GLUTEUS MEDIUS MUSCLE ACTIVATION IN CHRONIC LOW BACK PAIN PATIENTS DURING SINGLE LEG STANCE

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Gluteus medius muscle activation in chronic low back pain patients during single leg stance

By

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Abstract

Lumbopelvic dynamic stability is often evaluated by clinicians using the single leg stance (SLS) test when assessing patients with chronic low back pain (CLBP). One of the main stabilizing muscles that is thought to be dysfunctional when there is an inability to maintain lumbopelvic stability during SLS is the gluteus medius. Clinicians often note dysfunction of this hip muscle in patients with CLBP and treat these apparent muscle imbalances. However, there is insufficient evidence to support these clinical findings and the treatment approach. There is evidence of gluteus maximus, abdominal and back muscles contribution to lumbopelvic stability. These muscles contract in anticipation to movement to maintain equilibrium and stability of the spine. With CLBP, the deep stabilizing spinal muscles appear to become weak or have delayed recruitment and the superficial stabilizing muscles appear to become overactive. Other evidence supports the altered recruitment of the agonists/ antagonists and superficial/ deep muscle groups with CLBP compared to their healthy counterparts. As CLBP is heterogeneous in nature, a diverse pattern of motor recruitment has also been found in the gluteus maximus from weakness, poor endurance, and delay in recruitment to over activation. However, there are very few studies that examine the gluteus medius function and its relation to LBP. Weak hip abductors and co-ordination of right and left gluteus medius have been associated with the development of LBP in healthy subjects. However, there are no studies that examine gluteus medius recruitment and strength in a CLBP population.

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LIST OF ABBREVIATIONS

Ag-AgCl- silver-silver chloride
ASIS- anterior superior iliac spine
CLBP- chronic low back pain
CNS- central nervous system
dB- decibel
EMG- electromyography
F- female
Gmed- gluteus medius
Gmax- gluteus maximus
Hz- hertz
Kg- kilograms
L- left
LBP- low back pain
M- male
mm- millimeter
ms - millisecond
MVC- maximal voluntary contraction
PSIS- posterior superior iliac spine
R- right
RMS- root mean square
ROM- range of motion
SD- standard deviation
SE- standard error
SLS- single leg stance
V- volt
VAS- visual analogue scale
Ω -ohm

1. INTRODUCTION

1.0 Overview

Low back pain (LBP) is the most common chronic condition in Canada accounting for 25% of all chronic diseases and over a life time, 4 out 5 Canadians will experience at least one episode of LBP (Murphy et at., 2006). The direct and indirect economic costs of LBP are enormous, between visits to health care professionals, medication, insurance costs, hospitalization, lost wages, sick leave and reduced productivity. The indirect economic costs of employee absenteeism and disability far outweigh the direct medical cost of treating LBP (van Tulder, 2002; Coyte et al., 1998). Maeztel and Li (2002) report estimated annual losses of 149 million work-days due to LBP in the United States with 101.8 million of these days due to work related LBP. Given the financial and human costs of LBP, a large amount of research has been devoted to understanding the nature of LBP.

Diagnosing and treating LBP is very complex and despite the multitude of literature, it remains poorly understood. In fact, a specific cause of LBP such as disc herniation only accounts for 10% to 15% of all diagnoses (vanTulder et al., 2002). The majority of patients who present with LBP are classified as having non-specific LBP as there is no one identifiable cause. There are recognized risk factors that are linked with its development; such as sedentary lifestyle, weak trunk musculature, poor posture, obesity, smoking and heavy or incorrect lifting (Murphy et al., 2006). Improperly functioning muscles that support the trunk and pelvic girdle are thought to be one of the main contributors to LBP when they no longer provide support and stability to the spine (Panjabi, 1992; Hodges and Richardson, 1996; Hodges and Richardson, 1998; Nadler et al., 2002; Hungerford et al., 2003; Nelson-Wong et al. 2008).

One test that clinicians use to assess the ability of the lumbopelvic muscles to provide dynamic stability to the spine is single leg stance (SLS). The SLS test can be subdivided into Trendelenburg and Stork or Gillett tests. Patients may show lateral pelvis hiking or adduction on the stance side (Trendelenburg sign) with SLS or during gait indicating in part weakness of the gluteus medius (Hardcastle & Nade, 1985; Lee, 1997; Dorman 1997; Sahrmann 2002; Roussel et al., 2007; Tidstrand & Horneij, 2009). An anterior innominate movement during SLS indicates gluteus maximus dysfunction or sacroiliac dysfunction (Stork or Gillett test) (Hungerford et al., 2003; Hungerford et al., 2007; Potter & Rothstein, 1985). The SLS test has been shown to have high inter-rater and test-retest reliability in the chronic LBP (CLBP) group (Roussel et al., 2007; Tidstrand & Horneij, 2009). The inability to control the pelvis during SLS is thought to be due to weakness or poor motor control of the abdominals, deep back musculature and the glutei. To treat these deficits therapeutic exercises are prescribed accordingly. There are a multitude of studies that note motor control deficits of the deep abdominal and back muscles and gluteus maximus in the CLBP patient (Hodges & Richardson, 1996; Hodges & Richardson, 1998; Bruno and Bagust, 2007; Borghuis et al., 2008). One group showed that there were motor control deficits of the gluteus medius in healthy subjects who develop LBP during a prolonged standing task (Nelson-Wong et al., 2008; Nelson-Wong & Callaghan, 2009a; Nelson-Wong et al., 2009b). However, there is insufficient evidence to support the clinical finding that there are motor control deficits of the gluteus medius in the non-specific CLBP group.

1.1 Purpose of the study

This study aims to determine the relationship between altered gluteal muscle activation and CLBP. Our specific objectives are:

1) To measure the onset in the gluteal muscles (gluteus medius and gluteus maximus) in subjects with CLBP compared to a gender and age matched control group during single leg stance test.
2) To determine if a positive clinical test of single leg stance is associated with timing delays in the gluteal muscles.

1.2 Hypotheses

It was hypothesized that:

1) The LBP will have a delay in the gluteus medius activation compared to the control group.
2) There will be a greater amount of positive SLS tests in the LBP group compared to controls.
3) The gluteal muscles will be weaker in the LBP group compared to the control group.

2. Review of the Literature

2.0 Gluteus Medius Anatomy and Function

Gluteus medius is traditionally described as a hip abductor when the limb is non-weight bearing. This broad pennate muscle originates from the outer surface of the ala of the ilium and inserts into the greater trochanter. The anterior fibers of the gluteus medius contributes to hip internal rotation while the posterior fibers along with the gluteus maximus contribute to hip external rotation. During weight-bearing, the vertical orientated anterior and middle portions of the gluteus medius were found to be most active during the SLS phase of gait (Lyons et al., 1983; Soderberg & Distak, 1978; Gottschalk et al., 1989; Al-Hayani, 2009) providing a stable lumbopelvic region during single limb support.

The gluteus medius, like the multifidus is a uni-articular muscle that is comprised of mostly type I fibers, whose primary function is thought to be stabilization rather than movement (Richardson et al.1999; Gibbons & Comerford, 2001). Some authors propose the gluteus medius' prime function to be a hip and pelvic stabilizer rather than just a hip abductor (Gottschalk et al., 1989; Norris, 1995; Richardson et al., 1999; Gibbons & Comerford, 2001; Kibler et al., 2006; Borghuis et al., 2008). The fibers of the posterior portion of the gluteus medius are horizontal and run parallel to the neck of the femur (Gottschalk et al., 1989; Al-Hayani, 2009). Contraction of the posterior fibers first occurs at heel strike phase of the gait cycle and continues until toe off. It is thought that this posterior portion approximates the head of the femur into the acetabulum to maintain joint congruency during movement in a similar fashion to the supraspinatus in the glenohumeral joint (Gottschalk et al., 1989; Al-Hayani, 2009). Reverse origin-insertion contraction of the gluteus medius during closed kinetic chain activities maintains a level pelvis to create a stable base for contralateral lower limb movement and contributes to maintaining a neutral lumbar spine. When the gluteus medius is deficient, it is proposed to be one of the contributing factors to the inability to maintain a level pelvis during weight bearing activities (Sahrmann, 2002; Lee, 1997; Hardcastle, 1985; Roussel et al., 2007; Tidstrad & Horneij, 2009) which can be related to back or lower extremity dysfunction due to excessive pelvic motion. However, recent studies have found only a weak correlation between hip abductor weakness and lateral pelvic drop during SLS in healthy and LBP subjects (DiMattia et al., 2005; Marshall et al., 2010).

2.1 Motor Control and the Spine

Traditional clinical manual muscle testing on the CLBP population does not always elicit weakness but there can be apparent loss of functional lumbopelvic stability. The spine and pelvis maintains its functional stability by a complex interaction between the passive inert structures, active muscular system and neural control (Panjabi, 1992; Comerford & Mottram, 2001; Borghuis et al., 2008). This model of stability is true for all joints but it is particularly important in the spine as without the support of the muscular system mediated by the neural system, the spine would buckle under a load of only 2 Kg (Morris et al., 1961). In the spine, a properly functioning muscular system requires only 5-10% of the abdominals and 25% of back muscles' maximal voluntary contraction to provide maximal joint stiffness and functional stability (Cholewicki 1999; Cresswell et al., 1994). Insufficient muscle function leads to excess stress on the spinal joints and ligaments that may lead to pain and dysfunction (Hodges & Richardson, 1996; Panjabi, 1992; Hodges et al., 2003). There have been many studies that examine the extent of muscle activation or strength in the muscles that support the spine and pelvis with inconsistent results. Motor control studies that examine the onset of muscle contraction or the coordination between agonist and antagonist may be better suited to assess muscle dysfunction associated with CLBP.

The deep local stabilizing muscles of the spine are described as originating and inserting within the spine, cross one to 2 joints and have a high concentration of muscle spindles for proprioceptive feedback to maintain spinal stability (Bergmark, 1989; Comerford & Mottram, 2001; Gibbons & Comerford, 2001; Hammill et al., 2008; Borghuis et al., 2008). Examining the temporal analysis of deep lumbopelvic muscles that contribute to spinal stabilization has shown that the onset of muscle contraction occurs prior to external perturbation to the spine in the healthy population. These muscles, such as the transversus abdominus, multifidus and internal oblique seem to function to stabilize the spine in multiple directions. External perturbation to the spine created by rapid movement of the upper or lower limb or the application of external force to the trunk have shown that the transversus abdominus contracts in anticipation to prevent movement of the spine and that this muscle invariably contracts before all other trunk muscles (Cresswell et al.,1994; Hodges & Richardson, 1996; Hodges & Richardson, 1997; Hodges & Richardson, 1998; Hodges et al., 1999; Moseley et al., 2002; Hodges et al., 2003; Tsao et al., 2008). The deep stabilizing muscles are close to the axis of rotation producing lumbopelvic stabilization in multi-directions whereas the superficial trunk muscles contribute to spinal stabilization with specific directions.

The global muscle system is described as the larger, more superficial muscles that cross many joints and whose function is to transfer load between the thorax to the pelvis (Bergmark, 1989; Comerford & Mottram, 2001; Gibbons & Comerford, 2001; Hammill et al., 2008; Borghuis et al., 2008). Expanding on Rood's model of stabilizer and mobilizer muscle classification, Comerford and Mottram (2001) subdivide the local and global system into local stabilizers, global stabilizers and global mobilizers. The global stabilizing muscles also provide stabilization to the spine but in a different manner than the local muscles. Stability provided to the spine by the global stabilizing muscles is direction specific; the antagonist muscle group controls external perturbations with eccentric contractions. Direction specific preparatory activation has been shown with global muscle system. The abdominals anticipated movement during rapid shoulder extension, the erector spinae during rapid shoulder flexion (Aruin & Latash, 1995; Hodges & Richardson, 1996; Hodges et al., 1999) and the external obliques with oblique spinal perturbations (Santos & Aruin, 2008). However, with rapid lower extremity movement, all of the abdominals and erector spine have anticipatory activation with hip flexion, abduction and extension regardless of the direction of limb movement (Hodges & Richardson, 1997; Hodges & Richardson, 1998). These non-direction specific preparatory contractions may be due to the higher perturbation demand caused by the heavier lower limb movement. Likewise, when a 5 kg weight was applied to the trunk ventrally and dorsally, all of the abdominal and erector spinae muscles contracted in anticipation to both perturbation forces (Cresswell et al., 1994). Conversely, Santos and Aruin (2008) found that the rectus abdominus did not anticipate movement created by manual resistance of a swinging pendulum from various angles. As the local stabilizing muscles are thought to always contract in anticipation an external perturbation regardless of the load in the healthy population, the global stabilization muscles may respond to direction specific loads and when the demand of the external force is great enough regardless of the direction (Ebenbichler et al., 2001).

This anticipatory or feedforward contraction of muscles to create stability appears to be mediated by the central nervous system (CNS) in response to limb movements or external perturbations that displace the body's center of gravity (Bouisset & Zattara, 1981; Hodges & Richardson, 1996; Ebenbichler et al., 2001; Borghuis et al., 2008; Tsao et al., 2008). The CNS may mediate two parallel systems that generate voluntary contractions simultaneously with postural stabilizing contractions to maintain spinal equilibrium and stability (Ebenbichler et al., 2001). One system initiates the voluntary contraction while the second system initiates contraction of the stability muscles to control the perturbation created by the voluntary movement. The deep local stabilizing muscles that do not produce movement of the spine such as the transversus abdominus and deep multifidus are thought to function in this way (Hodges & Richardson, 1999; Ebenbichler et al., 2001; Gibbons & Comerford, 2001; Comerford & Mottram, 2001; Moseley et al., 2002). Conversely, there may be a hierarchical system where the reaction to perturbation is fixed (Hodges & Richardson, 1999; Ebenbichler et al., 2001). Global stabilizing postural muscles that are direction specific in their anticipatory functions may follow this theory in which they contract in anticipation depending on the direction of movement or amount of stability required. The anticipatory contraction to pre-stiffen joints prior to movement is not unique to the spine and has been shown in peripheral joints as well.

The contraction of the upper trapezius, biceps and rotator cuff of the shoulder and the vastus medialis of the knee (Comerford & Mottram, 2001; Richardson et al., 1999) have been shown to anticipate movement in healthy subjects. More proximally, anticipatory contractions of the glutei are thought to be direction specific global stabilizers of the lumbopelvic region.

There have been limited studies that examine the temporal parameters of the glutei. Bouisset & Zattara (1981) found that the gluteus maximus contracted before the deltoid during rapid finger pointing in the healthy population. Likewise, Bruno & Bagust (2007) found the gluteus maximus to contract prior to prone hip extension. However, Guimaraes et al. (2010) found the gluteus maximus to contract after the erector spinae and semitendinosus during prone hip extension. The gluteus medius has also been found to be anticipatory with unilateral perturbations to the spine on an oblique and lateral angle and bilaterally with resistance in the sagittal plane (Santos & Aurin, 2008). Rogers & Pai (1990) noted the gluteus medius to be anticipatory during SLS during self-paced and fast speeds but not during a slower speed. On the contrary, Hungerford et al. (2003) found that neither the gluteus maximus nor the gluteus medius were anticipatory to movement during SLS. The speed during SLS was not noted in this study, which could account for the conflicting findings as with slower speeds there may not be enough perturbation to the spine to trigger preparatory contraction.

2.2 LBP and Muscle Dysfunction

Changes in the motor control of the stabilizing lumbopelvic muscles have been associated with non-specific LBP. In subjects with chronic non-specific LBP the transversus abdominus and internal obliques have a delayed contraction compared to control subjects during rapid arm or leg movement in various directions (Hodges & Richardson, 1996; Hodges & Richardson, 1998, Tsao et al., 2008). Delays in transversus abdominus and internal obliques contraction have also been associated with specific sacroiliac dysfunction during SLS (Hungerford et al., 2003). Clinically induced acute LBP produced temporal delays of the transversus abdominus and deep multifidus muscles (Hodges et al., 2003) indicating that these changes may not be compensatory but a direct reaction to localized lumbar pain. Altered muscle recruitment is not only found in the periphery but in the CNS. Tsao et al. (2008) noted that the CLBP group who had a delay in the transversus abdominus contraction also displayed altered cortical mapping of the transversus abdominus in the motor cortex. The authors theorize that patients with CLBP have reorganization of postural muscle representation in the CNS not just in the periphery.

The superficial global stabilizing muscles have noted temporal and recruitment dysfunctions with certain directions of movement or functional tasks. The rectus abdominus, internal oblique and erector spinae were delayed in a CLBP group during rapid shoulder (Hodges & Richardson, 1996) or hip (Hodges & Richardson, 1998) flexion compared to a healthy group. However, only the erector spinae was delayed with rapid shoulder or hip extension in the same CLBP groups. Radebold et al. (2001) found that only the antagonist muscle group was delayed in contracting while the agonist was delayed in relaxing during quick trunk flexion and extension in a CLBP group. Chronic LBP has also been linked with early or over recruitment of certain global muscles. Ferguson et al. (2004) found that the erector spinae in a CLBP group contracted earlier and longer during functional lifting tasks compared to matched healthy subjects. This may indicate altered programming of motor recruitment patterns depending on the type of muscle involved and the demand of the work load of the task.

The deep stabilizing muscles are thought to be delayed or have reduced activation with pain and dysfunction, while the superficial global stabilizing or mobilizing groups tend to be over-recruited (Norris, 1997; O'Sullivan et al., 1997; Gibbons & Comerford, 2001; Comerford & Mottram, 2001). In addition to altered temporal parameters, changes in recruitment of agonist and antagonist muscles and activation ratios of lumbopelvic muscle groups have also been linked with the CLBP population. Nouwen et al. (1987) found greater activation of the erector spinae with end range of seated lumbar flexion with CLBP patient while the external oblique had less activation. vanDieen et al. (2003) also found the CLBP group had greater recruitment of the antagonist muscle group over the agonist group compared to the healthy group with seated trunk flexion and extension. In concurrence, Lariviere et al. (2000) found the erector spinae were overactive with repeated trunk movements in a LBP group however, they did not find any difference in the obliques or the rectus abdominus activation.

O'Sullivan et al. (1997) and Silfies et al. (2006) noted that the ratio of lower abdominal activity (internal obliques) was less than the rectus abdominus activity with CLBP groups. Likewise, Ng et al. (2002) found that the external oblique was over-active compared to the multifidus in the CLBP group during spinal movement. During gait, the erector spinae had noted early and greater activation compared to the pain free subjects (Lammoth et al., 2006; Vogt et al., 2003). vanDieen et al. (2003) did not find this same over-activation of the rectus abdominus over internal obliques with CLBP. Although there are varying results of muscle contraction in relation to CLBP, it is clear that there is altered contraction of the muscles that support the spine.

2.3 LBP and Hip/ Pelvic Dysfunction

Due to the hip joints' proximity to the lumbar spine, clinical examination of hip range of motion (ROM), strength and function are routinely performed when assessing LBP which have led to many studies examining these relationships to LBP. Hip-Spine Syndrome has been described when patients presents with non-specific LBP and conjunct hip dysfunction or osteoarthritis (Offierski & MacNab, 1983; Rieman et al., 2009). Vogt et al. (2003) found reduced sagittal hip ROM during the gait cycle with CLBP by more than 12 degrees compared to healthy subjects. Asymmetrical hip rotation has also been associated with LBP as reduced hip joint movement can result in increased mechanical forces in the lumbar spine contributing to LBP. Hip internal rotation that is significantly less than external rotation was found in male subjects with CLBP (Ellison et al., 1990; Mellin, 1998) while female subjects with CLBP showed more prominent loss of external rotation (Ellison et al., 1990). However, Gombatto et al. (2006) found that men with CLBP had reduced hip external rotation and increased lumbopelvic movement. Chestworth et al. (1994) and van Dillen et al. (2008) did not find any gender differences in their studies but they did find that the LBP group had significantly less overall hip rotation than the control group. LBP groups also demonstrated asymmetry between right and left hip ROM compared to matched healthy groups (vanDillen et al., 2008). Due to the heterogeneous nature of LBP, various asymmetries of hip ROM and possible altered hip muscle recruitment could be associated with LBP.

Muscles that act on the hip joint and link the hip to the pelvis and spine have been studied in association with LBP with varying results. A LBP group with sacroiliac dysfunction had a delay of onset of the gluteus maximus during SLS (Hungerford et al., 2003). Bruno and Bagust (2007) also found a significant delay in the gluteus maximus with prone hip extension in a CLBP while the erector spinae and hamstrings did not have any alteration in temporal parameters. In a similar study, Guimaraes et al. (2010) did not find any delay in the gluteus maximus during prone hip extension in subjects with CLBP compared to the onset of the semitendinosus and erector spinae. The extent of gluteus maximus activation was less variable during level walking, hill walking and stair climbing in a LBP group where as the healthy group were able to alter the amount of gluteus maximus contraction to match the demand of the activity (Himmelreich et al., 2008). Likewise, with a CLBP group Pirouzi et al. (2006) found over-recruitment of the gluteus maximus during isometric lumbar rotation and Vogt et al. (2003) found early and prolonged activation of the gluteus maximus during gait.

However, other research groups have found gluteus maximus to have greater fatigue and reduced recruitment during lumbar movement in a CLBP group compared to healthy controls. Kankaanpaa et al. (1998) and McKeon et al.

(2006) found that the gluteus maximus had reduced torque production and greater fatigue with resisted lumbar extension. Although considered a hip extensor, the gluteus maximus was also found to be a greater contributor to isometric lumbar extension fatigue than the erector spinae in healthy subjects during the Sorensen and Modified Sorensen test (Champagne et al. 2008). The gluteus maximus of a CLBP group showed a delay with lumbar flexion, early recruitment during lumbar extension and reduced endurance in both sagittal spinal movements compared to the erector spinae and their healthy counterparts (Leinonen et al., 2000). In addition to altered recruitment patterns, decreased gluteus maximus strength may also be associated with LBP. Nadler et al. (2001) found that college athletes that had asymmetrical gluteus maximus strength had a greater occurrence of LBP development during the academic year. This variation in the recruitment of the gluteus maximus associated with LBP may be a result of the various methodologies of investigation and an indication of the diverse motor recruitment patterns of the superficial global muscles that appears to occur in the LBP population.

Clinician text books note and clinical examinations suspect deficits in the gluteus medius and specific exercises are prescribed to treat the CLBP population accordingly (Lee, 1997; Sahrmann, 2002). However, there are very few studies that examine gluteus medius dysfunction and its possible relationship to LBP. Nadler et al. (2001 & 2002) compared the strength of the right and left hip abductors and extensors in college athletes over several academic years. They found that those female college athletes that required treatment for non-traumatic LBP had significantly reduced left hip abductor strength compared to the right (Nadler et al., 2002). However, in their earlier study they did not find any predictive value for hip abductor weakness (Nadler et al., 2001). Asymmetrical hip abductor or extensor strength was not predictive for LBP in male athletes in either study. A recent study found a significant difference of hip abductor strength in CLBP subjects compared to healthy subjects (Kendall et al., 2010). Although both of these groups consisted of male and female subjects, 80% of each group was females. Gender differences in hip muscle strength may be due to the increased Q-angle in females compared to males. The strength of the hip muscles in these studies was measured with a hand-held dynamometer which does not account for motor control patterns of muscle recruitment.

Nelson-Wong et al. (2008 & 2009b) and Nelson-Wong and Callaghan (2009) studied the co-ordination of spinal and hip muscles during a low level simulated occupational standing task with a healthy subject group. Prior to the standing task, the subjects underwent a typical physical therapy spinal exam and found that the only test that was predictive for the subjects developing LBP was their ability to control the pelvis during side lying hip abduction. During the standing task, independent examiners were able to predict which subjects developed LBP by the pattern of right and left gluteus medius recruitment. They found a significant difference in subjects who developed LBP throughout the standing task as they had co-activation of the right and left gluteus medius as opposed to a reciprocal synergistic contraction in the group that did not develop LBP. There was also a significant difference in the coordination of the left external oblique and left erector spinae in this group. However, there was no significant difference in the co-ordination between the lumbar and thoracic erector spinae, nor the rectus abdominus and erector spinae that was noted previously with the CLBP population (Nouwen et al., 1987; Lariviere et al., 2000; Silfies et al., 2006). Marshall et al. (2011) also found altered recruitment of the gluteus medius when they reproduced the 2 hour standing activity methodology. The authors purposed that during low level occupational standing activities altered coordination between the hip muscles would be a greater predictor for those employees who are at higher risk to developing LBP than coordination of the spinal muscles.

A motor control study of the lumbopelvic muscles in a LBP group diagnosed with sacroiliac joint dysfunction did reveal delay in deep abdominal muscles and gluteus maximus and early activation of the hamstrings on the affected side (Hungerford et al., 2003). Unlike an earlier study that noted preparatory activation of the gluteus medius during SLS (Rogers & Pai, 1990), there was no noted gluteus medius contraction prior to movement in either healthy or LBP group in this study. The gluteus medius is theorized to contribute to increased force closure of the sacroiliac joint to enhance joint stability (Dorman, 1997); however, there did not appear to be any gluteus medius motor recruitment deficits on the affected side of subjects with this sacroiliac joint dysfunction group. Perhaps the SLS activity or the speed of the SLS in this study was insufficient to perturb the spine and pelvis to pre-activate the gluteus medius. The SLS test can be used in many ways clinically to assess a patients' function.

2.4 Single Leg Stance

The single leg stance test is a very functional test used by clinicians to assess the co-ordination, strength and endurance of the lumbopelvic and lower extremity muscles. A negative SLS is noted by the ability to maintain a level pelvis for 20-30 seconds without any pelvic or spinal rotation or femoral adduction or rotation (Hardcastle & Nade, 1985; Lee, 1997; Sahrmann, 2002; Roussel et al., 2007; Tidstrand & Horneij, 2009). Although it is recognized that it requires a coordinated effort of the lumbopelvic and lower extremity muscles and the neurological system to maintain a single leg stance, movement dysfunction during this test leads to the assumption of gluteus medius weakness (Hardcastle & Nade, 1985; Lee, 1997). However, there are no studies that confirm that altered gluteus medius muscle recruitment, activation or strength is related to a positive SLS test. Schmitz et al. (2002) found that the gluteus medius had the greatest extent of electromyography (EMG) activity when the stance limb was at 0^0 of hip and knee extension in healthy subjects when compared to various degrees of hip knee and flexion. The gluteus medius anticipatory recruitment before the initiation of movement when transferring from double to single limb support during the SLS test indicates preparatory stabilization function of this muscle (Rogers & Pai, 1990).

Clinicians routinely use the functional SLS test when assessing the CLBP population. Maintenance of spinal and pelvic stability during single limb support activities such as walking, running and ambulating stairs depends on muscular control (Borghuis et al., 2008; Livengood et al., 2004). Therefore, any inability to maintain lumbopelvic stability during SLS is an indication of poor muscular control. An unstable pelvis during single limb support can lead to excessive lumbar movement during daily activities, leading to LBP. The SLS test has been shown to have high inter-rater and test-retest reliability in patients with CLBP (Roussel et al., 2007; Tidstrand & Horneij, 2009). The SLS test has been utilized as a key indicator for clinical outcome and predictor of long term recovery after surgery for lumbar disc herniation. One study compared several clinical functional tests in pre and post lumbar surgery and found that a positive SLS test at 6 weeks post surgery was predictive for increased pain at 1 year after surgery compared to those patients who had a negative test at 6 weeks (Millisdotter et al., 2003). However, these studies do not address the muscle dysfunction that may be involved in this test. Two studies have found a weak positive correlation of weak hip abductors and an inability to maintain a level pelvis (DiMattia et al., 2005 and Kendall et al., 2010). Determining if indeed the gluteus medius is at fault, would improve evidence based practice for clinicians.

2.5 Conclusion

There is building evidence that traditional classification of muscles into flexors-extensor or abductors-adductors, for example are too simple to explain the complex neuromuscular interaction involved in human movement (Aruin & Latash, 1995). The gluteus medius is now theorized to be primarily a lumbopelvic stabilizer rather than a hip mover. As a result, poor lumbopelvic stability during the SLS test is thought to be in part due to a dysfunctional gluteus medius. The evidence to support this clinical practice unfortunately is not available in the literature. Lack of spinal stability due to altered recruitment patterns, weakness and poor endurance of the gluteus maximus, abdominal and back musculature have all been associated with CLBP. The studies that examine the gluteus medius and its relation to LBP are very limited. The SLS test is recognized as a reliable test for the CLBP population but the muscle dysfunction related to a positive test are not known. Future studies that examine gluteus medius recruitment patterns and strength during a SLS test in the CLBP group will aid in improving evidence based practice for treating this population.

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Gluteus medius muscle activation in chronic low back pain patients during single leg stance

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Running Title: gluteal activation in low back pain

3.0 Abstract

Purpose: To compare the strength, timing and activation of the gluteus medius in a chronic low back pain (CLBP) group compared to controls during single leg stance (SLS). Spinal stabilizer muscle timing delays and global muscle weakness and altered activation have been associated with CLBP. However, the gluteus medius activation pattern is unknown in CLBP population.
Methods: Twenty-two male and female subjects with CLBP and 21 age and gender matched healthy subjects were studied. Maximum bilateral hip abductor and extensor strength was measured using a handheld dynamometer. Electromyography of the gluteus medius and maximus were recorded during SLS and manual muscle testing.
Results: The mean hip strength of each gluteal muscle in the low back pain group was lower than the control group, but only significant in the right gluteus medius (t= 2.58, $p<0.05$). No timing delay was found in the gluteal muscles of the CLBP group compared to the control. There was a significant difference between the right (t= 2.73, p=0.007) and left (t=2.08, $p<0.05$) gluteus medius extent of activation between the two groups.
Conclusion: Gluteal muscle strength impairment was demonstrated in a CLBP group. There are activation changes in the gluteal muscles of the CLBP group but they appear to be similar to other global muscles. These findings support the inclusion of gluteal muscle strength assessment in the chronic low back pain patient.

Key Words: gluteal, gluteus maximus, low back pain, stability, motor control

3.1 Introduction

Non-specific low back pain (LBP) that accounts for 80-85% of all diagnoses is thought to be in a large part due to dysfunctional muscles that surround and support the lumbopelvic area (vanTulder et al., 2002; Comerford & Mottram, 2001; Borghuis et al., 2008). The muscles that support the spine can be divided into the local stabilizing and global system. The local stabilizing muscles originate and insert within the spine, cross one to 2 joints and have a high concentration of muscle spindles for proprioceptive feedback to maintain spinal stability while the global muscle system is described as the larger, more superficial muscles that cross many joints and whose function is to transfer load between the thorax to the pelvis (Bergmark, 1989; Comerford & Mottram, 2001; Gibbons & Comerford, 2001; Hammill et al., 2008; Borghuis et al., 2008). The global muscle system has been further divided into the global stabizers and global mobilizers (Comerford & Mottram, 2001; Gibbons & Comerford, 2001).

In subjects with LBP, the deep local stabilizing muscles have demonstrated motor control deficits, specifically timing delays in the onset of contraction. For example, the transversus abdominis and the deep fibers of the multifidus have been found to have delayed contraction when the spine is perturbed in some manner (Cresswell et al., 1994; Hodges & Richardson, 1996; Hodges & Richardson, 1997; Hodges & Richardson, 1998; Hodges et al., 1999; Moseley et al., 2002; Hodges et al., 2003; Tsao et al., 2008). It is theorized that the global stability muscles will respond to pain and dysfunction with inner range weakness, inhibition and poor low threshold recruitment while the global mobilizer muscles tend to respond with over-activation and shortening, both resulting in global muscle imbalances (Comerford & Mottram, 2001; Gibbons & Comerford, 2001). However, the literature has demonstrated various responses in the LBP population of the global muscle system.

The erector spinae has been found to have delayed recruitment (Hodges & Richardson, 1996 & 1998), early recruitment (Ferguson et al., 2004), or over-activation (Nouwen et al., 1987; Laviviere et al., 2000; Vogt et al., 2003; Lammoth et al., 2006) in LBP groups. The internal obliques have been noted to be delayed (Hodges & Richardson, 1998) or to have decreased activation (O'Sullivan et al., 1997) while the external obliques have shown over activation (Ng, 2002; Ferguson et al., 2004; Silfies et al., 2005) in LBP subjects. The gluteus maximus has also shown a diverse activation pattern with LBP. It has been found to have a delay (Bruno and Bagust, 1995; Leinonen et al., 2000; Hungerford et al., 2003), to be over-active (Vogt et al., 2003; Pirouzi et al., 2006; Himmelreich et al., 2008), to have greater fatigability (Kankaanpaa et al., 1998; Leinonen et al., 2000; McKeon et al., 2006) and to display weakness (Nadler et al., 2000).

Clinically, gluteus medius dysfunction has been theorized to be associated with chronic LBP (CLBP) (Lee, 1997; Sahrmann, 2002), however there are few studies that examine this potential link in this population. Asymmetrical hip abductor strength has been linked with the development of LBP (Nadler et al., 2001; Nadler et al., 2002) and hip abductor weakness noted in the LBP population (Kendall et al., 2010). Co-active recruitment of right and left gluteus medius (Nelson-Wong et al., 2008; Nelson-Wong and Callaghan, 2009; Marshall et al., 2011) and poor endurance (Marshall et al., 2011) have been used to predict the development of LBP during standing tasks in a previously pain-free population. However, there are no studies that examine the motor control of the gluteus medius in patients with CLBP.

One clinical test that is used to assess the functional strength of the gluteus medius is the single leg stance (SLS) test. The ability to maintain a level pelvis during single limb support is an indication of the strength and function of the muscles that attach to the pelvis and femur. Weak gluteus maximus and/ or sacroiliac joint dysfunction is thought to cause increased anterior iliac movement (Hungerford et al., 2003; Hungerford et al., 2007; Potter & Rothstein, 1985) while gluteus medius weakness results in a lateral pelvic movement (Hardcastle & Nade, 1985; Gottschalk 1989; Lee, 1997, p. 449-450; Dorman 1997; Sahrmann 2002; Livengood et al., 2004; Roussel et al., 2007; Tidstrand & Horneij, 2009). However, only a weak correlation between hip abductor weakness and lateral pelvic drop during SLS has been found in healthy and LBP subjects (DiMattia et al., 2005; Marshall et al., 2010). The SLS test has been found to have high inter-rater reliability in the subjects with LBP but no correlation between a positive test and LBP has been examined.

This study aims to determine the relationship between altered gluteal muscle activation and CLBP. Our specific objectives are:

1) To measure the onset in the buttocks muscles (gluteus medius and gluteus maximus) in subjects with CLBP compared to a gender and age matched control group during single leg stance test.
2) To determine if a positive clinical test of single leg stance is associated with timing delays in the gluteal muscles.

3.2 Methodology

3.2.1 Participants

The LBP group consisted of 13 male and 9 female subjects with non-specific CLBP with a mean age of 46± 15.2 years, a mean height of 171± 8.7 cm and mean weight of 79.8± 17.9 kg. The control group consisted of 13 male and 8 female age matched control subjects with a mean age of 44± 15.5 years, a mean height of 171± 11.4 cm and mean weight of 78.5± 16.8 kg.

Inclusion and Exclusion Criteria: In the CLBP group, subjects who experience non-specific low back pain that may or may not radiate to the leg that was present for 12 weeks or greater were included. Participants in the control group were excluded if they were currently experiencing LBP or if the experienced regular LBP within the last 12 months. Subjects were excluded from both groups if they had been diagnosed with neurological deficits, had a specific diagnosis such as disc pathology, spinal stenosis, rheumatoid arthritis, had previous back surgery, had an underlying neurological condition, hip pathology, were pregnant or less than 6 months post-partum.

3.2.2 Outcome Measures:

The subject rated their pain by using the Visual Analog Scale (VAS), marking a pen mark between 0 mm and 100 mm line on a 100 mm line (Summers, 2001). The amount of perceived disability due to low back pain was rated on the Oswestry Disability Questionnaire with the highest level of disability scoring a maximum score of 100% (Fairbank and Pynsent, 2000). The Physical Activity Questionnaire recorded the perceived levels of activity with a maximum score of 11 indicating greater physical activity.

3.2.3 Electromyographic Recordings

Electromyography (EMG) activity was recorded with bipolar surface electrodes (Meditrace 133 Ag-AgCl, Kendall) from two muscles, gluteus medius and gluteus maximus. Electrodes were placed on bilateral gluteus medius, 1 inch distal to the iliac crest at the mid point between the anterior iliac spine (ASIS) and posterior iliac spine (PSIS) of the pelvis (Hungerford & Hodges, 2003; Nelson-Wong, 2008). The bilateral gluteus maximus electrodes were placed midway between the lateral border of the sacrum and greater trochanter in the mid-muscle belly (Ekstrom et al., 2007). A reference electrode was placed over the ASIS. All electrodes were placed parallel to the fiber orientation with an interelectrode distance of 20mm. The skin was shaved, abraded with sandpaper and cleaned with an isopropyl alcohol swab to reduce the skin impedance to below 5Ω. (Hodges & Bui, 1996; Hodges & Richardson, 1996; and Perry and Bekey, 1981). The raw EMG was amplified with a gain of 2000 and sampled at 2000 Hz with an input range of ±2.5V, input impedance = 2MΩ, common mode rejection ratio > 110 dB min (50/60 Hz), analog –to-digitally converted (12bit), and stored on a computer for later analysis. All EMG data was digitally filtered using FIR Blackman -92 dB bandpass filter (10 Hz and 500 Hz). A FIR filter was chosen as there is minimal delay of the filtered data.

3.2.4 Force Plate

The initiation of vertical motion was determined by using an AMTI Biomechanics force plate (model BP400600HF). Force plate data was collected for 30 seconds, sampled at 2000 Hz and analyzed using analog-to-digital NIAD software program.

3.2.5 Procedure

1) Single leg stance

Each subject stood with an equal bipedal stance as an experienced clinician who was blind to the subject group knelt behind the subject with their hands on the pelvis and eyes level to the subject's pelvis. The subject was asked to stand on one leg, lifting their non-stance leg between 60^0 and 90^0 of hip flexion for 30 seconds. Subjects were permitted to use one finger on the back of a chair on the stance side for balance. Subjects were rated for their ability to maintain pelvic control. A negative test was indicated if the stance side of the pelvis remained level without lateral drop or anterior or posterior rotation. A positive test was noted in 4 different ways for the stance side: 1) lateral pelvic tilt, 2) anterior iliac rotation, 3) posterior iliac rotation or 4) combined anterior and lateral.

2) Hip Abductor and Extensor Strength and Maximal Voluntary Isometric Contraction

Each subject was assessed by the same experienced physiotherapist who was blinded to the subject grouping for right and left hip abductor and extensor strength using a Layfayette hand held dynamometer. The subjects lay on their side as the examiner resisted hip abduction just superior to the ankle with the hip slightly extended. For hip extension, the subject laid prone as the physiotherapist manually resisted hip extension just above the knee with the knee flexed 90^0 (Kendall, 1993; Ekstrom et al., 2007). Each subject received strong verbal encouragement to provide their maximal resistances for a 3 second maximal voluntary contraction (MVC). Two repetitions with 1 minute of recovery between repetitions were performed unless there was greater than 5% difference between the two measures and thus a third contraction was performed. The amount of force that each muscle produced was recorded from the hand held dynamometer in kilograms. EMG was also recorded of the gluteus medius and maximus during each MVC trial in order to calculate the normalized values during the single leg stance procedure.

3) Single Leg Stance on the Force Plate

Subjects stood with one leg on the force plate (stance leg) while the other leg was on the floor which was level with the force plate. EMG for all muscles was collected as each subject balanced on their stance leg for 30 seconds by lifting the other leg to a minimum of 60^0 but less than 90^0 of hip flexion. The first 1-2 seconds of the trial was recorded with the subject in bipedal stance to record baseline vertical force. Subjects were permitted to use one finger for balance on the stance side on the back of a chair. Each subject performed 3 non-randomized trials on each leg with a quiet bipedal stance for 1 minute in between trials. A five minute rest was allotted between all three test procedures.

3.2.6 Data Analysis

Force Plate

Recording of the vertical ground reaction force on the force plate was used to determine the onset of movement from bipedal to single leg stance. A computer generated algorithm calculated the baseline mean of vertical force during bipedal stance. As in similar studies, the onset of movement was determined when the vertical force deviated greater than 3 standard deviations (SD) below the baseline mean for a 100 frames (50 ms) (Hungerford et al, 2003; Simms and Brauer, 2000; Rogers and Pai, 1990). Visual inspection of data of multiple random trials confirmed the accuracy of the computer generated onset times of movement. The onset time for vertical loading was used as a reference point as 'time zero' for the onset of EMG data of its corresponding trial.

Electromyography (EMG)

The EMG data was full-wave rectified and the digitally filtered with a critically dampened low pass 6 Hz (linear envelope) after the initial low pass filtering (50 Hz FIR Blackman -92 dB filter) (Bruno and Bagust, 2007; Hungerford et al., 2003; Hodges and Richardson, 1997; Hodges and Bui, 1996; DiFabio, 1987). The mean EMG amplitude during bipedal stance was calculated for each muscle to determine the baseline muscle activity. The onset of muscle activity on the stance side was determined when the mean activation was greater than 3 SD of the baseline mean in one 50 ms epochs. The onset of muscle contraction was checked visually to ensure to ensure the accuracy of the computer derived onset times of muscle contraction (Hodges and Richardson, 1997; Hodges and Bui, 1996). Onset of muscle contraction was compared to the onset of movement on the force plate (time zero). Onset of muscle contraction that occurred before 'time zero' reference point on the force plate was assigned a negative number and afterwards a positive number. Muscle activation prior to or within 20 ms after vertical loading ("time zero"), was considered to meet the criteria of preparatory or feedforward muscle activation, indicating gluteal muscle contraction prior to weight shift (See Figure 3.6). Any reflex muscle activity due to the onset of movement would require greater than 20 ms for nerve conduction and synaptic transmission to occur (Hungerford et al., 2003; Hodges and Richardson, 1997).

To evaluate the extent of gluteal muscle activity during the SLS trials, EMG activity was full wave rectified and averaged over 25 ms frames, calculating the root mean square (RMS). EMG data was normalized to the MVC.

3.2.7 Statistical Analysis

SPSS statistical software version 18.0 (SPSS, Inc., Chicago,IL, USA) was used for all analysis. Multivariate analysis of variance (MANOVA) was performed with dependent variables for all subject demographics (age, height, weight and sex) and questionnaires (VAS, Oswestry and Physical Activity) with the independent variable of subject group (LBP and control). Separate MANOVA's were performed for the dependent variables right and left mean gluteal onset times, peak gluteal strength and RMS of gluteal activation to determine if there was any difference between two independent variables of group (LBP and control) and right or left SLS test (positive or negative). Separate MANOVA's were performed to prevent comparing muscle activation for example on a non-stance side to the stance side which could produce result in error for this study design. The significance was set at $p < 0.05$. Effect size was estimated using partial eta squared (□^{2}) with a 0.0099 indicating a small effect, 0.0588 a medium effect and 0.1379 a large effect (Cohen, 1988). Kolmogorov-Smirnov test for normal distribution and Levene's test for homogeneity of the variance were also performed.

3.3 Results

Participant anthropometric data and questionnaires. There was no significant difference between the LBP and control group in age, height and weight (Table

3.7). The LBP group rated their pain and disability significantly greater than the control group (VAS $F_{(1,41)}$ = 30.96, p= 0.000); Oswestry $F_{(1,41)}$ = 69.28, p= 0.000) but the LBP group also had a significantly lower self-reported physical activity compared to the control ($F_{(1,41)}$ = 8.54, p= 0.006).

Group Effect: The multivariate group effect was not significant for gluteal onset, strength or activation when compared with subject group alone and with the respective SLS test (Pillai's Trace p >0.05). There was a large effect size for the right gluteal tests ($\square^2$ = 0.17) and for the left group ($\square^2$ = 0.13) indicating that 0.17% (right) and 0.13% (left) of the variance between the means can be attributed to LBP and control group differences.

Gluteal Onset. The univariate effect for each muscle onset time was not significant when compared between the two groups and between negative and positive SLS test. There was a medium effect size comparing right gluteus medius mean onset times between the two groups ($\square^2$ = 0.091) but when the SLS test was factored in the effect size was small ($\square^2$= 0.030). Left gluteus medius and maximus mean onset times had a small effect size between groups ($\square^2$ = 0.035 and $\square^2$ = 0.041, respectively). However, when SLS test was factored in the effect size was insignificant. The onset times of the gluteal muscles were found to meet the preparatory criteria in only a few subjects (greater number in the control group) with the onset of muscle contraction being before or within 20 ms of the start of movement. However, the overall mean onset time of each group did not meet the preparatory criteria as it was greater than 20 ms. The onset times had a large variation between subjects as indicated by the large standard deviation in both groups (Table 3.8; Figure 3.9).

Gluteal Strength. The overall mean peak strength of each gluteal muscle was stronger in the control group compared to the LBP group, however it was only significant in the right gluteus medius ($F_{(1,41)}$ = 5.996, p= 0.019, Figure 3.10, Table 3.11). The mean difference between the LBP and control group had a large effect size for the right gluteus medius ($\square^2$ = 0.13) and a medium effect size for right gluteus maximus ($\square^2$ = 0.068), left gluteus medius ($\square^2$ = 0.07) and left gluteus maximus ($\square^2$ = 0.058). When a positive or negative SLS test was factored with the subject grouping, only the left gluteus medius and maximus had a small effect size ($\square^2$ =0.040, $\square^2$ = 0.041 respectively) (Table 3.11).

Gluteal Activation: The overall relative EMG RMS amplitude of the gluteal muscles was greater in the LBP group compared to the control group from the onset of contraction until full SLS was achieved in all muscles except the left gluteus medius. The mean activation of the right gluteus medius was greater in both the control and LBP groups compared to all other muscles. The univariate analysis showed only the right gluteus medius activation to be significant between the LBP group and control group ($F_{(1,41)}$ =5.498; p = 0.024) with a medium effect size ($\square^2$ = 0.12) but a non-significant effect size when compared with SLS test. Right gluteus maximus mean RMS had a small effect size when the two independent variables of group and SLS test were compared ($\square^2$ = 0.025). The left gluteus maximus was non-significant between groups but it had a small effect size ($\square^2$ = 0.024) but not when SLS test was factored in (Table 3.12).

Single Leg Stance Test. Univariate tests that compared positive and negative SLS test to their respective gluteal muscle tests were non-significant for all dependent variables (gluteal onset, strength and activation) between the two groups. When each mean muscle strength was subdivided into LBP or control group with a negative or positive SLS rating, those with a positive SLS test had less strength in the all 4 muscles in the control group but only the right gluteus medius in the LBP group had less strength (Table 3.11). The left gluteus medius and maximus onset times were earlier in both the control and LBP groups if the subject had a negative SLS test (Table 3.10). However, only the right gluteus medius in the control group and the right gluteus maximus in the LBP group had earlier onset times if they had a negative SLS test (Table 3.8).

SLS test was found to be negative in both sides for only 5 subjects (4 in the control group and 1 in the LBP group). Right SLS test ratings was almost equal between the two groups each with each having 9 negative ratings, and the control group having 11 and the LBP group having 13 positive SLS tests. There was a greater difference between the two groups with the left SLS test. There were 17 positives in the LBP group but only 10 positives in the control group (Table 3.13). Subjects that were given a positive rating were also noted if the movement fault was anterior, lateral, posterior or a combination of two. There were many subjects with a positive SLS test that were unable to maintain a level pelvis in more than one direction movement (i.e. the pelvis moved anterior and lateral). The LBP had a greater number of positive tests that had a movement fault in more than one direction during compared to the control group (Table 3.14).

3.4 Discussion

The most important findings in this study there were as follows. 1) There was no significant difference in the onset times of the gluteal muscles between the LBP and control group and that overall; neither group met the preparatory activation criteria during SLS. 2) The overall gluteal strength in the LBP group was less than the control group with right gluteus medius strength being significantly weaker in the LBP group. 3) There was overall greater activation of the gluteal muscles in the LBP group with a significant difference in the right gluteus medius activation. 4) A simple rating of negative or positive SLS test was not sensitive enough to detect any difference between the control and LBP group.

3.4.1 Gluteal Onset

This study did not find the overall gluteus medius or maximus onset times to be preparatory during SLS in both of the test groups. As well, the gluteal onset times of the CLBP group were not significantly delayed compared to the control group. This study did find a trend of earlier gluteal onset times in the subjects who had a negative SLS test but it was not consistent in the right gluteal muscles. Likewise, Hungerford et al. (2003) found that the gluteus medius and maximus were not activated prior to the start of movement from bipedal to single limb stance in a healthy nor sacroiliac joint pain groups. However, unlike this study they did find the gluteus maximus to be significantly delayed in the symptomatic group than the asymptomatic group. These two studies did not control for the speed of the SLS test, whereas one study that encouraged increased speed during SLS did elicit preparatory gluteus medius contraction (Rogers & Pai, 1990).There are very limited studies that examine the temporal parameters of the gluteal muscles in the CLBP group but there are a few other studies that have examined the timing of the gluteus maximus. Bruno and Bagust (1995) compared the onset of the gluteus maximus to the erector spinae and hamstrings during prone hip extension and found that the CLBP group had a delay in the gluteus maximus contraction whereas the erector spinae and hamstrings did not show the same dysfunction. Leinonen et al. (2000) compared the onset of the gluteus maximus, bicep femoris and erector spinae during standing spinal flexion and extension. The healthy group recruited the gluteus maximus after the erector spinae and biceps femoris during flexion and extension. The CLBP group showed an altered recruitment pattern. During spinal extension, the gluteus maximus was activated first while in flexion it showed a delay in contraction compared to the healthy group.

Contradictory to the current study, the gluteus medius and maximus have been found to be preparatory in healthy subjects (Rogers & Pai, 1990; Santos and Aruin, 2008; Bouisett and Zatarra, 1981). During the transition to SLS on a force platform, the gluteus medius was found to be preparatory when the speed was controlled for natural and fast speed but not at a slow speed (Rogers and Pai, 1990). The methodology to determine the onset of movement in this study was calculated at toe off compared to calculating 3 standard deviations about baseline mean during bipedal stance as in the current study. Finding an anticipatory contraction of the gluteus medius during the former methodology is more likely as the point of comparison occurs at a later point of time. Santos and Aruin (2008) found the gluteus medius to be preparatory when a weighted external perturbation was applied in oblique and lateral angles to the trunk while subjects remained in bipedal stance. To maintain the body's center of mass during a resisted oblique or lateral movement a greater activation of the gluteus medius may be required. The gluteus maximus showed preparatory activation in the healthy population as well with quick shoulder flexion (Bouissett and Zattara, 1981) and prone hip extension (Bruno and Bagust, 1995). Both of these studies cause a shift in the body's center of mass in an anterior-posterior direction, targeting the posterior oriented gluteus maximus which is a different directional force required to transfer to a SLS as in this study.

Antagonistic muscle activation to counteract forces from an opposite direction to maintain the body's center of mass has been found in other global stabilizing muscles (Hodges and Richardson 1999; Hodges and Richardson, 1997; Cresswell et al., 1994; Radebold et al., 2001). In addition to the direction of the perturbation force, the amount of force required to maintain the body's center of mass may influence whether a muscle contracts in preparation. The neuromuscular demand to maintain equilibrium resisting a weighted bar would be greater than a controlled transfer to a SLS.

The gluteus medius has been theorized to act as a stabilizing muscle as it is uniarticular, has a pennate orientation and thought to have a greater concentration of type I muscle fibers (Gottschalk 1989; Richardson et al., 1999; Fredericson, 2000; Comerford and Mottram, 2001, Gibbons and Comerford, 2001; Livengood et al., 2004). Local deep stabilizing spinal muscles, such as the transversus abdominus and multifidus have similar anatomy to the gluteus medius. These muscles are found to have preparatory activation to stabilize the spine in the healthy population and with dysfunction, they have consistently been found to have a delay in contraction (Cresswell et al., 1994; Hodges & Richardson, 1996; Hodges & Richardson, 1997; Hodges & Richardson, 1998; Hodges et al., 1999; Moseley et al., 2002; Hodges et al., 2003; Tsao et al., 2008). This study did not find the gluteus medius to function in this way and may be better categorized as a global stabilization muscle.

Global stabilization muscles are recruited in a different pattern than the local stabilization muscles in the healthy population. When enough force is applied to perturb the spine, they are recruited after the local stability muscles antagonistically to maintain spinal equilibrium (Bergmark, 1989; Comerford & Mottram, 2001; Gibbons & Comerford, 2001; Hammill et al., 2008; Borghuis et al., 2008). Global stabilization muscle response during pain and dysfunction is different than the local stability group as well. These muscles may have recruitment imbalance between the agonist and antagonist muscle groups and develop adaptive shortening and weakness with dysfunction (Comerford and Mottram, 2001; Gibbons and Mottram, 2001; Hammill et al., 2008). Conversely, the global mobilizing muscles are thought to respond with an over activation and spasm when pain and dysfunction are present. Altered gluteus medius recruitment was found to be predictive to the development of LBP in previously pain free subjects that spent 2 hours standing in a simulated occupational task (Nelson-Wong and Callaghan, 2009; Marshal et al., 2011). These theories and the findings of this study support the classification of the gluteus medius and maximus into the global muscle group.

3.4.2 Gluteal Strength

This study found that the CLBP group had overall less strength in the hip abductors and extensors compared to the control group during isometric muscle testing with a hand held dynamometer. However, it was only significant in the right hip abductors. The control group did show a trend of having less gluteal strength in those who had a positive SLS test; however this trend was not shown in the CLBP group. Hip abductor and extensor weakness has been associated with LBP in other studies as well. Kendall et al. (2010) found hip abductor strength to be significantly less in a LBP group compared to a healthy subject group. Asymmetry of right and left hip abductor and extensor isometric strength was associated with the development of LBP (Nadler, 2002; Nadler 2001). Hip strength measured at the beginning of the academic year was found to be predictive to the development of non-traumatic LBP in female college students over the course of the year. These findings differ from those in a more recent study. Marshall et al. (2011) compared isometric hip abductor strength and activation patterns in healthy subjects during a prolonged standing activity. In the previously pain-free group, 71% developed LBP during the 2 hour standing simulated occupational tasks. They did find altered recruitment patterns to be correlated with LBP development but not hip abductor weakness. Subjects that have CLBP may have different recruitment patterns and strength compared to an acute clinically induced LBP. As well, clinical isometric muscle testing in standard test positions may not capture the functional strength of the hip abductors and extensors. Some authors propose that with dysfunction, muscles may only test weak in shortened or lengthened positions (Sahrmann, 2002; Kendall, 1993). As well, hip abductor strength alone may not be an indicator of lateral hip function. Complex interaction of all of the muscles that insert on the greater trochanter and those that control the iliotibial band play a role (Grimaldi, 2010).

3.4.3 Gluteal Activation

The extent of gluteal activation was greater in the CLBP group for all muscles except the left gluteus medius, but only the right gluteus medius activation level was significantly different between groups. Global stabilizing muscles are thought to have altered recruitment with pain and dysfunction (Comerford and Mottram, 2001, Gibbons and Mottram, 2001, Sahrman txt, 2002; Hammill et al., 2008). Some authors report an increase in the extent of activation in global muscles. Himmelreich (2008) found that a LBP group had a greater extent of activation in the gluteus maximus on incline and stair climbing compared to a control group. Likewise, Pirouzi (2006) and Laviviere (2000) found that the gluteus maximus and erector spinae had greater activation in the LBP group compared to the control group with resisted lumbar movement. Another global stabilizing muscle, the external oblique showed a greater extent of activation in a LBP group while the deep stabilizing muscle, multifidus had a decrease in activation with resisted lumbar rotation (Ng 2002). Altered muscle recruitment has also been found in global muscle during the gait cycle. Lammoth (2006) and Vogt (2003) found that the extent of activation in the gluteus maximus and erector spinae was greater in a LBP group compared to a healthy population. Some authors proposed that one muscle group may increase the extent of activation to compensate for those muscles that have decreased activation. Although the exact mechanism is not clear, it does appear that with pain and dysfunction the global muscles are recruited in a different pattern. These studies may reveal different results than this current study as the muscle demand to stand on one leg is less than more dynamic movements like walking and stair climbing or with resisted trunk movements.

3.4.4 Single Leg Stance Test

There was no significant difference between the LBP and control groups with the rating of positive and negative SLS test despite finding less hip abductor and extensor strength in the LBP group. As noted above, there was a trend for subjects with a positive SLS test to have less gluteal strength and later onset times compared to those with a negative SLS test. However, as most subjects in this study had at least one positive SLS test, there was no statistical difference between the two groups. This widely used clinical test appears to not be a specific test with a simple rating of positive or negative to detect group differences between CLBP and a pain free population.

This study defined any movement of the pelvis during the 30 second SLS test to be positive. We found that subjects who had a very small amount of pelvic movement near the end of the 30 seconds with maintenance of neutral spine and balance received the same positive rating as a subject who had immediate loss of a level pelvis, neutral spine and balance. Other studies have proposed the SLS test to have good inter-rater and test-retest reliability (Roussel et al., 2007; Tidstrand and Horneij, 2009) and a positive test to be predictor of future LBP in a surgical lumbar disc herniation group (Millsdotter et al. 2003). However, these studies only examine subjects with a CLBP diagnosis, with no comparison between healthy and LBP subjects. Although the SLS test may be reliable within the CLBP group, this study did not find that this test is sensitive enough to identify subjects with LBP with a positive rating. Having a positive SLS test sub-divided into weighted categories may able to detect group differences that the current simple rating was not.

A positive SLS test with a lateral pelvic drop, referred to as a Trendelenburg Sign, is thought to be related to weak hip abductors (Hardcastle & Nade, 1985; Gottschalk 1989; Lee, 1997; Dorman 1997; Sahrmann 2002; Livengood et al., 2004; Roussel et al., 2007; Tidstrand & Horneij, 2009). However, this has not been found in other studies. DiMattia et al. (2005) and Kendall et al. (2010) found only a weak positive correlation between weak hip abductors and a contralateral pelvic drop during a SLS test in CLBP and healthy groups. These authors suggest that weak hip abductors have limited use in determining pelvic control. Cadaveric studies showed that excision of the gluteus medius, minimus and maximus allowed 10^0 of lateral pelvic tilt but excision of the iliotibial band on its own allowed 30^0 of lateral pelvic tilt (Fetto and Austin, 1994). This evidence has led authors to suggest that the ability to maintain pelvic stability during SLS is due to a complex interaction between all of the muscles that insert on the greater trochanter and those that control the iliotibial band (Grimaldi, 2010).

3.5 Caveats

1) The challenge with studying muscle activation of the CLBP population is that they are heterogeneous in nature and although they may all have LBP they may present with very different muscle imbalances. This makes it very difficult in analyzing the results of a group that may not be exactly the same.

2) Rating the SLS test as a simple positive or negative was not able to capture a difference between the two groups. A positive test with a subcategory such as slight, moderate or severe amount of movement might help detect differences between groups. As well, since the gluteals also move the hip joint, palpating greater trochanter movement during SLS might aid in detecting a difference and may provide better information.

3) EMG was only recorded from the middle fibers of the gluteus medius. There is some evidence that the anterior fibers may be more active in single limb support. As well, the posterior or anterior fibers may have been dysfunctional in this group, not just the middle fibers.

3.6 Conclusion

The gluteus medius and the gluteus maximus were not found to be preparatory in the LBP or healthy group during the SLS test. A delay in contraction of the gluteal muscles during SLS was not associated with LBP. An overall gluteal weakness seems to be associated with the LBP group. Gluteus maximus and the right gluteus medius have a greater extent of activation in the LBP group. These findings are similar to those found in the global muscle system as opposed to the deep stabilizing muscles. Following this theory, retraining of these muscles would incorporate low-load strengthening while maintaining lumbopelvic stability.

The simple rating of a negative or positive SLS test was unable to capture any difference between the LBP and control groups. There was a trend of a positive SLS test, regardless of group, to have a later onset of gluteal contraction and less strength. Creating a grading sub-category in future studies such as mild, moderate and severe may allow identifying differences. As well, since the gluteal muscles also mobilize the hip joint, noting any change in greater trochanter movement may shed more light on their function during the SLS test.

3.7 FIGURE LEGEND

Figure 3.1 Blind examiner rating the 30 second SLS test. Negative test noted with maintaining level pelvis on the stance side. Positive test noted if the pelvis moved anteriorly, laterally, posteriorly or combined anterior-lateral.

Figure 3.2 Recording of MVC of gluteus medius EMG during manually resisted hip abduction with hand held dynamometer.

Figure 3.3 Recording of MVC of gluteus maximus EMG during manually resisted extension with hand held dynamometer.

Figure 3.4 SLS test with the stance side on the force plate. EMG recording in bipedal stance for 1-2 seconds at beginning of 30 second test gluteus medius and maximus.

Figure 3.5 SLS test on the force plate. Subject was required to maintain position for 30 seconds.

Table 3.6 Subject anthropometric data summary and questionnaire results.

Table 3.7 Summary of positive SLS test. Direction of stance side pelvic movement was noted to be anterior, lateral, posterior or a combination of the lateral and anterior.

Figure 3.8 Mean onset times (ms) of the gluteus medius and maximus on the stance side during SLS of the CLBP and control groups.

Figure 3.9 Mean hip abductor and extensor strength (kg) as recorded with hand held dynamometer, CLBP compared to control group. Asterisks indicates a significant difference ($p < 0.05$) between LBP and control groups.

Table 3.10 Mean RMS, standard deviation and p value of gluteus medius and maximus during SLS from the onset of contraction to the end of the 30 second trial.

Table 3.11 Gluteus medius and maximus fatigue index during the 30 second SLS trial (the first 5 seconds divided by the last 5 seconds). A number less than 1 would indicate an increase in EMG activity at the end of the trial.

Figures and Tables

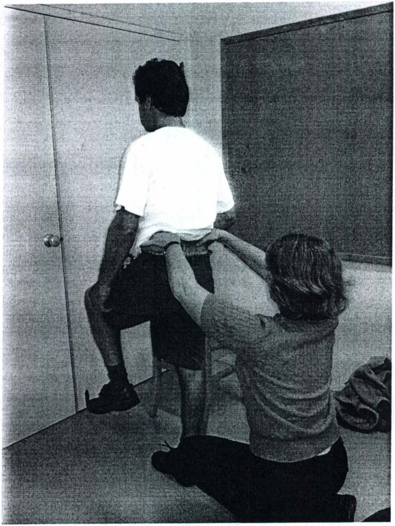


Figure 3.1

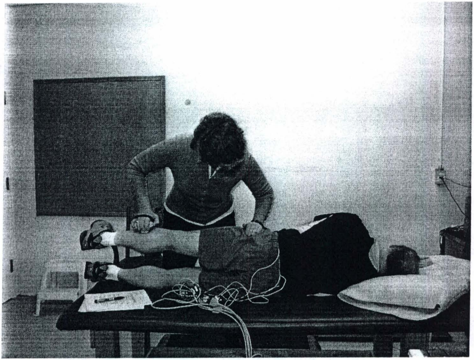
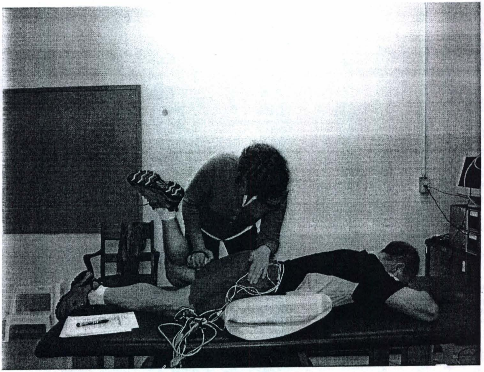


Figure 3.2



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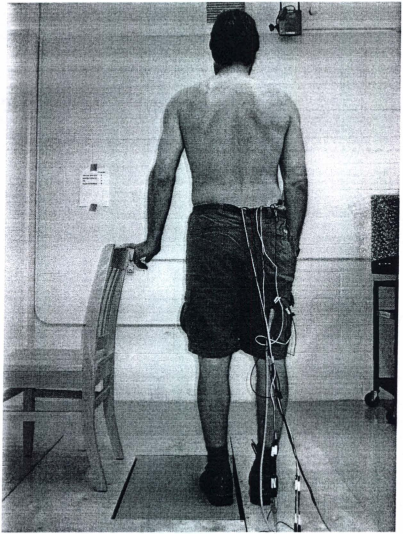

Figure 3.4

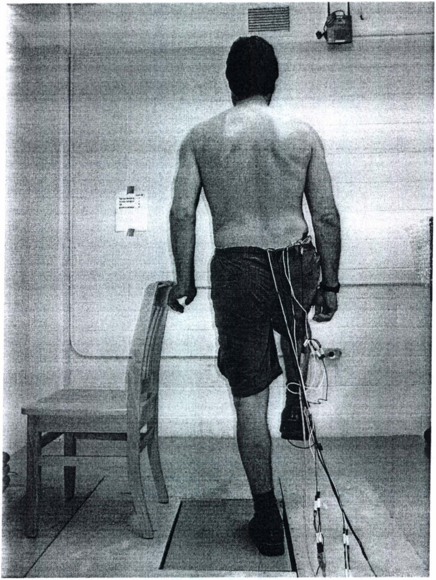

Figure 3.5

	LBP	Control
N	22 (M=13, F=9)	21 (M=13, F=8)
Age (years)	46± 15.2	44± 15.5
Weight (kg)	79.8±17.9	78.5±16.8
Height (cm)	171.0±8.7	171.0±11.4
VAS	20.5±15.9	0.9±2.4
Oswestry	17.9±9.2	0.5±2.4
Physical Activity	6.7±2.8	9.1±2.6

Table 3.6

	Right Positive				**L Positive**			
	Ant	Lat	Post	Total	Ant	Lat	Post	Total
LBP	7	3	5	15	12	9	0	21
Control	10	0	0	10	12	2	0	14

Table 3.7

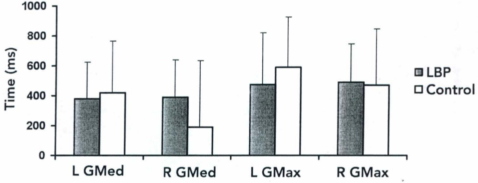

Figure 3.8

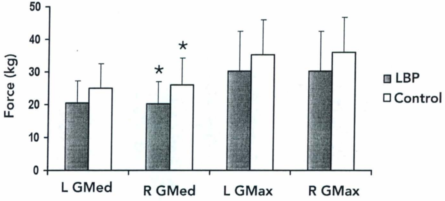

Figure 3.9

Muscle	Group	RMS	SD	p
L Max	LBP	1.17	+/- 1.30	p> 0.05
	Control	0.88	+/-0.66	
R Max	LBP	2.64	+/-2.10	p> 0.05
	Control	2.17	+/-1.54	
L Med	LBP	1.25	+/-0.57	p<0.05
	Control	1.46	+/-0.58	
R Med	LBP	5.63	+/-2.52	p= 0.007
	Control	4.43	+/-2.49	

Table 3.10

Muscle	Group	Fatigue Index	SD	p
L Max	LBP	1.01	+/-0.16	p< 0.05
	Control	0.93	+/-0.23	
R Max	LBP	1.01	+/-0.24	p> 0.05
	Control	0.92	+/-0.30	
L Med	LBP	1.14	+/-0.27	p< 0.05
	Control	1.04	+/-0.17	
R Med	LBP	1.83	+/-5.75	p> 0.05
	Control	1.55	+/-4.07	

Table 3.11

3.8 References

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