for omega squared interpretation: .010 is a small-sized effect; .059 is a medium-sized effect and .138 is a large effect.

Effect size measures for pairwise comparisons were calculated using the equation:

$$r = \sqrt{\frac{F(1,df_R)}{F(1,df_R+df_R)}} \text{ (Field, 2013, p.567)}^{[326]}$$

The benchmarks as proposed by Cohen<sup>[378]</sup> for small, medium and large along with Rosenthal's<sup>[379]</sup> addition of very large were used for interpretation of these coefficients ( .10 small; .30 medium; .50 large; .70 very large).

The case series data were divided into two groups based on thickness decreases exceeding MDC for the TrA and LM muscles. Between-group differences in performance of the pelvic floor muscle maneuvers by group was tested using Fisher's Exact Test.

### 4.3 Results

Ten consecutive women scheduled for open hysterectomy, who met the inclusion criteria, were recruited. One woman was unable to lie prone for image capture of the LM at either the initial or second appointments due to abdominal discomfort which was related to the reason for the hysterectomy and to incisional pain following surgery. She was also unable to tolerate the transducer over her midline lower abdomen for bladder base image capture on the post-operative visits due to incisional pain. She rescheduled her final visit three times because of respiratory illness and ultimately chose to withdraw from the study at that time. This resulted in a large amount of missing data so her data were not included in the analysis, leaving a sample of 9 participants.

Participants' mean age was  $46.3 \pm 6.0$  yrs (range 40-55) with a mean body mass index (BMI) of  $26.1 \pm 5.3$  (range 18.7 to 34.4). (Table 4-1) Six individuals reported participation in at least some regular exercise while three declared that they did none. Seventy percent of the sample had at least some post-secondary education and all had completed high school. Reasons for hysterectomy were fibroids and similar 3/9; menstrual disorders 5/9 and other (cancer prevention after skin melanoma) 1/9. This is consistent with CIHI reports for rural populations.<sup>[31]</sup>

Demographics and baseline muscle thickness of women in this case series were compared to the those of the non-hysterectomy sample evaluated in Chapter 3 (Table 4-1). The hysterectomy cases had a lower percentage of previous episodes of back pain, higher participation in regular exercise and lower rate of post-secondary education than the comparison group. Multivariate ANOVA comparing the initial muscle thickness and thickness change measures for each group showed no significant difference between the two groups,  $F_{1,37}=0.59$ ,  $p=0.78$ .

**Table 4-1 Descriptive statistics and initial muscle thickness measures of participants by group.**

	Comparison Group (n=30)	Hysterectomy Group (n=9)
Age, year (mean ± sd)	42.9±5.7	46.3±6.3
Body mass index, kg/m <sup>2</sup> (mean ± sd)	25.9±5.5	26.6±5.4
Prior history of back pain <sup>1</sup> (yes)%	56.7	44.5
Regular exercise (yes)%	67	89
Parity, median	2	2
Post-Secondary Education (yes)%	80	55
<i>Initial Muscle Thickness Measures (mean ± sd)</i>		
TrA - Hook-lying Rest (mm)	3.1±0.9 (1.6-5.2)	3.0±0.7 (1.9-4.2)
TrA - ADIM (mm)	4.9±1.3 (2.0-7.3)	4.5±0.8 (3.2-5.8)
TrA - Percent change ADIM (%)	56.1±23.9(12-112)	52.2±12.5 (30-69)
TrA - Supine Rest (mm)	3.0±0.8 (1.8-5.1)	3.0±0.7 (2.0-4.2)
TrA - ASLR (mm)	3.9±1.0 (1.7-5.6)	3.7±0.7 (2.8-4.8)
TrA - Percent change ASLR (%)	26.4±19.6 (-.02-69)	27.2±16.8 (6-50)
LM - Prone Rest (mm)	28.6±5.3 (20.2-39.0)	25.3±2.7 (21.1-28.1)
LM - CAL (mm)	33.6±5.9 (25.0-45.2)	30.5±3.6 (25.5-35.1)
LM - Percent change CAL (%)	18.2±7.3 (8-31)	20.44±6.4 (8-22)

**<sup>1</sup>Self report**

Abbreviations *sd* = standard deviation, *TrA*, transversus abdominis; *LM*, lumbar multifidus; *ADIM*, abdominal drawing-in maneuver; *ASLR*, active straight leg raise, *CAL*, contralateral arm lift

Qualitative observation of the mean values of the 6 TrA-related conditions over the 4 testing occasions (Table 4-2) shows an initial decrease in the mean value for each TrA measurement on the first post-surgical visit. None of the TrA measurements return to pre-surgical values by the end of the study at 12 weeks. (Figure 4-1).

**Table 4-2 Descriptive statistics for the muscle thickness measurements in the 9 conditions on the 4 occasions for the case series participants who underwent hysterectomy.**

Measure	Initial	Week 4	Week 8	Week 12
	Mean±SD (Min-Max)	Mean±SD (Min-Max)	Mean±SD (Min-Max)	Mean±SD (Min-Max)
<b>TrA</b>				
Hook-lying Rest (mm)	3.0±0.7 (1.9-4.2)	2.6±0.5 (2.0-3.6)	2.6±0.5 (2.0-3.3)	2.7±0.4 (2.0-3.1)
ADIM (mm)	4.5±0.8 (3.2-5.8)	3.3±0.5 (2.6-4.3)	3.7±0.6(3.0-5.2)	3.7±0.6 (3.1-4.8)
Percent change ADIM (%)	52.2±12.5 (30-69)	28.5±18.6 (6-56)	48.0±24.3 (15-86)	38.1±20.5 (6-64)
<b>TrA</b>				
Supine Rest (mm)	3.0±0.7 (2.0-4.2)	2.5±0.5 (2.0-3.5)	2.5±0.5 (1.9-3.3)	2.7±0.5(2.0-3.5)
ASLR (mm)	3.7±0.7 (2.8-4.8)	2.8±0.5 (2.1-3.7)	2.8±0.5 (2.0-3.7)	2.9±0.5 (2.0-4.0)
Percent change ASLR (%)	27.2±16.8 (6-50)	6.4±7.4 (0-22)	10.0±10.7 (0-32)	7.0±13.0 (0-35)
<b>LM</b>				
Prone Rest (mm)	25.3±2.7 (21.1-28.1)	24.8±2.0 (22.1-28.9)	25.9±2.0 (20.0-27.9)	25.8±2.6 (21.6-29.2)
CAL (mm)	30.5±3.6 (25.5-35.1)	28.3±2.4 (24.8-31.8)	29.9±1.8 (26.8-32.7)	30.5±2.6 (26.6-34.7)
Percent change CAL (%)	20.4±6.4 (8-22)	14.3±5.9 (3-21)	15.6±7.5 (4-29)	19.0±9.1 (7-33)

Abbreviations : *TrA*, transversus abdominis; *LM*, lumbar multifidus; *ADIM*, abdominal drawing-in maneuver; *ASLR*, active straight leg raise, *CAL*, contralateral arm lift

Observation of the LM resting thickness revealed that it remained stable over the four visits. The contracted measurement showed an initial small decrease but then returned to pre-surgical values by the end of the study. The percent change values showed an initial decrease with a return to pre-surgical values only for the LM by the final visit. (Figure 4-2).

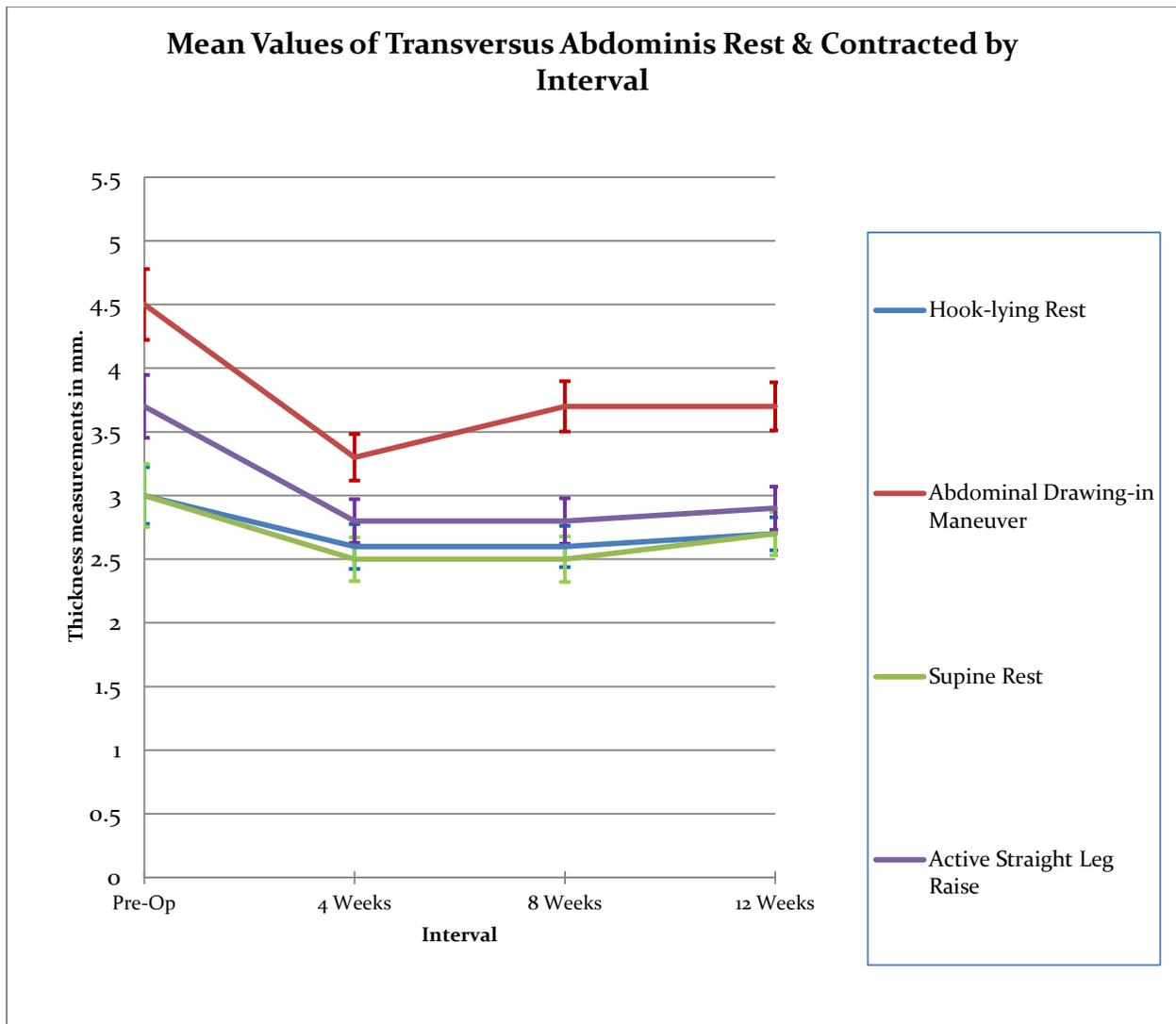


Figure 4-1 Transversus abdominis mean muscle thickness measurements - pre-operatively, and 4, 8 and 12 weeks post-operatively.

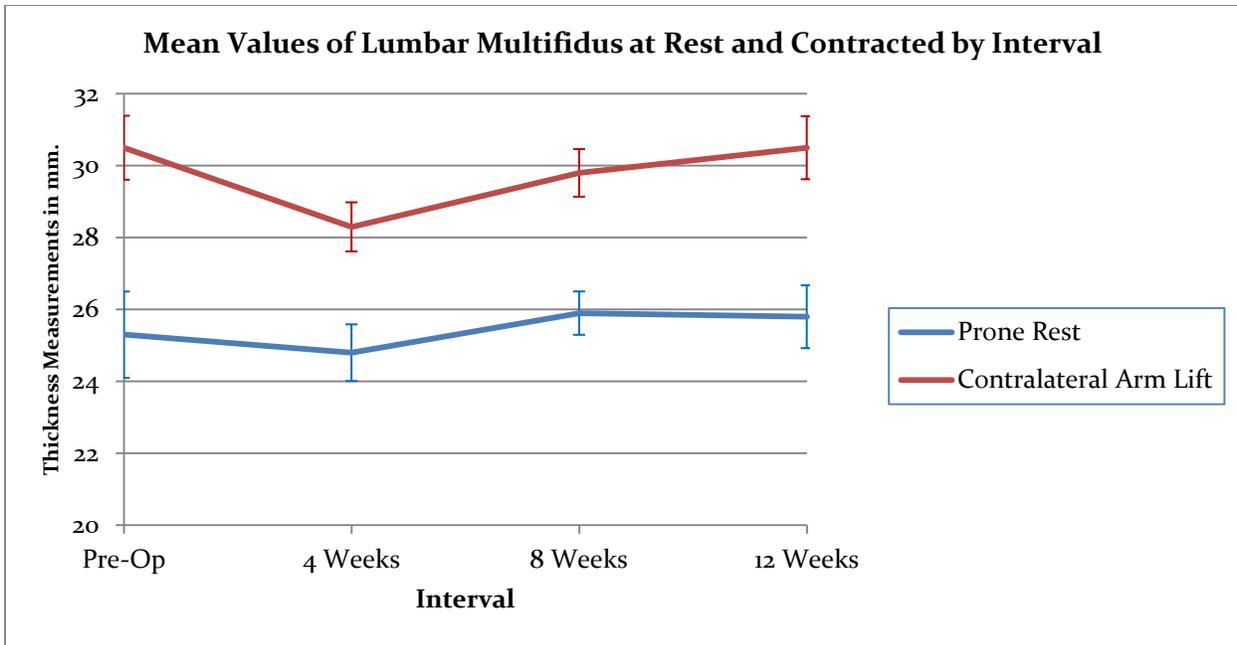


Figure 4-2 Lumbar multifidus muscle mean thickness measurements - pre-operatively, and 4, 8 and 12 weeks post-operatively.

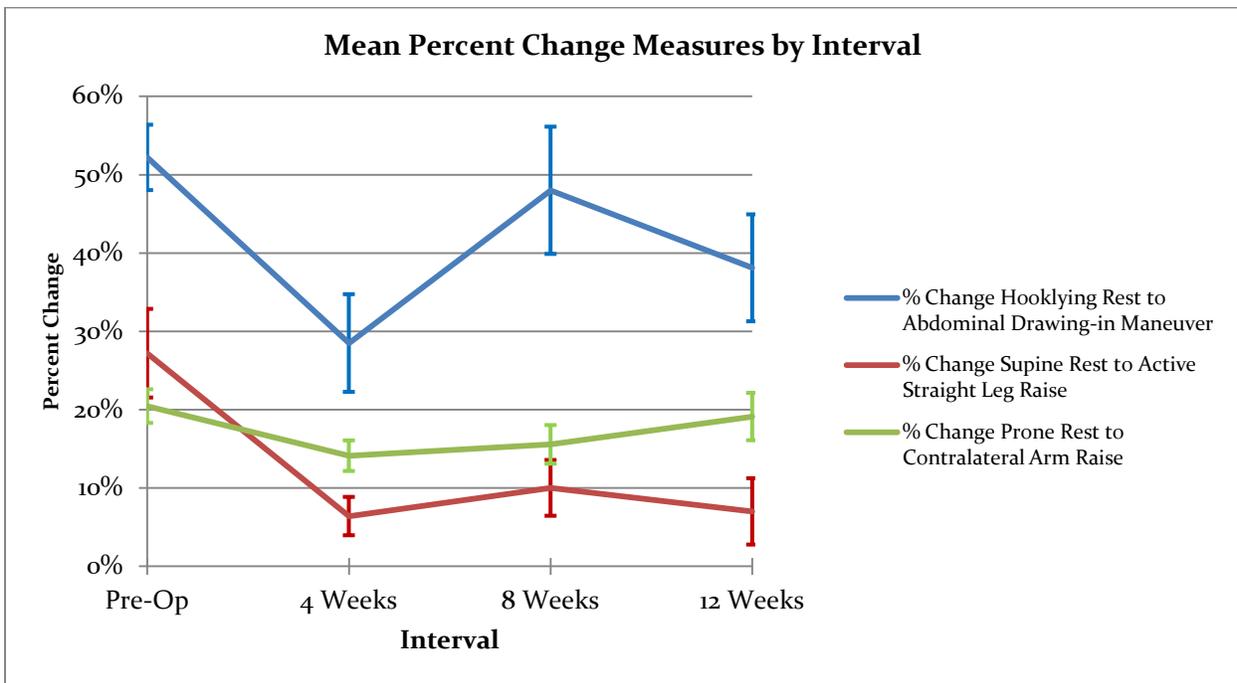


Figure 4-3 Mean percent change measurements - pre-operatively, and 4, 8 and 12 weeks post-operatively.

Repeated Measures ANOVAs using simple comparison with the initial visit, were performed for the dependent variables as shown in Table 4-3. The omnibus F statistic was significant for all measurements of the TrA and only for the CAL for LM. (Table 4-3) Large effect sizes were noted for the TrA during the ADIM ( $\omega^2=.29$ ), percent change with ADIM ( $\omega^2=.16$ ); ASLR ( $\omega^2=.40$ ) and percent change with ASLR ( $\omega^2=.36$ ). Medium effect sizes are noted for TrA hook lying ( $\omega^2=.07$ ) and supine rest ( $\omega^2=.08$ ) as well as LM CAL ( $\omega^2=.06$ ) and percent change with CAL ( $\omega^2=.06$ ).

Post Hoc contrasts between pairs of visits were significant for difference scores between baseline (pre-op) and 4 weeks post surgery for all rest and contracted muscle thickness measures of TrA and for LM contracted during the CAL. (Table 4-3) Both TrA resting measures were also significantly lower between baseline and the 8 week visit. The two contracted measures for TrA, ADIM and ASLR, were also significantly reduced between baseline and each of the 8 and 12 weeks visits. Percent change for ADIM was also significantly different between baseline and 4 and 12 weeks, but the ASLR was only significantly reduced on the 12 week visit. Neither the ASLR nor the ADIM percent change measures were significantly reduced from baseline to the 8 week interval. Effect sizes for the significant pairwise visit contrasts ranged from  $r=.43$  to  $r=.75$  (Table 4-3).

**Table 4-3 Repeated measures ANOVA results and within subject pairwise contrasts by visit for all RUSI measurements in participants with a hysterectomy.**

Measure	Repeated Measures ANOVA	Within Subject Contrasts by visit		
		Baseline vs. 4 weeks	Baseline vs. 8 weeks	Baseline vs. 12 weeks
TrA				
Hook-lying Rest	F <sub>3,24</sub> =4.61, p=.01* ( $\omega^2$ =.07)	F=9.72, p=.01** (r=.55)	F=8.46, p=.02* (r=.51)	F=2.77, p=.134 (r=.25)
ADIM	F=11.45, p<.001** ( $\omega^2$ =.29)	F=23.67, p=.001** (r=.75)	F=13.23, p=.007** (r=.42)	F=9.15, p=.016* (r=.53)
Percent change rest/ADIM	F=7.027, p=.001** ( $\omega^2$ =.16)	F=23.52, p=.001** (r=.75)	F=0.45, p=.519 (r=.05)	F=5.95, p=.041* (r=.43)
TrA				
Supine Rest	F=7.1, p=.001** ( $\omega^2$ =.09)	F=14.87, p=.005** (r=.65)	F=13.84, p=.006* (r=.43)	F=4.48, p=.067 (r=.36)
ASLR	F=13.67, p=.001** ( $\omega^2$ =.40)	F=22.11, p=.002** (r=.73)	F=18.66, p=.003** (r=.69)	F=11.30, p=.010* (r=.58)
Percent change rest/ASLR	F=4.09, p=.018* ( $\omega^2$ =.36)	F=4.33, p=.070 (r=.35)	F=4.15, p=.076 (r=.34)	F=10.09, p=.01* (r=.58)
LM				
Prone Rest	F=0.90, p=.456 ( $\omega^2$ =0)	n/c	n/c	n/c
CAL	F=3.39, p=.034* ( $\omega^2$ =.08)	F=8.33, p=.020* (r=.45)	F=0.39, p=.548 (r=.05)	F=0.03, p=.874 (r=0)
Percent change rest/CAL	F <sub>3,24</sub> =2.09, p=.128 ( $\omega^2$ =.06)	n/c	n/c	n/c

Abbreviations: TrA, transversus abdominis; LM, lumbar multifidus; ADIM, abdominal drawing in maneuver; ASLR, active straight leg raise; CAL, contralateral arm lift; n/a, not calculated as F was not significant;  $\omega^2$ , omega

\*Significant at  $\alpha$ =.05

\*\*Significant at  $\alpha$ =.01

The subgroups of individuals whose intersession mean muscle thickness differences exceeded measurement error for at least one abdominal muscle measurement (Group 1) and those who did not (Group 2) were compared for difference in potential LBP risk factors. (Table 4-4) The three study participants with BMI greater than 30 were in the group presenting differences in muscle measurements (Group 1) and as well as two of the three who had reported prior back pain/injury. The other individual reported her prior back pain was related to her uterine fibroids rather than a mechanical back pain. Age distribution was similar in the two groups as were parity and activity level. No measurement change for the contraction ratios (percent change) of TrA exceeded measurement error in either group.

**Table 4-4 Individual characteristics along with muscle thickness decreases exceeding MDC for the 4, 8 and 12 week intervals.**

ID	Hyst. Reason	PBI	BMI	Age	TrA Rest*	TrA ADIM	% TrA change ADIM	TrA ASLR	% TrA Change ASLR	LM Prone Rest	LM CAL	% LM Change CAL
<b>Group 1 - Individuals with thickness decreases exceeding MDC</b>												
19	Fibroid	Yes	≤25	>50	4,8	4,8,12	None	4,8	None	None	None	4,8
22	Menstrual	No	>30	40-45	4,8	4,8	None	4,8,12	None	None	None	8
77	Menstrual	No	>30	40-45	None*	4,8,12	None	None*	None	None	None	None
78	Menstrual	No	≤25	46-50	4	4,8,12	None	4,8,12	None	None	None	None
84	Other	Yes	>30	>50	4, 8,12	4,8,12	None	4,8,12	None	None	None	None
<b>Group 2 - Individuals with no thickness decreases exceeding MDC</b>												
11	Fibroid	Yes <sup>†</sup>	≤25	>50								
38	Menstrual	No	≤25	46-50				None				
88	Menstrual	No	≤25	40-45								
95	Fibroid	No	≤25	40-45								

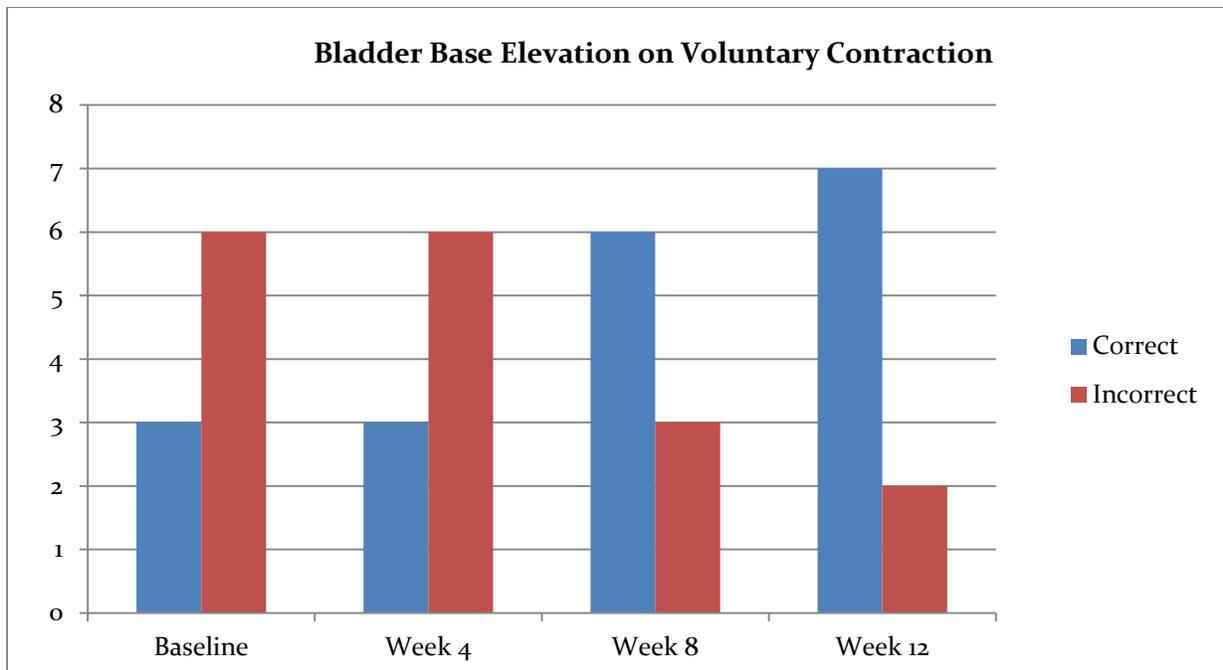
Abbreviations: ID, Identifier; Hyst., hysterectomy; PBI, Previous Back Injury; BMI, Body Mass Index; TrA, transversus abdominis; LM, lumbar multifidus; ADIM, abdominal drawing in maneuver; ASLR, active straight leg raise; CAL, contralateral arm lift

\*Already very small at baseline with change not exceeding measurement error.

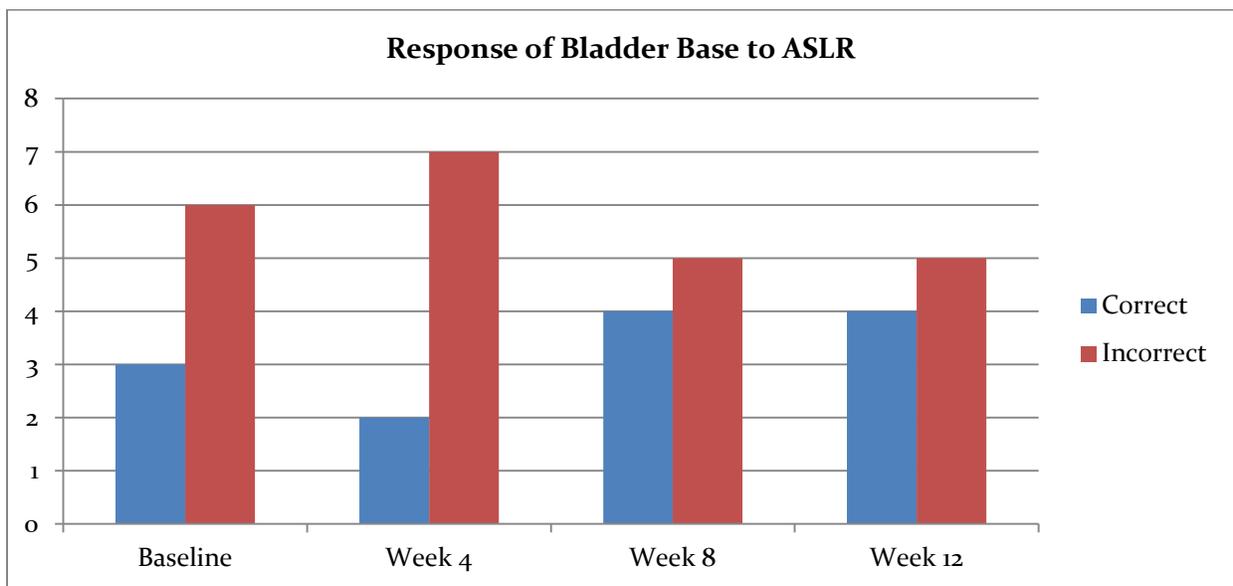
\*\*Hooklying rest and supine rest values were identical and therefore one column (TrA rest) represents these variables.

<sup>†</sup> Back pain in this case was related to the fibroid pressing on a nerve (self-report as explained to her by physician) Pain resolved following surgery

On the PFM measures, a correct response for each measure was noted in 33% of the sample at baseline. (Figure 4-4 and 4-5) For the Kegel, this proportion remained stable for the first post-surgical visit and then increased to 78% by the final visit. For the ASLR the proportion of correct responses initially decreased post-surgically and then improved to 44% on the following two visits.



**Figure 4-4** Number of cases with bladder base elevation in response to voluntary contraction (Kegel).



**Figure 4-5** Number of cases with correct/incorrect responses to ASLR. Correct response is no descent of the bladder base during the ASLR.

Individual performance by visit showed some variability. Individuals who had intersession decreases in TrA or LM measurements exceeding MDC (Group 1) had fewer correct responses

compared to those without such decreases (Group 2). By the second post-surgical visit, all but one case measure in Group 2 showed the correct response. The Group 1 cases showed more varied responses with two individuals never scoring a correct response (Table 4-5). Fisher's exact test for small samples found no significant difference by group for performance of the Kegel maneuver on any testing occasion but did show a significant difference for baseline ( $p=.048$ ) and week 8 ( $p=.008$ ) bladder base descent with ASLR.

Table 4-5 Individual results for the PFM tests comparing groups based on whether or not the TrA or the LM showed decreases exceeding MDC.

Characteristics				Baseline		Week 4		Week 8		Week 12		
ID	Hyst. Reason	PBI	BMI	Age	Kegel	ASLR	Kegel	ASLR	Kegel	ASLR	Kegel	ASLR
<b>Group 1 Individuals with TrA or LM thickness decreases exceeding MDC</b>												
19	Fibroid	Yes	≤25	>50	-	-	-	-	+	-	+	-
22	Menstrual	No	>30	40-45	-	-	-	-	-	-	-	-
77	Menstrual	No	>30	40-45	-	-	-	-	-	-	-	-
78	Menstrual	No	≤25	46-50	+	-	+	-	+	-	+	-
84	Other	Yes	>30	>50	-	-	-	-	-	-	+	+
<b>Group 2 Individuals with no TrA or LM thickness decreases exceeding MDC</b>												
11	Fibroid	Yes <sup>†</sup>	≤25	>50	+	+	+	+	+	+	+	+
38	Menstrual	No	≤25	46-50	-	-	-	+	+	+	+	+
88	Menstrual	No	≤25	40-45	-	+	-	-	+	+	+	+
95	Fibroid	No	≤25	40-45	+	+	+	-	+	+	+	-

**Key: + indicates a correct response i.e. bladder base elevation with Kegel; no bladder descent with ASLR**

Abbreviations: Hyst., hysterectomy; ASLR, active straight leg raise;; BMI, Body Mass Index; PBI, Prior Back Injury

### Self Report Scales: Surgical Impact and Return to Work

Abdominal Surgery Impact Scale (ASIS),<sup>[373]</sup> was administered to all participants at the first post surgical visit 4 weeks following hysterectomy to obtain information about their perceived pain. All scores were between 82 and 124 out of a possible best score of 126 with a mean of 106.2 and a standard deviation of 14.1. Incisional pain was the most common report overall and difficulty with frequent waking was the most frequent sleep domain issue. "I am not able to move easily" was the most common complaint in the physical domain. The two individuals (22 & 84) who scored lower than one standard deviation below the mean also had TrA muscle thickness measurements (Table 4-4) that were decreased more than MDC at the first post surgical visit and poor PFM function (Table 4-5). However, other individuals in Group 1 (19, 77 & 78) had scores within one standard deviation of the mean. All but one of the Group 1 individuals scored below the mean in the pain domain, indicating higher levels of pain than the Group 2 individuals. The

lone individual in Group 1 who indicated less pain was also had the lowest sleep score (undisturbed sleep).

**Table 4-6 Abdominal Surgery Impact Scale individual results by domain.**

Person ID	Physical Impairment	Functional Impairment	Pain	Visceral Function	Sleep	Psychological Function	Total
<b>Group 1 Individuals with TrA or LM thickness decreases exceeding MDC</b>							
19	21	21	17	21	6	21	107
22	8	11	15	15	13	20	82
77	17	21	15	21	21	21	116
78	20	21	16	21	14	21	113
84	16	21	11	12	11	14	85
<b>Group 2 Individuals with no TrA or LM thickness decreases exceeding MDC</b>							
11	17	19	18	21	15	21	113
38	20	20	17	21	15	20	113
88	21	21	19	21	21	21	124
95	19	18	18	18	13	17	103
<b>Mean</b>	<b>17.7</b>	<b>19.2</b>	<b>16.2</b>	<b>19.0</b>	<b>14.3</b>	<b>19.6</b>	<b>106.2</b>
<b>SD</b>	<b>4.1</b>	<b>3.3</b>	<b>2.4</b>	<b>3.4</b>	<b>4.7</b>	<b>2.5</b>	<b>14.1</b>

Abbreviation: SD, Standard Deviation

Scores on the ASIS did not correlate significantly with the difference scores for muscle thickness and percent change variables between baseline and 4 weeks (Table 4-7). The percent variance explained ranged from 0.4% to just under 10%.

**Table 4-7 Correlation coefficients for differences in muscle measurements between baseline and 4 weeks and the ASIS scores.**

Maneuver/Muscle Thickness Measure	Abdominal Surgery Impact Scale	
	Pearson Correlation	Significance 2-tailed
Hooklying Rest	r=.067	p=.867
Abdominal Drawing-in Maneuver	r=.190	p=.625
Percent Change Hooklying Rest/Abdominal Drawing-in Maneuver	r=.315	p=.409
Supine Rest	r=.078	p=.776
Active Straight Leg Raise	r=.297	p=.438
Percent Change Supine Rest/Active Straight Leg Raise	r=.299	p=.434
Prone Rest	r=-.122	p=.755
Contralateral Arm Lift	r=-.069	p=.860
Percent Change Prone Rest/Contralateral Arm Lift	r=.142	p=.716

At the 8 week visit, 8 of 9 participants were back at work and one had a return to work date but wanted to maximize her time off work. For the individuals who were back at work, most had low scores on the Readiness to Return to Work uncertain maintenance (UM) category (higher scores are associated with depressive symptoms) and no one scored higher than 12/25. On the proactive maintenance category (PM) the scores ranged from 8/20 to 20/20. (High scores are

indicative of issues with poorer physical health, more functional disability and fear-avoidance behaviour). There was no statistically significant association between UM or PM scores on the RRTW and muscle thickness difference measures or percent change differences at the time of administration of the scale (Table 4-8). However, ASLR and prone rest variables explained more than 36% of the variance in the PM category and the ADIM, CAL and percent change CAL variables explained more than 36% of the variance in the UM category. It should be noted that the four individuals who had no loss of muscle thickness/contraction greater than measurement error over the testing occasions had the lowest scores on the PM scale (range = 8-12) but the UM scores were evenly distributed between the two groups.

**Table 4-8 Correlation coefficients for comparison of week 8 difference scores with RRTW.**

Maneuver/Muscle Thickness Measure	Readiness for Return to Work Scale			
	Proactive Maintenance		Uncertain Maintenance	
Hooklying Rest	r=-.447	p=.267	r=-.259	p=.535
Abdominal Drawing-in Maneuver	r=-.337	p=.414	r=-.689	p=.059
Percent Change Hooklying Rest/Abdominal Drawing-in Maneuver	r=.170	p=.686	r=-.543	p=.164
Supine Rest	r=-.438	p=.295	r=-.256	p=.537
Active Straight Leg Raise	r=-.679	p=.064	r=-.495	p=.213
Percent Change Supine Rest/Active Straight Leg Raise	r=-.352	p=.393	r=-.314	p=.448
Prone Rest	r=.615	p=.104	r=-.052	p=.903
Contralateral Arm Lift	r=.051	p=.905	r=.638	p=.064
Percent Change Prone Rest/Contralateral Arm Lift	r=-.452	p=.261	r=.657	p=.054

## 4.4 Discussion

This is the first study to measure deep abdominal muscle thickness with RUSI before and after abdominal surgery, specifically open-approach hysterectomy, to evaluate the hypotheses that resting, contracted and percent change TrA and LM muscle thickness variables would decrease after surgical insult to the abdominal wall and not return to baseline by the 12 week interval. The results from repeated measures ANOVAs show initial support for this hypothesis for all of the TrA conditions. However, for the LM, only the CAL was significantly reduced and all of the variation seemed to be in the baseline to 4 weeks comparison. This reduction in contracted thickness could relate to difficulty lying prone 4 weeks after surgery even over a pillow or to pain inhibition. Pairwise comparisons for TrA showed that resting values were significantly reduced only for the first two post-surgical visits (4 and 8 weeks) whereas the contracted measures, ADIM and ASLR, were significantly reduced for all three intervals with large to very large effect sizes.

This indicates that resting thickness recovered to close to baseline by three months post-surgery but that active contraction of the TrA muscle may be affected for longer and could be an indication of motor adaptation to pain as proposed by Hodges and Tucker.<sup>[97]</sup>

This adaptation is described as reduced contraction of some muscles with redistribution of activity to other muscles.<sup>[97]</sup> This response is initially adaptive, and prevents pain in the short term, but for some individuals these changes persist.<sup>[97, 137, 138]</sup> In this case, avoiding contraction of the abdominal muscles would reduce post surgical pain in the short term by limiting forces through the abdominal fascia which could pull on the incision. However, when this pattern of movement persists past incisional healing, it can impact the muscle function in the long term through the development of altered motor control.

Recovery of the resting thickness but not the contracted thickness during the 12-week study period could indicate that the resting muscle tone, which is inhibited initially in response to pain, as proposed by the pain adaptation theory,<sup>[110]</sup> recovers more quickly. Muscle strengthening exercises are usually prescribed to build muscle in response to surgical or disuse atrophy. If the muscle is not being exercised as implied by the findings of decreased muscle thickness on contraction, why would any atrophy in the muscle have recovered? Other explanations of this differential recovery are that sub-maximal intensity use during normal activities compared to the higher challenges of the ADIM or ASLR is enough of a stimulus for recovery of resting thickness. The contraction strategies of the ADIM or ASLR imply a fairly isolated contraction which can remain inhibited longer while co-contraction with other muscles during normal activities may also contribute to the recovery of resting thickness.

Participants did report issues with incisional pain, difficulty moving, frequent waking related to pain with rolling in bed on the ASIS at the first post surgical visit (4 weeks). At 8 weeks post-surgery, most were back at work but some indicated concern about their physical ability to remain at work on the RRTW Scale, perhaps indicating an awareness of changed muscle function.

Individual results were assessed and compared to the minimal detectable change (MDC) values calculated in Chapter 3 for each of the measurements. The group of participants whose muscle size decreases exceeded the MDC value for some of the given conditions included the three individuals with BMI>30 and two of the three individuals with prior back pain/injury. Age distribution was equal between those with thickness decreases and those without. This suggests

the biological hypothesis might be amended to highlight the increased risk of post-surgical reduction in muscle thickness in these sub groups of individuals. Sample size limited the ability to perform covariate analyses of these variables and there are no published data related to a post-abdominal surgery population available for comparison of these findings. However, these initial findings are consistent with known risk factors of obesity<sup>[21]</sup> and prior back injury<sup>[8, 19, 22, 380]</sup> for back pain and disability in the literature.

Fewer correct PFM responses (bladder base elevation with Kegel; no descent of the bladder base with ASLR) were found in the group of individuals who had muscle size decreases exceeding MDC in the TrA. This could have been a result of changes in the TrA impacting pelvic floor function. Sapsford and Hodges<sup>[159]</sup> have demonstrated that co-activation of these two muscle groups is pre-programmed. The other explanation is that removal of the uterus and subsequent shift in pelvic organs could result in reduced PFM function, but if that was the case, it would be more likely to be throughout the sample of participants. It should be noted that the PFM function differed at baseline between the two sub-groups but while the Group 1 participants showed improvement, the Group 2 participants did not.

In summary, changes to the TrA and LM muscle thickness following hysterectomy as well as to the PFM were noted in some participants. Obese individuals and those with prior back injury may be at higher risk of developing altered muscle control strategies following hysterectomy.

#### 4.4.1 **Strengths and Limitations**

This case series study of women undergoing hysterectomy provided initial insight into changes in muscle thickness before and after surgery. The RUSI testing protocol was feasible with this post surgical population. The use of an assistant to operate the ultrasound machine for image capture enabled a two-handed grip on the transducer, minimizing transducer movement during muscle contraction. It also allowed the examiner to focus on timing of image capture at end expiration with a verbal command to the assistant. There are both strengths and limitations to this study.

First, abdominal wall thickness varies somewhat depending on the location of the ultrasound transducer.<sup>[256]</sup> Some studies have used markers either on the skin,<sup>[260]</sup> with transparencies using landmarks to ensure exact placement<sup>[282]</sup> between measurement sessions but

given the number of images captured per person at each session, this would have been prohibitive. Standardized participant positioning and measurement protocols were followed but without markings, some degree of variation could have been introduced. However, given that the reliability of the resting and contracted measures of the TrA and LM was good for a comparison group of women over the intervals of interest as outlined in Chapter 3, this potential variation should not cause much concern. The percent change measures were not shown to be reliable in Study 2, so while they are included herein, they should be interpreted with caution.

Second, this case series of N=9 was insufficient for statistical analyses, although conducting them plays a role in preparing for future research. The small sample reduced the ability to assess the potential impact of covariates and while most of the repeated measures ANOVAs in this study showed significant differences following surgery, generalizability may be limited. Nevertheless, the differences observed suggest further investigation would be worthwhile. Similarly, the value of conducting statistical analyses of the self-report measures with such a small sample is limited. However, interesting trends were noted when the two sub-groups were compared. The group with larger decreases in muscle thickness also reported slightly higher pain levels which supports the hypothesis of pain inhibiting muscle function. Once again, replication in a larger sample could provide more stable and relevant results.

Third, using the information cited earlier from the University Hospital of Northern BC's database, during the time frame for recruitment, at least 200 open approach hysterectomies would be expected to have taken place. This could mean that only 5% of women undergoing hysterectomy during that time volunteered for this study. However, changes in hospital staffing during the time frame of this study as evidenced by a drop in the reported rates of hysterectomy for the first 4 months of the recruitment period could mean that a higher percentage of women undergoing abdominal hysterectomy was represented. CIHI statistics for 2012<sup>[31]</sup> show a drop in hysterectomies from 587/100,000<sup>[70]</sup> in the previous year to 480/100,000 in 2012. Information spanning the balance of the recruitment period is not currently available. This risk for a volunteer bias could impact the results of this study since individuals self-referred to participate. These individuals could be different from the general population in education (all had completed high school and most had post-secondary education), socioeconomic status (most lived in middle class neighborhoods) and level of exercise/activity (most engaged in some regular structured exercise).

This would have exerted a conservative bias on the results. Use of volunteers may also limit the generalizability of the results to women with similar characteristics.

Fourth, only measurements of the right side of the abdominal wall were included in this analysis. This decision was made based on previous study findings that muscle thickness was unrelated to hand dominance, side measured or side of symptoms.<sup>[254]</sup> Surgical incisions were all supra-public midline ones and therefore likely to affect both sides. While this decision reduced study burden, it is possible that the impact of surgery could have varied from side to side and more change could have been observed by including bilateral measurements.

Fifth, given the lack of a bony landmark and variation in bladder position and bladder filling, no attempt was made to quantify the results of the bladder base changes. This may have interfered with the ability to detect important changes in pelvic floor function with the surgery. Transperineal ultrasound would have been a better alternative for quantification, as it has been shown to be more reliable as measurements are taken from a fixed bony landmark,<sup>[381]</sup> the pubic symphysis.<sup>[337]</sup> However, the inclusion of such an invasive test could have negatively impacted recruitment which was already challenging. Also the benefits of quantifying bladder base function in this circumstance might not justify the invasive nature of such a test. Although the nature of the data is not quantifiable, it describes the quality of muscle contraction. There was improvement in the number of correct pelvic floor response to both the Kegel and ASLR maneuvers, and this offers insight to physical recovery of pelvic floor muscles following removal of the uterus. The women who showed better overall recovery of the PFM were those with preserved TrA muscle thickness (the reduction did not exceed measurement error), and this may be related to the muscle synergy between abdominal and pelvic floor muscles.

Finally, although the purpose of this work was to establish that decreased muscle thickness in the TrA, LM and PFM could be an outcome of open hysterectomy and thus could predispose individuals to a future episode of low back pain, the cases were not followed to that outcome. The synergistic role of these deep core muscles as spinal stabilizers has been established<sup>[159, 382, 383]</sup> as has the importance of spinal stability in prevention of back pain and injury.<sup>[10, 190]</sup> What has not been clearly established is whether static or dynamic morphometric change in these muscles is a reliable predictor of future back pain. There is evidence of delayed<sup>[29, 106, 147-149]</sup> and diminished<sup>[107, 140, 187, 215]</sup> contraction as well as atrophy<sup>[152]</sup> of the deep stabilizing

muscles in individuals with lumbopelvic dysfunction. Specifically, Ferreira et al.<sup>[148]</sup> demonstrated that individuals with LBP had less TrA activity and significantly smaller increases in TrA thickness during an isometric knee flexion and extension task. Teyhen et al.<sup>[187, 253]</sup> showed smaller increases in TrA thickness on the ASLR and ADIM in individuals with low back pain. Likewise PFM function has been shown to be reduced in the LBP population.<sup>[99, 105]</sup> A systematic review by Wong et al.<sup>[154]</sup> found conflicting evidence regarding dynamic morphometry of TrA/LM as a predictor of LBP-related disability or pain reduction after conservative treatment in chronic LBP patients. However, they did note that poorer baseline TrA contraction ratio was a treatment effect modifier favoring motor control exercise over general exercise. Another article noted that in a study of chronic LBP patients consisting of 8 weeks of guided exercise, improved TrA lateral slide in individuals exhibiting a low baseline slide was associated with long-term pain reduction.<sup>[384]</sup> Another publication by the same group of the randomized control trial of LBP patients found no association between TrA onset and LBP.<sup>[385]</sup> They noted wide variations in activation patterns of the core muscles and suggested that there might be differential effects by subgroups. Given this uncertainty, a longer follow up in this prospective study could have provided valuable insights including how long the exposure might have to be there for the risk of LBP to increase. To examine risk properly both the longer follow up and a larger sample size that is representative of the population at large would be warranted. The sample should be large enough to perform covariate analysis of both obese individuals and those having a prior history of back pain. A study employing a larger sample would be justified given the changes in muscle thickness demonstrated in this case series. Investigation could be expanded to all open approach abdominal surgeries. Further study could include a longer follow up period to ascertain if back injuries are more likely in individuals whose abdominal wall does not return to pre-surgical thickness values. Further investigation of perceived abilities compared with true function could help with identification of individuals at risk who could benefit from post-surgical core muscle rehabilitation.

From a clinical perspective, assessment of core muscle function could be recommended for individuals following open-approach hysterectomy especially those with prior back injuries or who are obese who were found most likely to exhibit post-operative muscle deficits. Although research evidence is limited regarding the efficacy of core muscle rehabilitation in individuals with low back pain,<sup>[154, 384-386]</sup> the contribution of core muscles to spinal stability has been established<sup>[41, 162, 346, 387]</sup> as has the impact of reduced stability on back pain.<sup>[29, 120, 190]</sup> Prescription of

properly performed core muscle exercise has no negative effects and has been postulated to perform a role in injury prevention.<sup>[388]</sup> Further study of the effectiveness of post-surgical core muscle rehabilitation and its association with back injury is justified.

#### **4.5 Conclusions and Implications**

This study provides initial support for the hypothesis of post-hysterectomy reduction in muscle thickness of the TrA muscles at rest and in the contracted state as tested with the ADIM and ASLR. Resting thickness recovered by the third post-surgical visit in most individuals but reduction in contracted thickness persisted in some individuals, specifically those who had a history of back injury or who were obese. These results suggest that further investigation to more fully examine muscle dysfunction/recovery rate as risk factors using a larger sample would be justified. The LM measures showed little change save for the CAL at the first post-surgical visit which could relate more to difficulty lying prone on the incision than any real changes in muscle contraction. While back pain and reduced LM thickness has been associated with reduced TrA muscle thickness in published research studies, in this series of 9 women reduced TrA thickness following surgery was not associated with decreased LM thickness within the 12-week post-surgical period.

#### **4.6 Summary and Novelty**

This is the first study to demonstrate that the deep trunk stabilizers demonstrate reduced thickness at rest and during contraction when measured using RUSI, following open abdominal hysterectomy. In the TrA, this reduction in thickness in some individuals persisted through to the final assessment at end of the study at 12 weeks. Post-surgical rehabilitation to help restore pre-surgical muscle function may be warranted for the population with risk factors such as previous back injury and obesity. If this population is indeed at increased risk of back injury, targeting this population could save money through increased productivity and decreased healthcare costs from physician and rehabilitation visits as well as having the ability to maintain a healthy active lifestyle which has its own plethora of health benefits.

## 5. General Discussion

This chapter seeks to integrate the information presented in the preceding chapters as it applies to the central aim of the research and current research in the field of Rehabilitation Sciences. It will highlight the contributions of this research to the evidence base and the implications for clinical practice and future research. Key limitations of the work are acknowledged.

### 5.1 Overview

The aim of the research contained within this thesis was to investigate whether having an abdominal approach hysterectomy increased a woman's chances of future back pain or injury. This stemmed from clinical observations where it was noted that female healthcare workers who had physically demanding jobs and who were attending physiotherapy for treatment of low back injury, reported a higher than expected prevalence of prior hysterectomy. To investigate this hypothesis, two very different approaches were used. The first, a population based approach utilized linked health data to see if there was a higher incidence of back injury following hysterectomy in an cohort of healthcare workers. The second, a direct measurement study, recruited women undergoing hysterectomy to see if surgery altered core muscle function following the surgical splitting and repair of the midline abdominal fascia.

To study back injury risk following hysterectomy at a population level, a large database study using linked health databases housed at PopDataBC was undertaken. This approach, while effective for obtaining a large sample of healthcare workers involved several challenges that are outlined later in the chapter below.

To evaluate whether hysterectomy decreases abdominal strength/function, the clinical RUSI studies reported in Chapters 3 and 4 were undertaken. RUSI is used to assess muscle function noninvasively and changes in muscle thickness measures from resting to contracted states, reflect, to a degree, the findings on EMG. In Chapter 3, test-retest reliability of RUSI tests of the TrA, LM and PFM over intervals up to a three-month period was established. RUSI is used to assess muscle function noninvasively and muscle thickness changes reflect findings from EMG. This was the first study to evaluate the stability of muscle thickness of the TrA and LM in healthy women over a prolonged period of time corresponding to the length of time typically spent off-work or away from regular exercise/activities following a hysterectomy. This was deemed

necessary to interpret data collected in Chapter 4 to determine if changes in these muscles from pre- to various post-operative intervals exceeded measurement error. Overall, the intersession ICC<sub>3,1</sub> for the TrA and LM muscle thickness measurements of the muscles at rest as well as during the ADIM, ALSR and CAL maneuvers met the standard for conducting research. These reliabilities and associated MDCs formed the foundation from which to examine the changes in muscle thickness of these core muscles before and after hysterectomy.

Chapter 4 reports a case series of muscle thickness changes in a group of nine women undergoing hysterectomy showing that, following surgery, an initial decrease in both resting and contracted muscle thickness is noted in the TrA but not the LM. For the LM, only the first post-surgical measurement for the CAL at 4 weeks following surgery was reduced. No change was noted in the resting or percent change values for LM. Resting TrA thickness recovered to pre-surgical levels by the third post-surgical visit (12 weeks) in most individuals but reduction in contracted thickness of some individuals persisted through to the end of the study at the 12 week period. This offers initial support for a hypothesis of decreased abdominal strength/function following surgical interruption of the abdominal myofascial ring in some individuals.

## **5.1 Is Hysterectomy Associated with Back Pain?**

Several studies have reported a finding of back pain following hysterectomy.<sup>[35-37, 39, 79]</sup> Reasons for the pain have included personality factors resulting in less resistance to somatic symptoms,<sup>[79]</sup> and decreased (unmeasured) ovarian function leading to lower bone density in the vertebrae,<sup>[36]</sup> while others have opined that it could not be the muscle splitting surgical approach.<sup>[39]</sup> It is the muscle splitting surgical approach that forms the basis of the hypothesis in this thesis - that changes in muscle recruitment patterns will alter core muscle function thus impacting spinal stability and leading to potential back injury. Both the randomized control trial<sup>[36]</sup> and one of the population based studies<sup>[79]</sup> noted increased back pain evident at the 5 year mark while one study reported an increase in back pain at the 1 year mark.<sup>[39]</sup>

Study 1, reported in Chapter 2, did not find a relationship between hysterectomy and back injury within a 5 year time frame as defined by either a lost time workers' compensation claim (work-related low back injury) or by a visit to a physician in the MSP data coded for back injury (both work and non work related). As back injury was the outcome of interest, all individuals with back injury that preceded hysterectomy were excluded from the research sample of healthcare

workers. Healthcare workers are reported to have a significantly higher rates of musculoskeletal injuries (rate ratio (95% CI)=1.43(1.11-1.85))<sup>[53]</sup> with low back injury accounting for the largest proportion of these injuries, largely attributable to the physical demands of healthcare occupations.<sup>[54]</sup>This led to the exclusion of a large proportion of the extracted cohort of healthcare workers with a history of back injury before hysterectomy in order to tease out the independent effect of hysterectomy on back injury.

This study concluded that among front line healthcare workers with a previous work-related injury claim, those who subsequently underwent hysterectomy demonstrated no greater risk of back injury than those who did not. This result may not generalize to all front line healthcare workers as individuals who had no prior WCB claims were excluded as were individuals who had a reported back injury (work-related or not) prior to their hysterectomy. Therefore these results are limited to a population without previous back injury. By choosing to work with this 'clean' cohort, positive findings would have provided strong evidence for a causal link between hysterectomy and incident back injury. The finding of no increased risk in the hysterectomized population could mean that either open-approach hysterectomy does not decrease abdominal strength/function and therefore would not impact the risk of back injury, reduced abdominal strength/function does not increase the risk of back injury, or a change in employment status, type or location could have occurred.

There is a large amount of published literature highlighting the changes in abdominal muscle thickness in individuals with low back pain;<sup>[120, 140, 186, 190, 195, 252, 261, 289, 389]</sup> that the TrA is an important contributor to lumbar stability;<sup>[25, 382, 383]</sup> and that lumbar stability is essential for reducing risk of low back pain and injury.<sup>[10, 190]</sup> A recent systematic review by Wong et al.<sup>[154]</sup> found limited evidence that baseline features of TrA predict clinical outcomes in individuals with LBP but no research examining a temporal relationship between individuals who demonstrate decreased TrA function and subsequent risk of first back injury was located.

The current administrative database study was unable to establish evidence of an association between hysterectomy and back injury. As was noted in Chapter 4 of this thesis, there is initial support for a post-hysterectomy reduction in muscle thickness of the TrA so the null finding in this case could be more related to the method used to enumerate a cohort healthcare workers or the use of hysterectomy status (yes/no) as the explanatory variable with no direct measure of muscle function. Alternatively, as noted above, muscle impairment may not lead to

LBP in this group. Other considerations would include that other open abdominal surgery in the controls could possibly increase their risk of LBP and mask some of the effect of hysterectomies. The exclusion from the cohort of all individuals with prior LBP episodes may have identified a cohort particularly resistant to LBP regardless of the role of open abdominal surgery. Many episodes of LBP are not reported as a WorkSafeBC claim or in the medical system (MSP) if medical treatment is not sought out, thus the association between open hysterectomy and LBP would be attenuated due to missed cases of LBP treated privately or with other insurance coverage.

In light of the findings of the case series study of women before and after hysterectomy in Chapter 4, where individuals who had a history of back pain/injury were more likely to demonstrate a reduction in muscle thickness of the TrA, exclusion of individuals with prior back injury from the cohort might explain the null findings in the database study. The issue of including individuals with back injury in the cohort and creating a variable for prior back injury as a covariate in the analysis is that back injury is also the outcome of the study and many individuals had several work-related low back claims as well as many physician visits coded as back-related. Also, the non-specific MSP codes for back injury would include all spinal levels thereby classifying an individual with a prior neck injury in the group with prior LBP.

Finally, given the results from the case series study in Chapter 4, not all individuals experience a loss of muscle thickness following surgery and of those who do, some recover prior to returning to work resulting in no differential in risk for WRLBI between exposed and unexposed groups. Personal characteristics, such as age, are available in the database however lifestyle variables such as obesity, fitness level, smoking, etc., are not. This makes surgery status a poor surrogate for muscle morphology changes following surgery. Direct measurement of the muscles thickness changes before and after surgery is needed.

## **5.2 Reliability of RUSI Measurement of the ADIM, ASLR and CAL**

Reliability of RUSI for the measurement of TrA and LM thickness has been established for intersession periods of up to 2 weeks. <sup>[245, 251, 256, 263, 293, 297, 301]</sup> This is the first study to evaluate stability of muscle thickness measures over intersession periods of longer than two weeks. Establishing reliability of these measures over periods of 4, 8 and 12 weeks is an important contribution to current knowledge as a basis for comparison in both clinical and research

settings. The clinician using RUSI to evaluate individuals during and after rehabilitation will understand the natural variation in measurements over time when using RUSI to evaluate muscle thickness change in clients. The researcher will have benchmarks for comparison of muscle thickness change when implementing intervention studies using RUSI measurements of the TRA and LM as outcomes. Rehabilitation programs typically take place over 4,<sup>[87]</sup> 8<sup>[302-304, 390]</sup> or 12 weeks.<sup>[305]</sup> Interestingly, the longest test-retest intervals prior to the present study were 1-2 weeks for the TrA and LM.

Intrarater reliability over the longer intersession periods of 4, 8 and 12 weeks was lower than was found in the previously published studies that utilized 1 to 2 week intervals. For example, test-retest ICC values published by McMeeken et al.<sup>[263]</sup> and Rankin et al.<sup>[256]</sup> for hooklying TrA rest measurements taken one week apart were 0.96 to 0.99. However, in both cases, they appear to have used the averaged values ( $ICC_{3,2}$ ) rather than the individual values ( $ICC_{3,1}$ ). Similarly, Linek et al.<sup>[301]</sup> and Norasteh et al.<sup>[251]</sup> used averaged measures for  $ICC_{3,3}$  calculation of supine rest measurements of 0.90 and 0.80 respectively. Koppenhaver et al.,<sup>[286]</sup> over a one to three day interval, also used averaged measures ( $ICC_{3,2}$ ) to establish between day ICCs of 0.93 for hooklying TrA thickness at rest and 0.94 for supine rest.  $ICC_{3,1}$  calculations for hooklying rest for the three intervals in this research ranged from 0.86 to 0.89 and 0.87 to 0.90 for supine rest. Single measures ( $ICC_{3,1}$ ) were chosen in this study as the intent was to look at stability over time rather than using a comparison to an average taken over an extended period of time as the former method would be more clinically relevant. Had average measures been used,  $ICC_{3,3}$  values would have been between .91 and .95 for both rest conditions. It is likely, therefore, that most of the difference in ICC values is related to the method of calculation (single or average measures) and that muscle thickness measurements at rest are stable over time in a healthy population.

Intrarater  $ICC_{3,1}$  estimates for the measurement of the contracted TrA were between 0.80 to 0.82 for the ADIM and varied from 0.75 to 0.78 for the ASLR. Comparison with intersession  $ICC_{3,6}$  of 0.84 by Hides et al.<sup>[293]</sup> and  $ICC_{3,2}$  of 0.87 for Koppenhaver et al.<sup>[286]</sup> for ADIM as well as intersession  $ICC_{3,3}$  of 0.95 by Linek et al.<sup>[301]</sup> and  $ICC_{3,2}$  of 0.93 by Koppenhaver et al.<sup>[286]</sup> for the ASLR, indicate that the current study measurements were lower. Once again, these ICC values were all calculated using average measures and the ones in the current study were done using single measures. Recalculating, using average measures, found that the values for ADIM in the

current study ranged from 0.88 to 0.92 and for ASLR from 0.88 to 0.90. This also shows that most, if not all, of the difference relates to the method of calculation and whether the intent is to estimate the reliability for any measure over the interval or for the average of measures collected at both points of the interval. The test-retest error appears to be fairly stable no matter the interval or intent.

Published ICC<sub>3,2</sub> values for measurements of the LM prone at rest (0.93<sup>[282]</sup> to 0.98<sup>[286]</sup>) and during the CAL (0.97<sup>[282, 286]</sup>) were higher than the range of 0.75 to 0.83 calculated in this study for the reasons noted above. Likewise, the ICC<sub>3,1</sub> values estimated for single measurements for percent thickness change for the TrA and LM in this study were lower than reported in published studies for average of measurements obtained at both time points in the interval but were similar when the data was recalculated using to obtain an ICC<sub>3,3</sub> for average measures. Thus it can be concluded that the muscle thickness in resting and contracted states remains stable over intervals of 4, 8 and 12 weeks in a healthy cohort of women aged 35 to 55 years and that the rater in this study showed similar ability to other experienced raters supporting the use of these measures and rater to evaluate muscle thickness changes after hysterectomy.

For the transabdominal PFM assessment, reliability coefficients were less than optimal. Transperineal ultrasound has been found to be more reliable than transabdominal ultrasound for measuring the pelvic floor movement during valsalva maneuvers.<sup>[335]</sup> Increased abdominal pressure during the ASLR could push the probe in an outward direction. Reliability of transabdominal ultrasound utilizing the transverse view for imaging an active pelvic floor contraction has not been established. What was learned from RUSI of the PFM was that the ability to contract these muscles varied between testing occasions. Reasons for this variation were not ascertained and further study into this phenomenon could yield insight into improved PFM training.

### **5.3 Pre and Post Hysterectomy Muscle Thickness Changes**

Having established that the test-retest reliability of RUSI measurements for evaluating core muscle thickness under the conditions as outlined in Chapter 3 was adequate over a three month period, and believing that RUSI is a good indirect measure of muscle activity,<sup>[148, 263]</sup> a prospective case series study of nine women undergoing hysterectomy was done. Images were captured within the week prior to surgery and then at 4,8 and 12 weeks following surgery. The

hypothesis was that surgical compromise of the abdominal midline fascia would result in changes in function of the TrA muscles and reduced function in the TrA muscles could impact LM function through their relationship in the myofascial ring. It has been noted in previous research that individuals with back pain have inhibition in LM and subsequently TrA on the same side as the pain.<sup>[244]</sup> Examining LM concurrent with TrA following abdominal surgery would investigate whether pain in the TrA would inhibit LM. Pain could have inhibitory effects on muscle contraction and/or individuals could develop changes in contraction thickness patterns due to the incisional pain. As noted in the literature,<sup>[136-138]</sup> once this adaptive pattern was established, it would persist in some individuals leading to a higher risk of back injury. Delayed or diminished TrA contraction<sup>[29, 106, 140, 147, 148]</sup> concurrent with segmental inhibition in the LM<sup>[137, 152]</sup> has been noted in individuals with existing or induced back pain. Therefore, measurement of the LM was of interest to determine if decreased TrA function would immediately impact LM thickness.

In this study, there was an initial decrease in resting TrA muscle thickness that recovered to pre-surgical levels by 12 weeks post-surgery in all but one individual. ADIM thickness measurement decreases exceeding MDC persisted past the 12 week post-surgical period in four out of the nine individuals. Two of the four women had reported prior back injury and two had a BMI greater than 30, offering possible explanations for better understanding of the impact of surgery on muscle function and recovery. Significant ASLR measurement decreases were found in one third of the sample, one with a prior back injury and; two with BMI greater than 30. LM measures were largely unaffected by the surgery within the time frame of the study except for the measurement session immediately following surgery when the contracted thickness of the LM was reduced. These findings suggest that there may be clinically important post-surgical changes (with thickness change values exceeding MDC) in some individuals following hysterectomy. Given that TrA muscle function had not recovered within 12 weeks following surgery, it is reasonable to hypothesize that this could persist and result in a higher risk of back injury for individuals demonstrating this muscle function status. Replication of this study with a larger sample size could help to assess the impact of comorbid conditions such as obesity or prior back injury on recovery of the core muscle system following surgery as our preliminary results suggest that high BMI and prior back injuries may be factors. The case series study reported in this thesis demonstrates such an investigation is feasible and provides a reliable measurement protocol for implementation.

## 5.4 Strengths and Limitations

There are several important limitations in the interpretation of the results of these studies:

1. The administrative database study in Chapter 2 excluded individuals with pre-existing LBP. This eliminated almost three quarters of the sample. Information from the case series study of women undergoing hysterectomy in Chapter 4 raises the question of prior back injury as a comorbid condition. Therefore, inclusion of individuals with prior back injury might have changed the results. Also there was no information available regarding factors such as obesity which could also be a contributory to back injury. Also as noted above, using hysterectomy status as a surrogate measure for loss of muscle function may be too crude a measure for the exposure of interest.
2. Enumeration of the research cohort using WorkSafeBC claims information eliminated the sector of the population with no claims. While inclusion of these individuals with no risk of work-related low back injury in the cohort would have made the relationship closer to the null in the WRLBI analysis, inclusion of these individuals could have led to a different result in the 'any back injury' outcome. It is difficult to predict how the relationship would have changed due to the lack of specificity of the MSP data with regard to location (cervical vs. thoracic vs. lumbar) of injury. Also the inclusion of individuals with prior open abdominal surgery in the control group, would possibly increase their risk of LBP and mask the effect of hysterectomies on back injury. Exclusion of all individuals with a prior back injury from the cohort may have identified a cohort particularly resistant to LBP regardless of the role open abdominal surgery plays in that outcome. Since visits to allied health practitioners (physiotherapists, chiropractors, etc) are not included in the provincial health database and a doctor's referral is not required in BC to access care from these practitioners, the association between open hysterectomy and LBP would be attenuated due to missed cases of LBP treated privately or with other insurance coverage.
3. Recognizing that adaptations of muscle recruitment in response to pain are unique to each individual as evidenced in both the literature and the results of Study 3, hysterectomy as the exposure in Study 1 with no measure of muscle function, might have under-estimated the impact of hysterectomy and the ability to identify a relationship with back injury in the population-based study.

4. Results from the reliability study support the consistency of TrA and LM rest and contracted measures over a 12 week period but the use of a convenience sample that included a higher proportion of health-conscious, educated women and a single examiner limits generalizability to other examiners and populations. The method of recruitment (community posters and word of mouth) is likely to increase the likelihood of health-conscious individuals volunteering for the study. Other researchers have recruited patients from their physiotherapy practices who are attending for unrelated conditions. Using multiple approaches might provide a more heterogeneous population. Utilization of a second examiner, in conjunction with inter-rater reliability assessment, could improve generalizability of results.
5. The low number of participants in the clinical studies precluded the ability to statistically evaluate the impact of conditions such as prior back pain, obesity, age, activity level, parity, etc., on measured muscle thickness limiting the inferences that can be made.
6. The sample size of women undergoing hysterectomy was small and might not be representative of the population at large. Despite extensive recruitment efforts which included repeated visits to gynecologists offices, support from the head of the UBC Northern Medical Program, an appearance on CBC Radio as well as posters in all physician and physiotherapy offices as well as the University Hospital of Northern British Columbia only a small proportion of the women who underwent hysterectomy during the study period volunteered to participate. Without information on all individuals undergoing hysterectomy, it is difficult to ascertain if this sample was representative of the population of all women having this procedure in northern British Columbia. The demographics of the sample indicate that they were more educated and at a higher socio-economic level than the general population in the area. Recruitment from a larger centre such as Vancouver could have increased the sample size despite the lower rates of hysterectomy in Vancouver compared to Prince George. It would have been interesting to recruit volunteers in both the urban and rural settings to determine if location and/or city size impacted the rates of recruitment.
7. Although the purpose of this work was to generate evidence in support of a relationship between abdominal hysterectomy and subsequent increased risk of back injury, the cases were not followed to that conclusion. A prospective cohort study of women undergoing hysterectomy followed over a five-year period could yield more fruitful results.

## **5.5 Implications and Future Directions**

Identification of risk factors that could contribute to low back pain/injury and opportunities for prevention and/or rehabilitation is worthwhile as LBP is a prevalent and costly condition. The studies presented in Chapters 2-4 showed that while AH did not contribute to back injury in a population without a prior history of LBP, there are changes in the function of the TrA following surgery that could impact LBI risk.

This thesis provides support for the use of RUSI to measure TrA and LM over longer periods of time than had been previously reported. This is important because it shows the benefit of using RUSI to measure TrA and LM function before and after rehabilitation programs that often run between 4 and 12 weeks. Similar research should be carried out on a population with a greater range of characteristics including age and gender.

The method of image capture used in this study with the researcher using a two handed grip and the assistant capturing the images, was an effective way to reduce changes in transducer angle thus providing consistent images. This also allowed the examiner to focus on the patient breath and capture the image at the end of expiration. However, since this study's inception, there has been a movement from B-Mode RUSI as used in this study to M-mode RUSI allowing capture of film loops instead of a still picture. This would allow the researcher to find the muscle at its greatest thickness in the cycle and extract an image at that moment. Similarly in the clinic, patients are able to appreciate the muscle function when viewing it as it moves.

The case series research in Chapter 4 offers initial support for a reduction in TrA function following AH. However, a larger sample size would facilitate a greater ability to determine which individuals are more likely to experience reduced TrA function following surgery. All participants experienced an initial loss of TrA muscle thickness following surgery but most had rebounded between 8 and 12 weeks post-surgery. RUSI assessment of individuals at 8 weeks post surgery or just prior to returning to work could identify individuals whose core muscle function is not optimal. The impact of referral of those individuals to a core muscle rehabilitation program on future back injury rates is worth investigating.

### **5.5.1 Clinical Implications**

The questions posed in this thesis were driven by clinical experience. It was noted that there was a higher prevalence of hysterectomy in women with back injury than those without. It

was interpreted in the clinic that this was due to changes in muscle control of the spinal stabilizers leading to an increase in back injury risk. Turning to research to confirm this theory provided mixed results. There was no increase of back injury risk in the large database study but there was a difference in muscle recovery in the case series study with only some women exhibiting changes in muscle function that went past the normal incisional healing time. In light of the uniqueness of muscle pattern changes for each individual, and how these alterations might affect lumbar stability, the best approach might be to continue to collect data in the clinic during regular physiotherapy sessions in order to develop new ideas about how to group muscle adaptation observations. Information about potential covariates could be teased out. This clinical inquiry could drive more specific research questions in the ongoing investigation of post-surgical changes.

In practice, a history of previous back pain/injury and/or abdominal surgery should lead the clinician to assess if the core muscles are functioning properly. RUSI is an ideal way to gain information about these stabilizers and has been shown to be reliable over intersession periods of up to three months. There are a number of factors that contribute to injury and rehabilitation. Causes of back pain/injury are multifactorial including biologic as well as psychosocial factors. This study has focused only on the biological aspect of back pain/injury risk. However, in physiotherapy practice the focus is largely on physical changes related to injury that can be addressed with education, exercise and modalities. As noted in chapter 1, Dean's<sup>[30]</sup> Psychobiological Adaptation Model for physiotherapy practice states that the object of physiotherapy is that of optimal treatment outcome. Addition of RUSI to the assessment of patients following abdominal surgery is warranted.

## **5.6 Conclusion**

This thesis provides initial insight into the impact of abdominal surgery, specifically hysterectomy, on core muscle function. While existing research has highlighted the necessity of properly functioning deep trunk stabilizers in the prevention and treatment of low back injury, this is the first study to examine the impact of surgical insult to the abdominal fascia of the myofascial ring that contains these muscles. While the administrative database analysis showed no increased risk of abdominal hysterectomy for first back injury, the clinical study does raise the question of a potential additive effect of hysterectomy and prior low back injury in assessing risk

of back injury following surgery. Further research is needed to evaluate the impact of hysterectomy on subsequent risk of low back injury in a larger sample of women.

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## Appendix A - Abdominal Surgery Impact Scale (ASIS)

This questionnaire contains a number of statements in which your abdominal surgery might have affected you. Please circle the most appropriate number to indicate the degree to which you agree or disagree with each statement. If you are unsure about how to answer a statement, please give the best answer you can. When answering each question, please think about how you have been feeling over the past day (24 hours).

1= Strongly disagree      2=Disagree      3=Somewhat disagree      4=Neither agree nor disagree  
 5=Somewhat agree      6=Agree      7= Strongly Agree

I <b>cannot</b> climb a flight of stairs	1	2	3	4	5	6	7
I am <b>not</b> able to move easily	1	2	3	4	5	6	7
I am <b>not</b> able to stand comfortably for 5 min.	1	2	3	4	5	6	7
It is difficult for me to get dressed	1	2	3	4	5	6	7
I am unable to care for myself	1	2	3	4	5	6	7
I feel dependent on others to care for me	1	2	3	4	5	6	7
I am afraid to move because it might cause pain	1	2	3	4	5	6	7
I have severe pain in and around my abdomen	1	2	3	4	5	6	7
My incision(s) is/are causing me pain	1	2	3	4	5	6	7
I am not able to move my bowels normally							
I am uncomfortable because I am thirsty	1	2	3	4	5	6	7
I do not have a good appetite	1	2	3	4	5	6	7
I wake up feeling that sleep has not refreshed me	1	2	3	4	5	6	7
I have trouble falling asleep	1	2	3	4	5	6	7
I wake up a lot in the night	1	2	3	4	5	6	7
I have difficulty concentrating on what I am doing (conversation, watching TV, or reading)	1	2	3	4	5	6	7
I feel helpless	1	2	3	4	5	6	7
I feel anxious	1	2	3	4	5	6	7

## Appendix B - The Readiness for Return-to-Work (RRTW) Scale

### READINESS FOR RETURN-TO-WORK

The following section is about your feelings about getting ready to return to work. Keep in mind that 'back to work' could mean back to part-time or modified work.

1. Are you currently back at work?  No → *complete a1 to a13 only*  
 Yes → *complete b1 to b9 only*

<u>FOR THOSE NOT BACK AT WORK</u>	Strongly disagree	Disagree	Neither disagree nor agree	Agree	Strongly agree
a1) You don't think you will ever be able to go back to work (PC) <sup>1</sup> .	1	2	3	4	5
a2) As far as you're concerned, there is no point in thinking about returning to work (PC).	1	2	3	4	5
a3) You are actively doing things now to get back to work (PA-B).	1	2	3	4	5
a4) Physically, you are starting to feel ready to go back to work (PA-S).	1	2	3	4	5
a5) You have been increasing your activities at home in order to build up your strength to go back to work (PA-B).	1	2	3	4	5
a6) You are getting help from others to return to work (PA-B).	1	2	3	4	5
a7) You are not ready to go back to work (PA-S).	1	2	3	4	5
a8) You have found strategies to make your work manageable so you can return to work (PA-S).	1	2	3	4	5
a9) You have been wondering if there is something you could do to return to work (C).	1	2	3	4	5
a10) You have a date for your first day back at work (PA-S).	1	2	3	4	5
a11) You wish you had more ideas about how to get back to work (C).	1	2	3	4	5
a12) You would like to have some advice about how to go back to work (C).	1	2	3	4	5
a13) As far as you are concerned, you don't need to go back to work ever (PC).	1	2	3	4	5

<sup>1</sup> The letters in parentheses correspond to the stage to which each item belongs to based on a factor analysis (see Franche R-L et al., 2007 for details). The acronyms are: Precontemplation (PC), Contemplation (C), Prepared for Action—Self-evaluative (PA-S), Prepared for Action—Behavioural (PA-B), Uncertain Maintenance (UM), and Proactive Maintenance (PM).

<b>FOR THOSE WHO ARE CURRENTLY BACK AT WORK</b>	<b>Strongly disagree</b>	<b>Disagree</b>	<b>Neither disagree nor agree</b>	<b>Agree</b>	<b>Strongly agree</b>
b1) You are doing everything you can to stay at work <b>(PM)</b> .	1	2	3	4	5
b2) You have learned different ways to cope with your pain so that you can stay at work <b>(PM)</b> .	1	2	3	4	5
b3) You are taking steps to prevent having to go off work again due to your injury <b>(PM)</b> .	1	2	3	4	5
b4) You have found strategies to make your work manageable so you can stay at work <b>(PM)</b> .	1	2	3	4	5
b5) You are back at work but not sure you can keep up the effort <b>(UM)</b> .	1	2	3	4	5
b6) You worry about having to stop working again due to your injury <b>(UM)</b> .	1	2	3	4	5
b7) You still find yourself struggling to stay at work due to the effects of your injury <b>(UM)</b> .	1	2	3	4	5
b8) You are back at work and it is going well <b>(UM)</b> .	1	2	3	4	5
b9) You feel you may need help in order to stay at work <b>(UM)</b> .	1	2	3	4	5

<b>SCALE INFORMATION</b>	
<i>Number of Items:</i>	Scored Scale: 13 items for those not working, 9 items for those working.
<i>Item Scaling and Scoring:</i>	<p>There are five response options. Each item is scored using the following scale:  <i>For each item, participants are asked to indicate how much they disagree or agree with each statement as it applies to them at the time of interview.</i></p> <p>1 - Strongly disagree            2 -            3 -            4 -            5- Strongly agree</p> <p>Each stage of Readiness for Change is scored by taking the mean of all items creating that factor. A higher score indicates a higher level of what is measured - higher scores on <i>Pre-contemplation</i> indicate higher levels of Pre-contemplation beliefs, while higher scores of <i>Prepared for Action</i> indicate higher levels of Preparation for action beliefs.</p> <p><u>Item scale is reversed:</u>            a7) You are not ready to go back to work.            b8) You are back at work and it is going well.</p>
<i>Reference:</i>	Franché R-L, Corbière M, Lee H, Breslin C, Hepburn G. The Readiness for Return-To-Work (RRTW) scale: Development and validation of a self-report staging scale in lost-time claimants with musculoskeletal disorders. <i>Journal of Occupational Rehabilitation</i> 2007 Sep; 17(3):450-472.

## Appendix C - Questionnaire for Grading the Severity of Chronic Pain

### Questionnaire of von Korff et al for Grading the Severity of Chronic Pain

Overview: The severity of chronic pain can be graded based on its characteristics and its impact on a person's activities.

Questions [text slightly modified from Appendix page 147]

(1) How would you rate your pain on a 0-10 scale at the present time (right now)? [Pain Right Now]

- responses 0 to 10
- 0 = no pain
- 10 = pain as bad as it could be

(2) During the past 6 months how intense was your worst pain? [Worst Pain]

- responses 0 to 10
- 0 = no pain
- 10 = pain as bad as it could be

(3) During the past 6 months on the average how intense was your pain? (That is your usual pain at times you were experiencing pain.) [Average Pain]

- responses 0 to 10
- 0 = no pain
- 10 = pain as bad as it could be

(4) About how many days in the past 6 months have you been kept from your usual activities (work school or housework) because of your pain? [Disability Days]

- response the total number of days disabled
- points assigned below

(5) In the past 6 months how much has the pain interfered with your daily activities? [Daily Activities]

- responses 0 to 10
- 0 = no interference
- 10 = unable to carry on any activities

(6) In the past 6 months how much has the pain changed your ability to take part in recreational social and family activities? [Social Activities]

- responses 0 to 10

- 0 = no change
- 10 = extreme change

(7) In the past 6 months how much has the pain changed your ability to work (including housework)? [Work Activities]

- responses 0 to 10
- 0 = no change
- 10 = extreme change

characteristic pain intensity =  $((\text{response question 1}) + (\text{response question 2}) + (\text{response question 3})) / 3 * 10$

disability score =  $((\text{response question 5}) + (\text{response question 6}) + (\text{response question 7})) / 3 * 10$

disability points = (points for disability days) + (points for disability score)

Parameter	Finding	Points
disability days from question 4	0 - 6 days	0
	7 - 14 days	1
	15 - 30 days	2
	>= 31 days	3
disability score (above)	0 - 29	0
	30 - 49	1
	40 - 69	2
	>= 70	3

#### Interpretation

Findings	Type	Grade
no pain problems for the prior 6 months	pain free	0
characteristic pain intensity < 50 disability points < 3	low disability low intensity	I
characteristic pain intensity >= 50 disability points < 3	low disability high intensity	II
disability points 3 or 4	high disability moderately limiting	III
disability points 5 or 6	high disability severely limiting	IV

## **Appendix D - Instructions to Participants**

### **Sequence 1 – TrA Hooklying Rest to ADIM**

- Fully relax your belly – Capture resting TrA
  - Full relaxation was confirmed on ultrasound
- Take a breath in and exhale fully
  
- Hold the breath out
  - Don't tense up
- Gently pull in the lower abdomen - Capture ADIM
- Fully relax your belly
  - Full relaxation was confirmed on ultrasound

Visit 1 - After 3-5 practices – Capture images in sequence three times

Subsequent visits – Verbal reminder of the instructions with 1 practice round.

### **Sequence 2 – TrA Supine lying to ASLR**

- Fully relax your belly – Capture resting TrA
  - Full relaxation was confirmed on ultrasound
- Take a breath in and exhale fully
  
- Hold the breath out
  - Don't tense up
- Lift your leg to touch your shin to the ruler (20 cm) (image capture)
  - Lower leg
- Fully relax your belly
  - Full relaxation was confirmed on ultrasound

Visit 1 - After 2-3 practices– Capture images in sequence three times

Subsequent visits – Verbal reminder of the instructions with 1 practice round

### **Sequence 3 – PFM - Kegel contraction in hooklying with legs on bolster**

- Fully relax your belly and pelvic floor – Capture resting PFM
  - Relaxation confirmed on ultrasound
- Take a breath in and exhale fully

- Hold the breath out
  - Don't tense up
- Perform a Kegel exercise (most confirmed that they knew how to do this) – (image capture)
  - Cue to tighten the rear passage and pull the contraction forward into the vagina if they did not know how
- Fully relax your belly and pelvic floor
  - Full relaxation was confirmed on ultrasound

Visit 1 - After 2-3 practices– Capture images in sequence three times

Subsequent visits – Verbal reminder of the instructions with 1 practice round

#### **Sequence 4 – PFM - ASLR from hooklying with legs on bolster**

- Fully relax your belly and PFM – Capture resting PFM
  - Full relaxation was confirmed on ultrasound
- Take a breath in and exhale fully
  
- Hold the breath out
  - Don't tense up
- Lift your leg about 20 cm off bolster (image capture)
  - Lower leg
- Fully relax your belly and PFM
  - Full relaxation was confirmed on ultrasound

Visit 1 - After 2-3 practices– Capture images in sequence three times

Visit 1 - After 2-3 practices– Capture images in sequence three times

Subsequent visits – Verbal reminder of the instructions with 1 practice round

#### **Sequence 5 – LM - Prone Lying rest over pillows to CAL**

- Fully relax your belly and back – Capture resting LM
  - Full relaxation was confirmed on ultrasound
- Take a breath in and exhale fully
  
- Hold the breath out
  - Don't tense up
- Lift your arm with weight about 5 cm off plinth (image capture)
  - Lower arm
- Fully relax your belly and back
  - Full relaxation was confirmed on ultrasound

Visit 1 - After 2-3 practices- Capture images in sequence three times

Subsequent visits – Verbal reminder of the instructions with 1 practice round