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# Gluteus medius dysfunction in chronic low back pain

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# GLUTEUS MEDIUS DYSFUNCTION IN CHRONIC LOW BACK PAIN

by

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CERTIFICATE OF APPROVAL

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PH.D. THESIS

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To Jessica & Lucie

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ABSTRACT

Low back pain is a common but severe health problem. Chronic low back pain accounts for the bulk of the burden of low back pain. Exercise interventions are effective in the management of chronic low back pain. Current clinical thinking in physical therapy treats low back pain as a heterogeneous entity seeking to match specific interventions to subpopulations. None of these subgroups assess the role of gluteus medius dysfunction in chronic low back pain. These projects seek to describe the prevalence of gluteus medius weakness in people with chronic low back pain and test the effectiveness of a gluteus medius strengthening exercise intervention in people with chronic low back pain.

Gluteus medius strength was assessed in 150 people seeking care for chronic low back pain and 75 healthy people without low back pain. Gluteus medius was found to be weaker on affected sides compared to unaffected sides within people with chronic low back pain and weaker than people without low back pain. Gluteus medius weakness was a strong predictor of the presence of low back pain.

A gluteus medius strengthening program was compared with lumbar stabilization exercises in 56 people with chronic low back pain. Although there was a clinically significant improvement in pain in people who performed the gluteus medius strengthening exercise program, this was not significantly different from the stabilization exercise intervention. Adherence to exercise was significantly correlated with reduction in pain and perceived improvement of low back pain.

Although gluteus medius weakness is common in people with low back pain and treating this weakness with a targeted exercise intervention is effective, it is not better than a standard stabilization exercise intervention. Doing exercise is likely more important than what exercise is done.

PUBLIC ABSTRACT

Low back pain is a common problem and chronic low back pain is a severe burden. Current thinking in physical therapy tries subgroups people with low back pain based on their symptoms in order to better treat their pain. The role of the gluteus medius muscle is unknown in chronic low back pain. We believe gluteus medius weakness is common and that using exercises to specifically make gluteus medius stronger will be a better treatment than a standard exercise program. In 150 people with chronic low back pain and 75 without any low back pain gluteus medius weakness was more common in those with chronic low back pain. In a group of 56 people with chronic low back pain with gluteus medius weakness, an exercise program focused on gluteus medius strengthening was effective in reducing pain. However it was no more effective than the standard exercise program. People who did more exercise, regardless of group, had less pain and felt that their chronic low back pain was more improved than people who did less exercise. For people with chronic low back pain, performing an exercise program is likely more important than which exercises they do.

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# CHAPTER 1: INTRODUCTION

## Scope & Impact of Chronic Low Back Pain

Low back pain (LBP) is a common complaint with the lifetime prevalence estimated to be as high as 84%.[1] It has been defined as pain reported anywhere for the lower margin of the rib cage to the lower gluteal fold, with or without referral into the lower extremity.[2] It may be attributable to a specific etiology where addressing the underlying pathology can adequately treat the pain. However, non-specific LBP, where there is no known etiology, is much more common: representing as much as 85% of the population of people with low back pain.[3] Most acute episodes of non-specific low back pain resolve spontaneously without any significant intervention.[4] When episodes of non-specific LBP do not resolve they often transition to chronic non-specific low back pain. Chronic low back pain is most commonly defined as low back pain that persists for more than three months, although this is widely recognized to be a problematic definition.[2] More recently a consensus definition of chronic low back pain lasting for at least three months and having been a problem on at least half of the past six months has been proposed.[5] The clinical entity of chronic non-specific low back pain is a tremendous burden, accounting for most of the expenses related to low back pain care. Recent estimates of the annual costs of low back pain in the United States found $90.6 billion in direct costs and $19.8 billion in indirect costs.[6,7] Low back pain is the fifth most common reason to visit a physician and the second most common reason for lost productivity in the workplace.[8]

## General Management of Chronic Low Back Pain

Given the magnitude of this problem, myriad interventions have been utilized to manage low back pain. Current best practice, as directed by an inter-professional practice guideline from the American Pain Society & American College of Physicians, supports the use of psychological interventions, exercise interventions, interdisciplinary

rehabilitation, non-steroidal anti-inflammatory drugs (NSAIDs), and spinal manipulation for chronic LBP.[9] Other practice guidelines for other groups and other nations have come to similar conclusions: focusing on cognitive behavioral therapy, supervised exercise, and interdisciplinary rehabilitation as the optimal treatments for chronic low back pain.[10]

## Exercise and Classification in Chronic Low Back Pain

Despite exercise being an intervention of choice for chronic non-specific LBP, there is little information on what exercise interventions are the optimal for any specific patient. Systematic reviews demonstrate effectiveness for exercise interventions in general, but do not clearly support any specific exercise intervention. Characteristics of more successful exercise interventions include individual exercise prescription, supervision, stretching exercises, and strengthening exercises.[11] Given the lack of any one broadly effective exercise intervention, identifying subpopulations for specific interventions that may lead to better outcomes has become a research priority.[12,13]

Current thinking in physical therapy has focused on this individualization of exercise interventions to subpopulations of patients with LBP. This has resulted in a proliferation of subgrouping schemes for patients with low back pain. A recent review identified 28 different classification schemes.[14] However most of the literature has focused on five main classification schemes: Mechanical Diagnosis & Treatment (MDT), Treatment Based Classification (TBC), Pathoanatomic Based Classification (PBC), Movement System Impairment Syndromes (MSI), and O'Sullivan Classification System (OCS).[14] Mechanical Diagnosis and Treatment seeks to group patients to direct treatment: Postural Syndrome, where pain is believed to be secondary to postural dysfunction and is treated with postural correction; Dysfunction Syndrome, where there is believed to be anatomical dysfunction of the soft tissue and treatment is directed to remodel the affected tissue; Derangement Syndrome, where the joint surfaces are abnormally positioned and treatment is guided by directional preference of movement; and Other, which includes

groups that do not fit the criteria of these groups.[15] Treatment Based Classification attempts to be a comprehensive low back pain management system by advocating screening for underlying pathology and then classifying only those appropriate for physical therapy management to one of four treatments based on criteria that predict success with each intervention: Manipulation, Stabilization, Specific Exercise, and Traction.[16,17] Pathoanatomic Based Classification attempts to classify patients low back pain into one of 13 categories based on suspected pathology: Disc Syndrome, Adherent Nerve Root, Nerve Root Entrapment, Nerve Root Compression, Spinal Stenosis, Zygapophysial Joint, Postural, Sacroiliac Joint, Dysfunction, Myofascial Pain, Adverse Neural Tension, Abnormal Pain, & Inconclusive.[18] The Movement System Impairment attempts to classify low back pain into one of several categories: Lumbar Flexion Syndrome: where symptoms are worse with flexion & better with extension; Lumbar Extension Syndrome: symptoms are worse with extension and better with flexion; Lumbar Rotation syndrome: lumbar rotation aggravates symptoms; Lumbar Rotation with Flexion Syndrome: lumbar flexion and rotation increase symptoms; and Lumbar Rotation with Extension Syndrome: symptoms are aggravated by extension and rotation of the lumbar spine.[19] O'Sullivan Classification System seeks to identify maladaptive movement or motor control impairments and then focus treatment on these maladaptive strategies.[20]

The most recent physical therapy clinical practice guideline by the American Physical Therapy Association coalesces around the Treatment Based Classification system.[21] However when applied to patients with chronic non-specific low back pain Treatment Based Classification does not outperform a standard intervention.[22,23] The Movement System Impairment system also fails to outperform a standard intervention in people with chronic non-specific LBP.[23] The failure of these systems when compared to a standard intervention may be for multiple reasons. It is possible that choice of exercise intervention is unimportant and the simple fact that they are doing some sort of exercise

leads to benefit for patients. Alternatively, it is well established that chronic non-specific low back pain is a heterogeneous entity and existing systems may not be broad enough to appropriately group patients.

None of the existing interventions account for the role of the gluteus medius in low back dysfunction. These projects seek to demonstrate the prevalence of gluteus medius dysfunction in patients with chronic non-specific LBP and the effects of treatment targeted to address this dysfunction in patients with chronic non-specific LBP.

I believe a subpopulation of patients with chronic low back pain with symptoms associated with gluteus medius dysfunction exists and that exercise interventions targeting the gluteus medius will lead to superior outcomes in this population. I will test this belief with two projects seeking to support two hypotheses. The first project will test the hypothesis that gluteus medius weakness and tenderness occurs in the majority of people with chronic non-specific LBP compared to people without LBP. The second project will test the hypothesis that gluteus medius strengthening is more effective than a standard exercise program for people with chronic non-specific LBP with gluteus medius weakness and tenderness on examination.

# CHAPTER 2: REVIEW OF LITERATURE

## Exercise Intervention and Classification in Chronic Low Back Pain

The most current Cochrane review of exercise interventions for chronic low back pain supports exercise interventions for chronic low back pain.[11] The meta-analysis conducted as part of this review concluded that exercise interventions had superior outcomes compared to no treatment or other treatments at short (less than 12 weeks), intermediate (six months), and long-term (12 or more months) follow-ups.[11] However, these pooled exercise interventions are widely variable, using a variety of strengthening, stretching, aerobic, coordination, and mobilizing interventions. They also treat chronic low back pain as a homogenous entity, although it is widely acknowledged to be heterogeneous.

Another more recent systematic review summarized the comparisons of exercise interventions against other interventions in the literature in chronic low back pain[24] The authors conclude that exercise is superior to usual care.[24] However they did not find significant differences between exercise interventions compared to wait list or no treatment controls, back schools, behavioral interventions, passive modalities, manipulation, psychotherapy or upon comparison to other exercise interventions.[24] This is followed by the caveat that the vast majority of the evidence is low quality.[24] Common issues include poor blinding, unclear monitoring of concurrent interventions, and lack of monitoring of patient adherence with prescribed exercise.[24] As with the Cochrane review, the exercise interventions are heterogeneous making pooling data from various studies difficult to interpret. In addition to varying in exercise mode, the various interventions widely vary in exercise volume, duration, and intensity. They also treat chronic low back pain as a homogenous entity where clinic practice suggests that this is not the case.

This clinical observation that chronic low back pain is not monolithic has inspired multiple classification schemes in an attempt to guide intervention. Recent reviews have identified numerous classification schemes.[14,25] Classification schemes that direct treatment have the most clinical utility and much of the literature has focused around a handful for classification schemes that seek to match treatment in chronic low back pain. Most of this literature utilizes Mechanical Diagnosis & Treatment (MDT), Treatment Based Classification (TBC), Pathoanatomic Based Classification (PBC), Movement System Impairment Syndromes (MSI), or O'Sullivan Classification System (OCS) to classify participants. However few studies exist evaluating the effectiveness of these schemes.

McKenzie's Mechanical Diagnosis & Treatment (MDT) has a relatively large body of literature supporting its use for low back pain in general. A 2006 review of MDT interventions for low back pain suggested its efficacy, but noted its limited effects in chronic low back pain.[26] Since then several other studies have been reported with mixed results. Paatelma and colleagues found improvements in acute work-related low back pain and disability using MDT at six and twelve month follow-ups.[27] However this was no different than a comparison intervention consisting of manipulation and undefined exercises.[27] Garcia and colleagues reported no differences between using a back school intervention compared to MDT interventions in patients with chronic low back pain, other than disability at the initial follow-up.[28] Hosseinifar and colleagues reported better outcomes with a stabilization intervention compared to McKenzie MDT exercises in people with chronic LBP.[29] However it is not clear if the MDT exercise intervention was performed by physical therapists with training in the MDT methods. The description of the intervention does not state or imply that any method was made to match patients with specific intervention as all patients were prescribed a mix of flexion and extension exercises. This is inconsistent with the directed treatment interventions advocated by the MDT system. One positive study using MDT in people with chronic LBP was reported

by Al-Obaidi and colleagues.[30] They found improvements at five and ten weeks in disability, fear-avoidance beliefs, self-report of pain as well as function as assessed by walking, sit-to-stand, and trunk flexion testing. This study used a MDT-trained physical therapist to provide the intervention. However they included people with more than two months of symptoms and they excluded potential participants who did not demonstrate centralization of their symptoms with the MDT assessment this using a targeted subpopulation. On the whole the literature is still unclear regarding the effectiveness of MDT for chronic low back pain.

The Treatment Based Classification (TBC) system seeks to pragmatically integrate multiple interventions based on a patient's characteristics compared to characteristics that were predictive of success with an intervention. Currently this system groups patients into one of four categories: Manipulation, Stabilization, Specific Exercise, and Traction. Most of the work supporting this system has focused on manipulation interventions and more acute LBP. Flynn and colleagues originally reported the manipulation group characteristics.[31] This has been supported by a validation study.[32] Later studies supporting this work found a preference for thrust manipulations over non-thrust interventions without displaying a difference between specific modes of thrust manipulation.[33-35] More recently, a large clinical trial failed to find a clinically significant benefit for manipulation treatment over standard care.[36] Hicks and colleagues developed stabilization grouping criteria.[37] One study has been reported attempting to validate these criteria and had positive results, although these did not reach statistical significance.[38] The specific exercise category has simply appropriated McKenzie's ideas of directional preference and centralization of symptoms as a subgroup of patients in low back pain. There has not been further exploration of this directional exercise grouping criteria by proponents of TBC. Traction grouping criteria were reported by Fritz and colleagues.[39] A validation study was undertaken, but failed to find superior outcomes in those treated

with traction.[40] This system has wide acceptance but has been demonstrated to be of limited utility in chronic low back pain.[22,23]

The other three more widespread classification systems have much more limited evidence to support their use on people with chronic low back pain. Pathoanatomic Based Classification (PBC) supports the idea of tailored interventions for differing presentations.[18] However there have yet to be reported any interventional studies based on these grouping criteria. Movement System Impairment (MSI) classifies low back pain into one of five movement categories. Use of this classification system has been demonstrated reliable in chronic low back pain.[41] However, it has been shown to be no more effective than a standard intervention in chronic low back pain.[23] The O'Sullivan Classification System (OCS) has proposed dividing chronic low back pain broadly into either movement impairments or control impairments.[20] They advocate a cognitive-functional therapeutic approach to challenge these movement or control dysfunctions. One study has demonstrated this approach to be more effective than an exercise and manual therapy intervention.[42] Further work will better clarify the utility of these systems for classifying and managing patients with low back pain.

All of these currently popular systems are focused on lumbar spine mechanics and its direct control via the paraspinal and abdominal musculature. There is little attention given to the hip musculature and its role in controlling lumbar function despite intermittent commentary to this effect throughout the literature.

## Inter-relationship Between the Hip and Low Back Pain

The relationship between the hip and low back has been referenced in the literature for a long time although there are relatively few papers that focus on this relationship. The interaction between hip function and LBP has been suggested to play a role in subgrouping patients with LBP.[43] These interactions may be grouped into several

categories: hip-spine syndrome, hip range of motion deficits, greater trochanteric pain syndrome (GTPS) and specific gluteal muscle weakness.

Offierski and McNab described an interaction between the arthritic hip and spine that they termed hip-spine syndrome.[44] Others have described the compensatory interactions between the spine and hip joint in multiple disease entities.[45-47] Hip joint pathology overlaps significantly with back pain. Sembrano and Polly found that 17.5% of their spine surgery clinical population had concurrent spine and hip or pelvic dysfunction.[48] Ben-Galim and colleagues reported that total hip arthroplasty was able to improve not only hip joint symptoms, but concurrent LBP as well in people with both hip joint pain and LBP.[49] This supports the idea that treatment directed at the hip may be an effective intervention in low back pain.

Hip range of motion has also been implicated in low back pain. Mellin initially reported correlations between hip mobility deficits and low back pain.[50] Ellison and colleagues later categorized hip internal (IR) and external rotation (ER) ROM in LBP into three categories: symmetrical ER and IR, greater ER than IR, and greater IR than ER.[51] They found the pattern of limited IR compared to ER was more common in people with LBP.[51] Chesworth and colleagues also found limited hip internal and external rotation in people with LBP compared to controls.[52] Cibulka and colleagues also reported limited IR in people with low back pain.[53] The idea of interaction of hip rotation ROM and LBP is also present in the criteria for predicting success with manipulation in the TBC system.[21] Relative hypomobility in the spine and hip internal rotation greater than 35 degrees are part of the criteria for manipulation described by Flynn and colleagues.[31] This further supports the idea that deficits at the hip may impact low back pain.

The relationship between trochanteric bursitis, or greater trochanteric pain syndrome (GTPS), as it is more widely and properly termed, and low back pain has been supported by several studies. Swezey reported trochanteric bursitis as the actual problem in 30% of elderly adults seeking care for low back pain.[54] He also noted that in total,

trochanteric bursitis was present in 44% of these elderly adults seeking care for low back pain.[54] Later Collée and colleagues found trochanteric bursitis to be the actual chief complaint in 35% of patients seeking care for chronic low back pain in rheumatology or orthopaedic specialty clinics.[55] Collée and colleagues next examined people seeking care for low back pain in multiple settings to assess the prevalence of GTPS in these populations.[56] GTPS was found in patients seeking care for low back pain in 25% of patients at a rural general outpatient practice, 18% of patients in an occupational health clinic, and 40% of patients in a rheumatology specialty clinic.[56] More recently Tortolani and colleagues reported a high prevalence of greater trochanteric pain syndrome in patients seen in an orthopaedic spine specialty clinic for evaluation of low back pain.[57] They found 20.2% of their patients evaluated for low back pain presented with GTPS.[57] Sayegh and colleagues reported symptomatic GTPS as the primary problem in 7.4% of the female patients referred to an outpatient orthopaedic clinic for chronic LBP.[58] All of these studies recognize the overlap of symptoms of low back pain and dysfunction at the hip. Others have made more direct links between low back pain and gluteus medius dysfunction.

## Role of Gluteus Medius Dysfunction in Low Back Pain

Several authors have reported direct interactions between gluteus medius dysfunction and low back pain. One of the earlier works implicating gluteus medius as a source of low back pain was Simons and Travell's description of gluteus medius myofascial pain.[59] Myofascial pain from the gluteus medius muscle has been reported to be a common component of low back pain.[59] They describe pain referred from gluteus medius as presenting medial toward the sacrum, superiorly along the iliac crest as well as throughout the buttock.[59] Later Njoo and van der Does reported finding gluteus medius myofascial trigger points in 32% of a sample of patients seeking care for low back pain

compared to only 6% in a control population.[60] They defined trigger points as palpation tenderness and either recognition of this tenderness as their pain complaint or involuntary contraction of the muscle in response to palpation.[60] These studies suggest that pain from the gluteus medius muscle plays a role in low back pain.

In addition to myofascial pain, relative weakness of the hip abductors had been reported in people with LBP. Nourbakhsh & Arab reported significant deficits in hip abductor strength as well as hip adductor, flexor, and extensor strength in a large sample of people with LBP compared to a control population.[61] Later these authors reported significantly lower hip abductor strength in people with low back pain compared to controls without low back pain.[62] Kendall and colleagues also reported a difference in hip abductor strength in people with non-specific LBP compared to healthy controls.[63] These strength deficits may play a role in low back pain.

Further, strength imbalances around the hip have been implicated in low back pain. In their initial publication on the topic, Nadler and colleagues, reported a significant difference in hip extensor strength assessed by dynamometry between sides in female athletes who had experienced low back pain.[64] They assessed hip abductor strength as well, but found no asymmetries among any of the colligate athletes assessed in this retrospective study.[64] They confirmed this with a prospective study: hip extensor strength asymmetry was predictive of seeking treatment for LBP in female collegiate athletes, while there were no differences in males.[65] They again found no relationship between hip abductor strength differences and LBP.[65] However, over the next season they reported that, among the female collegiate athletes, those who had an asymmetry of hip abduction strength were more likely to seek care for low back pain.[66] They also found no relationship between hip extensor asymmetry and low back pain treatment in opposition to their prior reports.[66] Together these studies suggest that gluteal strength imbalances are related to low back pain.

In addition to strength asymmetries, differing recruitment patterns have been implicated as a mechanism of gluteus medius dysfunction leading to LBP. Nelson-Wong and colleagues assessed muscle activation of the lumbar and thoracic paraspinals, oblique and rectus abdominals, and gluteus medius with surface EMG during an experimental standing task in people without low back pain.[67] They found that people who developed LBP during the standing task had a different recruitment pattern of gluteus medius compared to those who did not develop LBP.[67] People who developed LBP demonstrated a co-contraction pattern of gluteus medius during standing, while those who did not develop LBP utilized a reciprocal activation pattern.[67] They subsequently proposed a clinical screening test, the Active Hip Abduction test, to identify people who would develop pain during the same experimental standing task.[68] This screening tool was demonstrated to be predictive of development of pain during the experimental standing task.[69] Later, in a follow-up study, the authors reported that those who had developed LBP during the standing task were more likely to report experiencing low back pain during the ensuing three years.[70] This supports the idea that poor trunk control when using the hip abductors, especially gluteus medius, is potentially predictive of the development of low back pain.

Bewyer & Bewyer suggest that there may be a sizeable proportion of patients seeking care for low back pain with gluteus medius dysfunction and associated pain and tenderness.[71] They suggest a treatment of exercises focused on gluteus medius strengthening.[71] They later reported a significantly greater likelihood that pregnant women had low back pain if they had gluteus medius weakness on examination.[72] Together, all of these studies imply that gluteus medius dysfunction plays a role in low back pain and is worthy of further investigation. In order to better understand the role of gluteus medius function we next need to review how to best assess its function.

## Gluteus Medius Assessment

The choice of how to optimally assess gluteus medius function is still unclear. Gluteus medius is most commonly assessed via functional measures, the most common and longstanding being the Trendelenburg test. Other more recently developed functional assessments may be of greater clinical utility although this currently remains unclear. Other common clinical assessments utilize muscle function testing with manual muscle testing or dynamometry.

### Functional Assessment of Gluteus Medius

The most prominent functional assessment of gluteus medius function is the Trendelenburg Test. Trendelenburg first reported this in 1895. He described loss of frontal plane control during standing or walking because of gluteus medius weakness secondary to congenital hip dislocation.[73] More recently Hardcastle and Nade have tried to standardize the test.[74] Despite this, several groups have suggested that the Trendelenburg Test may not be appropriate for many situations. Youdas and colleagues assessed the utility of the Trendelenburg Test for differentiating the presence of hip OA.[75] They found it to be of limited utility, especially in early stage hip OA when hip muscle weakness is less marked.[75] Kendall and colleagues also recommend against using the Trendelenburg test.[63] They attempted to correlate performance on Trendelenburg's Test with hip abductor strength in healthy people as well as in people with non-specific low back pain.[63] Although they observed a significant difference in hip abductor strength between groups, there was no significant difference in pelvic drop during walking or in static during Trendelenburg's Test, nor was there a significant correlation between strength and pelvic drop in either situation.[63] Kendall and colleagues went on to attempt to assess if there was a cutoff in strength where the Trendelenburg Test would be an appropriate assessment.[76] Using an ultrasound-guided nerve block of the superior gluteal nerve to induce hip abductor weakness in otherwise normal strength individuals they

assessed the Trendelenburg Test and hip abductor strength in this experimental population.[76] They only found a positive Trendelenburg Test in one person.[76] All the other people, despite having induced weakness of the hip abductors, did not have positive Trendelenburg Tests.[76] They suggest that hip abductor strength of less than 17% body weight (BW) and possibly below 10% BW may be necessary to observe the changes Trendelenburg reported.[76] These findings suggest that Trendelenburg Tests may be of limited value and other, more appropriate, functional assessments should be explored.

Based on their work with gluteus medius activation patterns, Nelson-Wong and colleagues developed a screening test, the Active Hip Abduction test (AHAbd), to predict people developing LBP during an experimental standing test.[68] In this test the participant is positioned on their side with the trunk, pelvis, and lower extremities aligned in the frontal plane. The participant is instructed to abduct their top lower extremity: "Please keep your knee straight and raise your top thigh and leg towards the ceiling, keeping them in line with your body, and try not to let your pelvis tip forwards or backwards."[68] Examiners scored the test on a four-point scale: 0 (no deviation from the frontal plane) if the participant is able to maintain their pelvis and lower extremity in the frontal plane; 1 (minimal deviation from the frontal plane) if they demonstrate some departure, but are able to regain control to keep their pelvis in the frontal plane; 2 (moderate deviation from the frontal plane) if they rotate their shoulders, trunk, or pelvis from the frontal plane or if they flex, extend, or rotate at the hip with abduction; and 3 (severe deviation from the frontal plane) if they demonstrate the same deviations as 2, but at a greater severity.[68] Participants were also asked to rate the difficulty of the test on a five-point scale with anchors at zero of no difficulty and at five of unable to perform.[68] They reported no differences in using a score of 1 or 2 by the examiner as a cut-off for the test based on receiver operating characteristic (ROC) analysis, however subsequent analysis demonstrated a greater odds ratio using 2 or greater to represent a positive test.[68] The clinician assessed test has been reported to have an inter-rater reliability of 0.70 using the

four point scale and 0.59 using a dichotomous scale: interpreting a score of 0 or 1 as a negative test and 2 or 3 as a positive test.[77] Intrarater reliability has been reported 0.74 in the same sample.[77] Participant self-report of the difficulty of the test was interpreted as positive if the participant rated the difficulty of the test 4 or 5 on a scale of 0-5.[68] The authors report a sensitivity of 0.41 and specificity of 0.85 for predicting who will develop LBP during prolonged standing as well as a positive likelihood ratio of 2.68 and odds ratio of 3.85.[69] As yet, this test has not been assessed in a clinical population.

Crossley and colleagues describe another test: a single limb squat test to assess hip abductor muscle function via clinical obseravation.[78] Participants stood on a box and performed a single limb squat. The single limb squat was graded as "good", "fair", or "poor." This grading system was based on five criteria: overall impression, trunk posture, pelvis position, hip joint, and knee joint.[78] Participants were scored "good" if they met all the requirements for 4/5 of the criteria.[78] Participants were scored "poor" if they failed to meet all the requirements of at least one of the criteria.[78] Participants were scored "fair" if they did not meet the definitions of "good" or "poor."[78] Intrarater agreement was reported to be between 87% and 73% with kappa of 0.800 to 0.613.[78] This testing was also supported with HHD assessment of hip abduction in supine for all people in this sample. There was a significant difference in hip abduction strength normalized to body weight (BW) between participants scored as "good" and participants scored as "poor" (0.167 Nm/BW vs. 0.12 Nm/BW, p=0.016).[78] As with the Active Hip Abduction Test, the Single Limb Squat Test needs to be further assessed regarding its clinical utility specifically in low back pain. These functional tests are complimented by more direct assessment of gluteus medius with the strength testing modalities of manual muscle testing and dynamometry.

**Table 1:** Grading Criteria for the Single Limb Squat Test

| Criterion | Requirements for Good Rating |
|---|---|
| **Overall Performance Criterion** | |
| Balance | No loss of balance |
| Perturbations | Smooth performance |
| Squat depth | To at least 60deg knee flexion |
| Squat speed | Rate of 1 squat/2 seconds |
| **Trunk Posture Criterion** | |
| Trunk lateral deviation | No trunk lateral deviation |
| Trunk rotation | No trunk rotation |
| Trunk lateral flexion | No trunk lateral flexion |
| Trunk flexion | No trunk flexion |
| **Pelvis Position Criterion** | |
| Pelvic lateral deviation | No pelvis lateral deviation |
| Pelvic rotation | No pelvis rotation |
| Pelvic tilt | No pelvis tilt |
| **Hip Joint Criterion** | |
| Hip adduction | No hip adduction |
| Hip internal rotation | No hip internal rotation |
| **Knee Joint Criterion** | |
| Knee valgus | No knee valgus |
| Knee position | Knee remains over foot |

Manual Muscle Testing & Dynamometry Assessments

One of the most straightforward assessments of hip abductor function is assessment of muscle strength. This is commonly performed with manual muscle testing (MMT) in the clinic. However the utility of MMT is limited when muscles are able to generate antigravity forces. Using dynamometry is a better assessment for most people. Multiple authors have reported using MMT as well as both hand held dynamometry (HHD) and dynamometry using laboratory equipment to better control the force assessment. However using more complicated laboratory-based setups to better assess force generation is not usually feasible clinically. Utilizing HHD is a reasonable clinical compromise.

There is significant variability in hip abductor strength assessments used in the literature. The variability includes patient positioning, means of resistance application, and type of testing. Supine and sidelying positions are commonly used to assess strength.

Resistance is most commonly applied either by an examiner in MMT or HHD or using a fixed setting for the participant to work against. Isometric testing utilizes a make test or a break test. During a make test the participant applies a force up to their maximum in that position. During a break an examiner provides force until they are able to overcome the participant's force-generating capacity and move the participant's limb from the test position.

Manual muscle testing is widely performed in the clinical setting. Gluteus medius manual muscle testing is commonly performed with patients positioned on their side with the superior hip abducted and extended.[79] Reliability for this testing is relatively low, with Kappa's of 0.30 to 0.42 reported for gluteus medius MMT assessment.[80] One of the chief problems with MMT is the absence of criteria for assessment beyond anti-gravity strength.[79,80] This weakness can be overcome by the use of hand-held dynamometry to improve confidence in these assessments.

Multiple authors have reported on HHD for the assessment of hip abduction with excellent reliability. Kremer and colleagues reported acceptable reliability (ICC: 0.84-0.97) with HHD hip abduction assessed with a make test in supine in samples of healthy adult and elderly women.[81] Jaramillo and colleagues reported ICCs from 0.91 to 0.98 for hip abduction HHD in sidelying using a make test in a sample of people evaluated after knee arthroscopy.[82] Bohannon found high reliability (ICC: 0.949-0.950) for hip abduction HHD using a make test in a gravity-eliminated position in a sample of healthy adults.[83] All of these studies used force applied at the distal femur, just proximal to the knee, to assess hip abduction torque.[81-83] Krause and colleagues recommend using a longer lever: applying force just proximal to the ankle and using a break test to better assess the hip abductors.[84] They found using a long lever to be similarly reliable compared to using a short lever arm: ICCs of 0.93 and 0.91 respectively.[84] In another study they again found better reliability with a long lever test compared to using a short lever: ICCs of 0.98 and 0.81 respectively.[85] Further, Krause and colleagues found that using a long lever arm

mitigated the effect of assessor strength on hip abduction dynamometry.[85] Additionally, Widler and colleagues recommend using a side-lying position rather than supine or standing position to better assess the strength of the hip abductors.[86] In summary hip abduction HHD is reliable and best performed in a side-lying position, using a break test, with force applied at the distal leg, just proximal to the ankle, in order to best assess hip abduction function. Both dynamometry and functional tests can assess gluteus medius dysfunction and can serve as assessments for the effectiveness of exercise interventions to improve its function.

## Exercises Targeting Gluteus Medius

Exercise intervention for gluteus medius strengthening in low back pain has been investigated only on a cursory level. However, multiple EMG based studies can guide exercise selection. There also exist several reports of targeted gluteus medius strengthening interventions in other conditions. To my knowledge only one study has used a gluteus medius strengthening exercise protocol in people with low back pain.[63]

### EMG Assessment of Exercises Targeting Gluteus Medius

Several studies utilizing electromyography (EMG) give guidance regarding exercise selection for exercises targeting gluteus medius.[87-95] These studies allow the relative recruitment of the exercises to be assessed by comparing the electrical activity in the muscle during the exercise to the maximal voluntary isometric contraction (MVIC) and expressing it as a percentage thereof (%MVIC). These exercises can be grouped into several broad types: exercises performed in sidelying, various standing exercises, forms of step-ups, squat and lunge exercises, bridging and planks, quadruped exercises, dynamic exercises, and isometrics. These groups and the exercises within them allow for the creation of a progressive gluteus medius exercise program.

The results of these studies are summarized below. Two recent reviews of this literature suggest that the side plank, single-limb stance (SLS) squat, and sidelying hip abduction exercises are the most challenging exercises focusing on gluteus medius.[96,97] Even though there are several studies assessing these gluteus medius-strengthening exercises, there are few studies that assess the effectiveness of specific gluteus medius exercise interventions, either in low back pain or other conditions.

**Table 2:** Gluteus medius muscle activation (%MVIC) for various exercises

| | Bolgla & Uhl, 2005[87] | Ayotte et al, 2007[88] | Ekstrom et al, 2007[89] | Boudreau et al, 2009[90] | diStefano et al, 2009[91] | Boren et al, 2011[92] | Philippon et al, 2011[95] | McBeth et al, 2012[93] | Selkowitz et al, 2013[94] | mean |
|---|---|---|---|---|---|---|---|---|---|---|
| Plank: Side Plank on Elbow | | | 74 | | | 103 | | | | 88.5 |
| Plank: SLS Plank on Elbows | | | | | | 75 | | | | 75.0 |
| Sidelying: Hip Abduction c IR | | | | | | | 66 | | | 66.0 |
| Dynamic: Lateral Band Walk | | | | | 61 | | | | | 61.0 |
| Sidelying: Hip Abduction | 42 | | 39 | | 81 | 63 | 58 | 79 | 44 | 58.0 |
| Standing: Pelvic Drop | 57 | | | | | 58 | | | | 57.5 |
| Dynamic: Lateral Hop | | | | | 57 | | | | | 57.0 |
| Standing: SLS Deadlift | | | | | 58 | 56 | | | | 57.0 |
| Standing: Dynamic Leg Swing | | | | | | 57 | | | | 57.0 |
| Isometric: Prone Heel Squeeze | | | | | | | 55 | | | 55.0 |
| Sidelying: Hip Abduction c ER | | | | | | | 55 | 53 | | 54.0 |
| Squat: SLS Squat | | 36 | | 30 | 64 | 82 | | | | 53.0 |
| Squat: SLS Wall Squat | | 52 | | | | | | | | 52.0 |
| Bridging: SLS Bridge | | | 47 | | | 55 | 73 | | 31 | 51.5 |
| Dynamic: Transverse Hop | | | | | 48 | | | | | 48.0 |
| Lunge: Transverse Lunge | | | | | 48 | | | | | 48.0 |
| Step-Up: Lateral | | 38 | 43 | | | 60 | | | | 47.0 |
| Standing: Abduction, hip flexed, WB | 46 | | | | | | | | | 46.0 |
| Dynamic: Forward Hop | | | | | 45 | | | | | 45.0 |
| Isometric: Gluteal Squeeze | | | | | | 44 | | | | 44.0 |
| Step-Up: Forward | | 44 | | | | 55 | | | 30 | 43.0 |
| Standing: Abduction, WB side | 42 | | | | | | | | | 42.0 |
| Quadruped: Hip extension | | | 42 | | | 47 | | | 31 | 40.0 |
| Sidelying: Clam, 30° hip flexion | | | | | 40 | | | | | 40.0 |
| Lunge: Sideways Lunge | | | | | 39 | | | | | 39.0 |
| Sidelying: Clam, 60° hip flexion | | | | | 38 | | | | | 38.0 |
| Standing: Hip Hike | | | | | | | | | 38 | 38.0 |

**Table 2** - continued

| | Bolgla & Uhl, 2005[87] | Ayotte et al, 2007[88] | Ekstrom et al, 2007[89] | Boudreau et al, 2009[90] | diStefano et al, 2009[91] | Boren et al, 2011[92] | Philippon et al, 2011[95] | McBeth et al, 2012[93] | Selkowitz et al, 2013[94] | mean |
|---|---|---|---|---|---|---|---|---|---|---|
| Sidelying: Clam, 45° hip flexion | | | | | | 47 | 43 | 33 | 27 | 37.5 |
| Step-Up: Reverse | | 37 | | | | | | | | 37.0 |
| Standing: Abduction, NWB side | 33 | | | | | | | | | 33.0 |
| Dynamic: Side Step | | | | | | | | | 30 | 30.0 |
| Lunge: Forward | | | 29 | 19 | 42 | | | | | 30.0 |
| Sidelying: Clam, 0° hip flexion | | | | | | | 28 | | | 28.0 |
| Standing: Abduction, hip flexed, NWB | 28 | | | | | | | | | 28.0 |
| Bridging: Bridge | | | 28 | | | | 26 | | | 27.0 |
| Plank: Front Plank on elbows | | | 27 | | | | | | | 27.0 |
| Step-Up: Step Up & Over | | | | 15 | | | | | | 15.0 |
| Squat | | | | | | | | | 10 | 10.0 |

Exercise Intervention in Non-LBP Entities

Studies in clinical entities other than low back pain have evaluated gluteus medius strengthening protocols. Fredericson and colleagues demonstrated significant strength improvements in runners with iliotibial band syndrome.[98] They utilized two exercises: sidelying hip abduction and a pelvic drop.[98] These were dosed at one set of fifteen repetitions daily of each exercise and progressed up to three sets of 30 reps over a six-week training period with once weekly clinic visits.[98] They found significant improvement in strength with this intervention; at the six-week assessment hip abductor strength was no different than a control group.[98]

Sled and colleagues used a hip abductor strengthening exercise program in a population of patients with knee OA.[99] They used sidelying hip abduction, standing hip abduction, and pelvic drops each performed to fatigue at a frequency of 3-4 bouts per week over an eight-week training period.[99] They scheduled two clinic visits over that period to assess form and progress resistance of exercises as needed; they also called participants every other week to ensure adherence.[99] Participants documented their

exercise in a training calendar.[99] They found that there was significant improvement in hip abductor strength after the strengthening program and this final strength assessment was no different than a control sample.[99]

Ferber and colleagues treated a sample of people with patellofemoral pain with a hip abductor strengthening program.[100] They used two exercises in standing: hip abduction in the frontal plane and hip abduction with 45° of hip extension.[100] Both of these exercises were performed against resistance provided with elastic exercise bands secured at the ankle.[100] They performed three sets of 10 repetitions of each exercise daily over three weeks.[100] They found a significant increase in hip abductor strength as assessed by dynamometry.[100] This final strength assessment was not different compared to a control sample.[100]

## Exercise Intervention in LBP

Kendall and colleagues reported a hip abductor strengthening program in ten people with non-specific low back pain.[63] They prescribed two exercises in standing using elastic resistance bands: participants abducted their limb in the frontal plane for the first exercise and abducted and extended their limb in a plane 45° from either the frontal or sagittal plane.[63] Resistance was determined by using the band that allowed participants to maintain desired form during ten to 15 repetitions while reporting fatigue in the hip abductor musculature.[63] Participants were prescribed three sets of ten repetitions of both of these exercises to be completed daily over a three-week intervention period.[63] Resistance was not progressed over the intervention period.[63] After the intervention normalized hip abduction strength was significantly improved from 6.6 N/kg to 7.4 N/kg ($p=0.02$).[63] Pain, rated on a 0-10 VAS, in this population was also improved: from 5.9 to 1.8 although this did not reach significance, suggesting large variability and insufficient sample size.[63]

These studies suggest that gluteus medius dysfunction has a role to play in low back pain, can be assessed clinically in multiple modes, and is amenable to treatment with exercise. However chronic low back pain is not a straightforward entity with psychological factors playing a significant role. These factors need to be monitored in any intervention in chronic low back pain.

## Psychological Factors in Chronic Pain

It is widely accepted that psychological factors play a significant role in chronic pain conditions. Currently, the literature focuses on the fear-avoidance model presented by Vlaeyen and Linton.[101] This model describes a chronic pain condition where the painful experience is catastrophized leading to fear of pain and avoidance of activities that may trigger that pain. This fear and avoidance leads to disuse, disability, and depression which all negatively feed back into the pain experience, continuing the cycle. Monitoring of these psychological factors is recommended in low back pain research as well as in psychologically informed physical therapy practice.[5,102]

These psychological factors are easily assessed with questionnaires. The Pain Catastrophizing Scale (PCS) is a 13 question tool scored on a five point Likert scale.[103] It has been demonstrated to be valid and reliable.[103] The Fear-Avoidance Beliefs Questionnaire (FABQ) is commonly used to assess fear of pain and avoidance of painful activities in chronic low back pain.[104,105] It assesses fear of both general activities and work activities.[104] It is valid and reliable in the chronic low back pain population.[104] The Tampa Scale for Kinesiophobia is also frequently used to assess fear of movement in chronic low back pain.[105,106] Multiple assessments exist for the assessment of depressive symptoms. The Beck Depression Inventory is the most commonly used depression assessment used in outcome assessments in chronic low back pain populations.[105,107] It is valid and reliable.[107] Multiple other depression assessments are used clinically and in

research, including the Hospital Anxiety and Depression Scale (HADS) and the Center for Epidemiological Studies Depression Scale (CES-D).[108,109] In addition to assessment of psychological factors, outcomes need to be assessed in chronic low back pain. Several assessments are widely recommended as outcomes in chronic low back pain.

## Monitoring Outcomes in Chronic Low Back Pain

It is important to assess multiple dimensions of outcome in chronic low back pain. A minimum data set has been proposed to describe the participants evaluated.[5] This includes demographic information as well as self-report of pain, function, psychosocial factors and affect.[5] Additionally some of these items, including pain and the Patient Reported Outcomes Measurement Information System (PROMIS) short form, are appropriate as an outcome measures.[5] Other self-reports of function such as the Oswestry or Roland-Morris Disability Questionnaires are appropriate alternatives.[5,110,111] Additionally, functional assessments should also be part of the outcome assessment in chronic LBP. Novy and colleagues suggest function assessments cluster around two factors: speed & coordination and endurance & strength.[112] The fifty-foot walk, repeated trunk flexion, repeated sit-to-stand, and rollover tests all clustered as the speed & coordination construct.[112] While 5-minute walk, loaded reach, and Sorensen test clustered as the endurance & strength construct.[112] All of these tests have been demonstrated to be reliable and valid.[113]

## Summary

Despite the sizeable body of literature supporting exercise interventions as effective and an intervention of choice in chronic low back pain the choice of precisely what exercises to select remains uncertain. Classification schemes developed over the past two decades have begun to aid clinicians in the process of matching effective

exercise to some patients. These systems generally do not integrate dysfunction across the hip as a part of the clinical entity of low back pain. This is in spite of the evidence to support interactions of low back and hip complaints as well as more direct evidence to support the idea of gluteus medius dysfunction playing a direct role in low back pain. Assessment of gluteus medius function has been reported with multiple functional assessments as well as more direct strength assessments. These assessments allow for the evaluation of exercise interventions that have been demonstrated to be effective treatments for gluteus medius strength deficits. Exercise choice is informed by both EMG studies and prior interventional studies. Additionally in the context of chronic low back pain psychological factors play a role and should be monitored. Outcomes in chronic low back pain are widely recognized to include both pain and disability reporting. Direct functional assessment also is important to include as an outcome.

The first project below tested the hypothesis that gluteus medius weakness and tenderness occurs in the majority of people with chronic non-specific low back pain compared to people without low back pain. I assessed three specific aims. The first aim was to determine the prevalence of gluteus medius weakness and tenderness in people with and without chronic low back pain. The second aim was to compare gluteus medius strength and tenderness between people with and without chronic low back pain. The third aim was to assess the ability of gluteus medius weakness and tenderness to explain the presence of chronic low back pain in this sample of people.

The second project tested the hypothesis that gluteus medius strengthening is more effective than a standard exercise program for people with chronic non-specific low back pain with gluteus medius weakness and tenderness on examination. I assessed two specific aims. The first aim was to determine the effectiveness of a gluteus medius strengthening program compared to a standard exercise program in participants with chronic low back pain. Using a randomized trial design, I compared a standard exercise program with a gluteus medius strengthening program for the treatment of non-specific

chronic low back pain. The primary outcome was self-reported pain. Secondary outcomes included global rating of change, low back pain-related disability, quality of life, function, and fear-avoidance. The second aim was to determine if this gluteus medius strengthening program improved gluteus medius muscle strength. I assessed strength with handheld dynamometry, as well as functional strength utilizing the Active Hip Abduction Test and Single Limb Squat Test.

# CHAPTER 3: PREVALENCE OF GLUTEUS MEDIUS DYSFUNCTION IN CHRONIC NON-SPECIFIC LOW BACK PAIN

This chapter is a modified version of a published manuscript: Cooper, N.A., Scavo, K.M., Strickland, K.J. et al. Prevalence of gluteus medius weakness in people with chronic low back pain compared to healthy controls *Eur Spine J* (2016) 25:1258.

## Introduction

Low back pain (LBP) was recently reported to be the single largest cause of disability across the globe.[114] Current interdisciplinary practice guidelines show strong evidence for exercise as an intervention for LBP and thus recommend exercise for management of both acute and chronic LBP.[9,115] A variety of exercise interventions have been studies in randomized controlled trials and have been shown to improve pain and disability in people with LBP.[24,116] Despite this support, it remains unclear which exercise interventions are optimal in people with chronic LBP.[24] Current physical therapy guidelines suggest several possible exercise treatment strategies depending on the patient's presentation.[21] Most patients with long-standing LBP are matched to exercise treatment based on the physical therapy evaluation.[21] Specifically, exercise interventions provided by physical therapists typically focus on the abdominal and lumbar musculature strength or directional preference exercises.[21,117,118]

An alternative to these interventions may be to focus on the hip abductor musculature. Simons and Travell describe myofascial pain from the gluteus medius muscle as a common component of LBP.[59] Subsequently, Njoo and van der Does reported a higher prevalence of gluteus medius myofascial trigger points in people with LBP.[60] We also suggested gluteus medius weakness is associated myofascial pain and trochanteric bursitis is a common clinical presentation in people with LBP.[71] In addition to myofascial pain, weakness of hip abductors has been described in LBP when compared

to healthy controls.[61-63] Further, asymmetry in hip abductor strength has been correlated with increased likelihood to seek care for LBP in collegiate athletes and we reported gluteus medius weakness was associated with onset of LBP during pregnancy.[66,72] More recently Nelson-Wong and colleagues reported that subjects who developed LBP during an experimental standing task had a different recruitment pattern of gluteus medius muscle compared to those who did not develop LBP.[67] Although these findings are suggestive of hip abductors playing a role in LBP, it is unclear what proportion of the population with LBP presents with hip abductor weakness and associated symptoms when compared to healthy controls as well as which hip abductor muscles are weak.

In this study we quantified the prevalence of hip muscle weakness and tenderness of the hip and low back in people with chronic non-specific LBP. We hypothesized that gluteus medius weakness and tenderness occurs in the majority of people with non-specific chronic LBP compared to people without LBP. We supported this with three aims: The first aim was to determine the prevalence of gluteus medius weakness and tenderness in people with and without chronic low back pain. The second aim was to compare gluteus medius strength and tenderness between people with chronic low back pain, stratified by affected side, and without chronic low back pain. The third aim was to assess the ability of gluteus medius weakness and tenderness to explain the presence of chronic low back pain in this sample of people.

## Methods

### Participants

Two groups of participants were recruited. One hundred fifty people seeking care for LBP lasting longer than three months at the University of Iowa Spine Center Physical Therapy Clinic were serially recruited at time of presentation to the clinic. Potential participants were recruited if they had non-specific LBP, defined as pain anywhere from

the inferior rib margin to the gluteal fold, for more than three months.[2] People with a defined etiology, including radiculopathy, neurogenic claudication, fracture, primary or secondary spinal tumors, or other specific pathology, were excluded. One hundred fifty-one people were approached and agreed to participate with one participant withdrawing after participation. After recruitment of the LBP group, an age and sex matched cohort of 75 control participants was recruited. These participants were matched to age by decade. Potential participants were questioned about their personal history with LBP: only people reporting no to having current LBP and no to having a history of more than three months of LBP were included. Two people were excluded for histories of more than three months of LBP. The University of Iowa Institutional Review Board approved this study and informed consent was obtained from all participants.

## Screening Examination

All potential participants were screened for exclusionary diagnoses with a standardized history and physical examination. This included questions screening for lower extremity paresthesia & weakness, bowel & bladder dysfunction, predominant lower extremity pain with standing & walking, history of trauma, presence of systemic illness, weight loss, and predominant night pain. The physical examination screening included assessment for reflex asymmetry, myotomal weakness, sensory disturbance, straight leg raise, and groin pain with hip internal rotation. Potential participants were excluded if screening was suggestive of specific pathology. Potential control participants were screened identically and additionally were excluded if they presented with either acute or chronic low back pain.

## Muscle Strength

Gluteus medius, TFL, & gluteus maximus manual muscle tests (MMTs) were performed using break tests as described by Hislop & Montgomery.[79] Gluteus medius strength was tested by positioning the participant in side-lying and having the participant

abduct and slightly extend the hip while keeping the pelvis rotated slightly forward. Resistance was applied at the ankle. TFL strength was tested by positioning the participant in side-lying with the limb to be tested flexed at the hip. The hip was abducted in this flexed position and resistance was applied at the ankle. Gluteus maximus strength was tested positioning the participant in prone with the knee flexed, then the hip was extended with the knee remaining flexed and resistance was applied at the posterior thigh just above the knee. MMTs were scored using the criteria defined by Hislop & Montgomery.[79] If the participant was able to resist maximal resistance they were scored 5/5, if they broke against resistance: 4/5; if they were unable to tolerate resistance, but could move against gravity: 3/5; if they could move the limb when positioned to minimize the effect of gravity: 2/5; palpable contraction, but no movement: 1/5, and no palpable activity: 0/5.

### Trendelenburg Sign

The Trendelenburg sign was assessed as a functional measure of gluteus medius strength.[73] This was performed as outlined by Hardcastle & Nade.[74] Participants stood with the examiner behind them, observing the iliac crests visually and with palpation, and were instructed to lift one foot off the ground by flexing the hip. The sign was considered absent if the participant was able to maintain the pelvis in neutral or with the non-stance side elevated and present if the participant was unable to maintain the pelvis level or had to shift the trunk to keep the pelvis level.

### Tenderness

The gluteals, greater trochanters, lumbar paraspinals, and piriformis were palpated for tenderness bilaterally. Gluteus medius was palpated from its distal insertion at the greater trochanter over the muscle belly toward the posterior superior iliac spine (PSIS) and then over its proximal attachment along the ilium just inferior to the iliac crest. Gluteus maximus was palpated at its origin along the posterior ilium and lateral sacrum,

then over the muscle belly to its distal insertion at the iliotibial band inferior to the greater trochanter. The greater trochanters were palpated most laterally initially and then posteriorly and superiorly to the apex of the trochanter. The lumbar paraspinals were palpated from just medial to the PSIS superiorly to the thorax. Palpation of the piriformis was attempted from its lateral insertion at the greater trochanter, over the muscle belly, toward its origin on the sacrum. Tenderness was defined as reproduction of the participant's pain complaint when using enough pressure to blanch the examiner's nail.

## Inter-Rater Reliability

Inter-rater reliability was assessed between all four assessors. Assessors had one to forty years in performing these assessments. All assessors independently and in random order assessed a series of six female pilot participants with a mean age of 30 years, three with LBP and three without LBP, using the above described MMT, Trendelenburg sign, and muscle tenderness examination. The examiners were blinded to the presence of LBP in these participants. Reliability of MMT was poor with paired weighted $\kappa$'s ranging from 0 to 0.667. The assessors had perfect reliability ($\kappa$=1 for all pairs) for the Trendelenburg sign and muscle tenderness examination.

## Data Analysis

Data from participants with chronic LBP were divided into affected and unaffected sides based on the location of their symptoms. Participants with bilateral complaints were treated as both sides being affected sides. The percentage of participants with each symptom was calculated. Age, height, weight, and BMI were compared with independent samples t-tests. Sex distribution was compared between groups with a chi-squared test. Manual muscle testing, the presence of the Trendelenburg sign, and palpation tenderness were assessed between groups and side using a generalized estimating equation. Logistic regression was performed to identify predictors of the presence of LBP in the total sample population. Any demographic differences between

samples were treated as covariates. Potential predictors included age, sex, BMI, gluteus medius strength, gluteal tenderness to palpation, and the presence of Trendelenburg sign. Regression was performed in both forward and backward methods using $p<0.05$ as entry criterion and $p>0.1$ as exit criterion. Significance was set at $p=0.01$ for all tests. SPSS 24 was used for all analyses.

## Results

One hundred fifty participants with chronic LBP and 75 age and sex matched control participants were recruited and enrolled. Characteristics of both groups are presented in Table 3. Participants with chronic LBP had a higher BMI. Eighty-four participants with LBP had unilateral symptoms and 66 had bilateral symptoms, totaling 216 affected and 84 unaffected sides.

**Table 3:** Participant characteristics, mean ± standard deviation. Only weight and BMI were significantly different.

| | Chronic LBP (n=150) | Control (n=75) | Comparison |
|---|---|---|---|
| **Age (years)** | 41.4±13.0 | 40.7±13.9 | t=0.329 p=0.743 |
| **Sex (% female)** | 64.7% | 65.3% | $\chi^2$=1.508 p=0.219 |
| **Height (cm)** | 169.4±11.4 | 168.2±9.4 | t=0.801 p=0.424 |
| **Weight (kg)** | 84.9±22.2 | 73.2±21.2 | t=3.623 p<0.001 |
| **BMI (kg/m$^2$)** | 29.6±7.2 | 25.8±7.0 | t=3.543 p<0.001 |

There were significant main effects for MMT of the gluteus medius and TFL (Figure 1). A significant decrease in gluteus medius strength was observed for the affected side (MMT grade±SD, 3.35±0.73) compared to the unaffected side (4.56±0.66, $p<0.001$) or control group (4.46±0.50, $p<0.001$). TFL strength was significantly greater on the unaffected side (4.93±0.26) compared to controls (4.48±0.50, $p<0.001$), but not

the affected side (4.81±0.44). There were no significant differences in gluteus maximus strength. There was a significant main effect for the Trendelenburg sign between groups The Trendelenburg sign was more frequently present on the affected side (54.2%) compared to the unaffected side (7.1%, $p<0.001$) or controls (9.7%, $p<0.001$, Figure 1d).

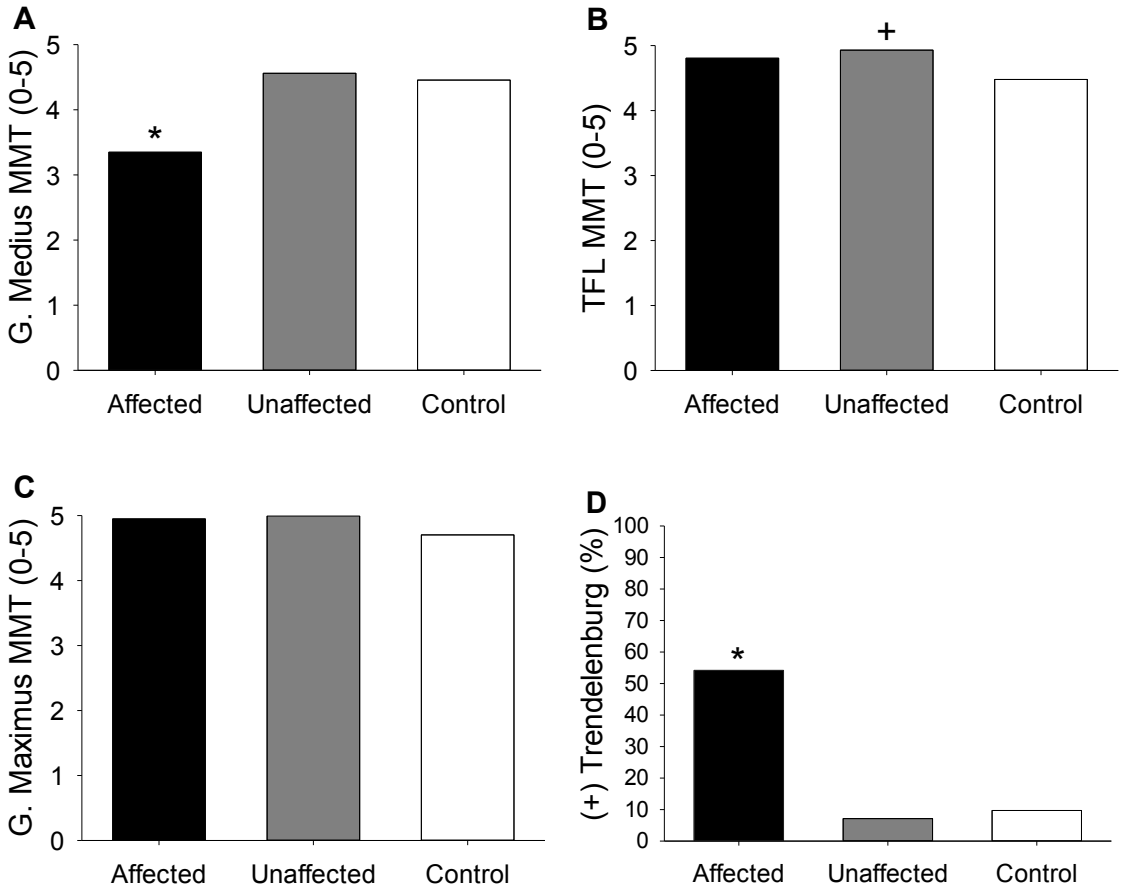


**Figure 1:** Gluteus medius strength is significantly less on the affected side compared to the unaffected side or controls (*p<0.001). TFL strength is greater on the unaffected side compared to controls (+p<0.001). Trendelenburg sign is significantly more prevalent on the affected side compared to both the unaffected side and controls (*p<0.001)

There was a significant difference for the presence of palpation tenderness between groups ($p<0.001$, Figure 2a). There were significant main effects for palpation tenderness over the gluteals, greater trochanter, and lumbar paraspinals ($p<0.001$, Figure

2b-d). Gluteal tenderness was more prevalent on the affected side (68.1%) compared to the unaffected side (4.8%, p<0.001) or controls (11.2%, p<0.001). Similarly, there was more frequent tenderness over the greater trochanter on the affected side (44.9%) compared to the unaffected side (6.0%, p<0.001) or controls (6.0%, p<0.001). Lumbar paraspinal tenderness was more prevalent on the affected side (53.2%) compared to the unaffected side (23.8%, p<0.001) or the controls (0.7%, p<0.001), as well as being different between the unaffected side and controls (p<0.001). There was no significant difference in piriformis tenderness.

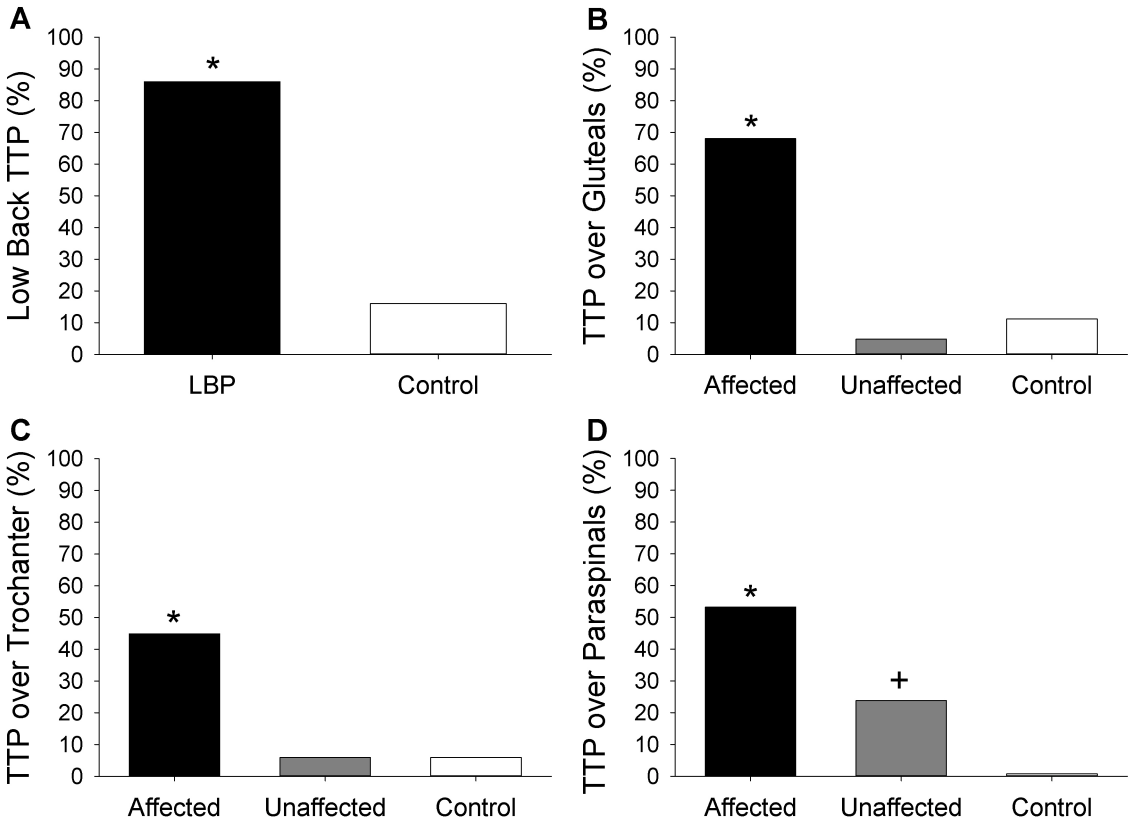


**Figure 2:** Low back tenderness is more prevalent in participants with LBP (*p<0.001). Tenderness is more prevalent over the gluteals, greater trochanter, and lumbar paraspinals on the affected side compared to both the unaffected side and controls (*p<0.001). There is more paraspinal tenderness on the unaffected side compared to controls (+p=0.001).

Logistic linear regression found that higher BMI, gluteus medius weakness, low back regional tenderness, and male sex as predictors of LBP across this sample (Table 4).

**Table 4:** Logistic regression with BMI as a covariate. Gluteus medius strength, gluteal tenderness, and male sex were predictive of LBP.

| | Beta | Standard Error | Wald chi-square | p | OR | Model OR |
|---|---|---|---|---|---|---|
| **Constant** | 2.962 | 0.882 | 11.274 | 0.001 | | 6.52 |
| **BMI** | 0.098 | 0.021 | 21.254 | <0.001 | 1.83 | |
| **G. Medius Strength** | -1.069 | 0.201 | 28.279 | <0.001 | 1.1 | |
| **Male Sex** | 1.051 | 0.287 | 13.416 | <0.001 | 3.58 | |
| **Gluteal Tender** | -1.049 | 0.366 | 8.194 | 0.004 | 0.01 | |

## Discussion

The current study identifies a sub-population of patients with chronic non-specific LBP with signs of hip abductor dysfunction: significant gluteus medius weakness, gluteal tenderness, and the Trendelenburg sign. However only the gluteus medius weakness and gluteal tenderness were significant predictors of the presence of LBP when compared to the controls. Future studies will need to confirm this subgroup in other settings and determine if treatment of the gluteus medius weakness and tenderness has a positive effect on symptoms.

Our data agree with prior studies showing relative hip abductor weakness in people with LBP compared to controls.[62,63] Both of these studies look at hip abduction in the frontal plane with contributions from the TFL and gluteus medius. Neither study assessed the composite abduction and extension that is performed by the gluteus medius with minimal TFL contributions.[79] The current study was specifically designed to separate out the contribution of the TFL from the gluteus medius by attempting to evaluate each individually. Our results demonstrated no difference in TFL strength between controls and the affected side of participants with LBP, but significant weakness

in the gluteus medius in participants with LBP. Thus, the current study suggests gluteus medius muscle weakness contributes to the presentation of chronic non-specific LBP. Reproduction of these results with a quantitative strength assessment such as dynamometry could be used to confirm the current results. Further the effects of treatment of the gluteus medius muscle weakness on LBP itself would further help determine the relevance of the weakness to the pain itself. Additionally there may be some amount of gluteus medius muscle weakness in the population in general. A large proportion of our control population scored only 4/5 on MMT of gluteus medius muscle and thus this could be a potential risk factor for development of non-specific LBP.

Others have also suggested that gluteus medius dysfunction plays a role in LBP. Simons and Travell described gluteus medius muscle referred pain as a component of LBP.[59] Nadler and colleagues demonstrated a higher likelihood of onset of LBP in female athletes with hip abductor strength differences between sides.[66] Nelson-Wong and colleagues demonstrated gluteus medius co-activation as a predictor of onset LBP during an experimental standing task.[67] Together these data suggest that gluteus medius muscle may play a significant role in chronic LBP. However, it is unclear if initial gluteus medius muscle weakness is a cause or consequence of LBP as well as how to manage this observed dysfunction.

Current physical therapy management of patients with LBP is guided by a treatment based classification system that attempts to match subgroups of patients with the interventions that lead to the best outcomes.[21] Much of this work has focused on acute LBP; patients with chronic LBP do not readily fit into this classification system.[22] A recent review of classification systems for chronic LBP found strong evidence to support the reliability of only two systems: the McKenzie and the Movement Impairment classification systems.[25].They also report some evidence to support the effectiveness of the McKenzie classification system.[25] There does not exist a comprehensive classification system that directs intervention and successfully predicts outcome. One of the difficulties

in directing exercise treatment in chronic LBP may be the broad effect of any exercise intervention.

Most exercise interventions in chronic LBP populations are effective.[116] The most recent Cochrane meta-analysis of exercise in LBP found that individually prescribed exercise interventions that included strengthening and stabilization exercises were most common in chronic LBP populations.[11] These exercise interventions were concluded to be effective in improving pain and function in chronic LBP.[11] This finding was reiterated in the clinical practice guidelines from the American Pain Society and American College of Physicians.[115] However, they do not differentiate between choice of exercise intervention.[115] One of the chief reasons for the paucity of advice regarding specific exercise selection is the poor description of exercise interventions in the literature. Future experiments should examine specific populations with well-described targeted exercise programs.[11] We believe patients with chronic non-specific LBP who present with gluteus medius weakness and associated tenderness may represent a treatment subgroup that could benefit from targeted gluteus medius strengthening. A preliminary study of ten people with non-specific LBP treated with three weeks of hip abductor strengthening reduced pain by 48%, but was not statistically significant.[63] Future clinical studies will need to confirm that gluteus medius strengthening produces superior results than other forms of exercise in this subgroup of patients with chronic LBP.

The current study demonstrated a statistical difference in TFL strength between the unaffected side of participants with LBP and control participants. The assessed strength values are extremely close: 4.48 in the controls and 4.93 in the participants with LBP on the unaffected side. Although this difference reached statistical significance we believe this does not represent a clinically significant difference, especially given the lack of objective criteria for MMT grades above 3/5.[79] Use of dynamometry may better evaluate this apparent difference in muscle strength.

There are several limitations in this study. The clinical sample was recruited from one specialty physical therapy clinic in a major university hospital. The population referred to our clinic may be uniquely different than those seen in a general practice. Therefore, future studies should confirm this distribution across other practice settings. Although our controls were matched by age and sex to the clinical sample, they had a lower BMI. It is possible that our controls were healthier or more physically active and thus stronger. The assessments we used are performed routinely in clinical settings, however they have limited objectivity. The high inter-rater reliability for tenderness and Trendelenburg sign may represent extensive training of our examiners prior to data collection. Alternatively, this may represent systematic bias of the assessors. While inter-rater reliability of MMT is low, this is similar to prior reports.[80] MMT is a subjective assessment with limited resolution and vulnerable to bias. Further, we acknowledge that MMT used clinically is an indirect measure of muscle function and not as strong as dynamometry.[85] Using palpation, a commonly used clinical measure, is similarly less specific than using pressure pain thresholds, which could be confirmed with pressure algometry. Additionally, a larger sample of people examined to assess reliability would give more confidence in these assessments. Future studies should utilize quantitative assessments such as pressure algometry to measure pain thresholds, dynamometry to measure muscle strength, and electromyography to examine muscle activation patterns to directly compare and confirm the clinical measures of palpation tenderness and MMT. Future studies should also determine if strengthening of the gluteus medius muscle will alleviate LBP symptoms and which of these measures individually or in combination predicts outcomes to treatment.

## Conclusion

Gluteus medius muscle weakness and associated tenderness is a common presentation in people with chronic non-specific LBP. Focusing on assessment and treatment of gluteus medius muscle dysfunction may allow for better clinical decision making and better treatment outcomes for people with LBP.

# CHAPTER 4: GLUTEUS MEDIUS STRENGTHENING IN CHRONIC NON-SPECIFIC LOW BACK PAIN, A PILOT STUDY

## Specific Aims

Low back pain is the most common form of chronic pain affecting more than 8% of the US population and costing more than $90 million in health care costs.[6,119] Despite this, there are few effective treatments for chronic low back pain. However, exercise is one treatment that has substantial literature supporting its effectiveness.[115] Several forms of exercise are effective including aerobic, core strengthening, and motor control exercises for low back pain.[120] Non-specific chronic low back pain, defined as pain without an underlying pathology, is the most common. Our preliminary data demonstrate that 90% of people referred to physical therapy with non-specific chronic low back pain have weakness of the gluteus medius muscle that is associated with back, hip, or gluteal tenderness; this is substantially greater than age- and sex-matched healthy controls. This led to the hypothesis that an exercise program that includes targeted strengthening the gluteus medius muscle would be more effective than a standard exercise program.

Specific Aim 1 will determine the effectiveness of a gluteus medius strengthening program compared to a standard exercise program in participants with chronic low back pain. Using a randomized trial design, we will compare a standard exercise program with a hip abductor (gluteus medius) strengthening program for the treatment of non-specific chronic low back pain. The primary outcome will be self-reported pain. Secondary outcomes include global rating of change, low back pain-related disability, quality of life, function, and fear-avoidance.

Specific Aim 2 will determine if the gluteus medius strengthening program improves gluteus medius muscle strength. We will assess strength with handheld dynamometry, as well as functional strength utilizing the Active Hip Abduction Test and Single Limb Squat Test.

The expected outcomes of this work are to demonstrate that the addition of specific gluteus medius muscle strengthening exercises will show greater improvement in low back pain, disability, quality of life, function, and fear avoidance when compared to the standard exercise program. We also expect to see concomitant increases in gluteus medius muscle strength in the gluteus medius strengthening group. The positive impact of this work will be improved clinical decision making by physical therapists treating patients with chronic low back pain leading to better treatment outcomes.

## Background

Chronic low back pain is the most common form of chronic pain.[119] Non-specific low back pain, pain without underlying pathology, is the most common type of chronic low back pain. Despite being a common problem, there are few effective treatments for chronic low back pain. Low back pain results in reduced physical activity, reduced function and disability. It has become increasingly clear that fear of pain, particularly pain with movement, results in avoidance of physical activity and contributes to disability. This has been referred to as the fear avoidance model.[104] Exercise interventions are an effective treatment for chronic low back pain.[115] While fear of movement and activity can reduce physical activity and be a barrier to exercise, effective exercise treatment can reduce fear-avoidance.[121,122] Even though exercise therapy is an effective treatment for chronic low back pain, it is not clear what exercise interventions are best in this population.

In the acute low back pain population a treatment based classification schema has been developed based on subgroups. Using this classification approach improved outcomes are observed when compared with treating low back pain as a homogenous condition; however these subgroups have not been useful in chronic low back pain.[22,123] It is likely that subgroups are present in chronic low back pain, although what these

subgroups are is unclear. Our group has found there is a subgroup of patients with chronic low back pain that has significant gluteus medius muscle weakness.[124] Our previously published data, presented in Chapter 3, show the prevalence of gluteus medius muscle weakness and associated symptoms in people with non-specific chronic low back pain referred to physical therapy when compared to age- and sex-matched controls.[124] Specifically, we show that almost 80% of people seeking treatment for chronic non-specific low back pain at the University of Iowa Spine Center Physical Therapy Clinic are weak in one or both gluteus medius muscles. The average muscle strength ratings are approximately 3/5: able move against gravity, but not able to tolerate additional resistance. In addition, palpation tenderness that reproduces the patient's pain complaint was frequently present over the greater trochanter, gluteal muscles, or lumbar paraspinal muscles while tenderness was rarely found in healthy controls. These data demonstrate that a significant portion of the non-specific chronic low back pain population has significant gluteus medius muscle weakness and tenderness of the region that reproduces symptoms. In our clinical experience utilizing exercises targeting the gluteus medius muscle has excellent outcomes. However there is little research on the role of gluteus medius muscle weakness in low back pain. Additionally, Simons and Travell reported the gluteus medius muscle as a potential source of low back pain.[59] Njoo and Van der Does, expanding on the work of Simons and Travell, show muscle tenderness on palpation of the gluteus medius muscle that reproduces the patient's pain complaint: 34% of their participants with acute low back pain had gluteus medius muscle tenderness.[60] Bewyer and Bewyer proposed a low back pain subcategory of pain secondary to gluteus medius muscle weakness and referred pain.[71] Gluteus medius muscle weakness has been correlated with the onset of low back pain during pregnancy.[72] Thus, we hypothesize gluteus medius muscle weakness with associated tenderness is a subgroup of people with non-specific chronic low back pain that may benefit from a targeted exercise program.

## Methodology

This study used a randomized controlled comparative effectiveness trial to assess the effect of gluteus medius muscle strengthening to a standard exercise protocol in people with chronic low back pain who have gluteus medius muscle weakness with associated tenderness. This was a pilot to assess the feasibility of the study design and to gather preliminary data on the effectiveness of the gluteus medius strengthening intervention.

## Participants

### Inclusion Criteria

Male and female adults at least 18 years old were eligible to participate. Inclusion criteria included having chronic non-specific low back pain. Non-specific low back pain was defined as pain anywhere from the inferior costal margin to the inferior gluteal fold, with or without radiating pain to the lower extremity.[2] Pain was chronic, with chronic defined as present for three or more months and bothersome on at least half of the days of the past six months.[2,5] On examination participants must have had a negative straight leg raise test bilaterally, less than four out of five gluteus medius muscle strength on manual muscle testing, as well as tenderness over the lumbar paraspinal muscles, gluteal muscles, and/or greater trochanter region.

### Exclusion Criteria

Potential participants were excluded if they had any signs or symptoms of serious spinal pathology that merited further work up including radiculopathy, cauda equina syndrome, discitis, cancer, or fracture. Potential participants were excluded if they had any specifically identified pathology that was a source of their back pain, a prior history of thoracolumbar or pelvis fracture, thoracic or lumbar spine surgery or abdominal

surgery, neurological injuries, diseases affecting the lower extremities, lower extremity musculoskeletal injuries or diseases, or any lower extremity orthopedic surgeries will be excluded.

**Table 5:** Inclusion & Exclusion Criteria

| | Inclusion Criteria | Exclusion Criteria |
|---|---|---|
| **Demographics** | Age 18+<br>CLBP<br>At least 4/10 pain | Ages <18<br><3 months of LBP<br>Specific etiology of LBP |
| **Target Subgroup of CLBP** | <4/5 gluteus medius MMT<br>TTP over gluteal bellies<br>Reproduction of pain complaint with gluteus medius MMT or palpation | ≥4/5 gluteus medius MMT<br>No gluteal TTP<br>No pain with both gluteus medius MMT or palpation |
| **Signs of Serious Spinal Pathology** | Negative SLR<br>Intact sensory and motor function | Positive SLR<br>Dermatomal paresthesia<br>Myotomal weakness<br>Bowel or bladder incontinence<br>Saddle paresthesia<br>Current systemic infection<br>Unexplained weight loss<br>Non-mechanical pain |
| **History** | No fractures of thoracic or lumbar vertebra, pelvis, or LE<br>No abdominal, thoracolumbar, pelvis, or LE surgery<br>Unimpaired LE function | Fracture: thoracic or lumbar vertebra, pelvis, or LE<br>Surgery: Abdominal, thoracolumbar, pelvis, or LE<br>LE function: injury or disease with sequelae impacting LE function |

## Population

Participants were initially attempted to be recruited from the University of Iowa Spine Center physical therapy and physiatry clinics. This was not an adequate population as all potential participants were excluded secondary to history or comorbidity over the initial six-week recruitment period. Subsequently, participants were recruited from the University of Iowa community through an IRB-approved mass email.

## Randomization

Participants were randomized to treatment immediately before the intervention was begun and randomization was stratified by sex. An allocation concealment method

with permuted block randomization (4 per block) was used to randomize participants to one of the two treatments.

### Demographic data

Participant age, sex, height, and weight were assessed at the initial visit.

## Intervention

### Exercise Program

Both groups performed standardized exercise protocols. The stabilization exercise protocol was based on the protocols utilized by Hicks and colleagues and Rabin and colleagues.[37,38] They used a series of four exercises designed to improve the stabilizing function of the abdominal musculature using the abdominal drawing in maneuver (ADIM) in various activities.[37,38] They used explicit criteria to advance participants through progressively more challenging exercises for each muscle group. This exercise intervention was selected because it is the most common matched intervention for people with chronic non-specific low back pain within the Treatment Based Classification system that is currently recommended as standard of practice within the physical therapy profession.[21] The gluteus medius strengthening group performed exercises targeting the gluteus medius muscle. These are based on the EMG literature and previously reported gluteus medius strengthening programs.[63,87-95,98-100] These also used a criterion-based progression to standardize treatment.

At each visit the participant performed an exercise from each progression, starting with the first exercise on the first visit or the exercise that was previously prescribed at their prior visit. If they met the criterion for progression, they performed the next exercise, if they did not meet the criterion for progression that exercise is prescribed. This

was repeated for each exercise progression until the participant failed to meet the criteria for progression.

**Table 6:** Stabilization Exercise Protocol

| Exercise | Progression Criterion |
|---|---|
| **Quadruped Progression** | |
| ADIM in quadruped | 30 reps with 8 sec hold |
| ADIM in quadruped, UE lifts | 30 reps with 8 sec hold, both sides |
| ADIM in quadruped, LE lifts | 30 reps with 8 sec hold, both sides |
| ADIM in quadruped, UE & LE lifts | 30 reps with 8 sec hold, both sides |
| ADIM in quadruped, dynamic UE & LE lifts | |
| **Supine Progression** | |
| ADIM in supine | 30 reps with 8 sec hold |
| ADIM in supine, heel slides | 20 reps with 4 sec hold, both sides |
| ADIM in supine, LE lift | 20 reps with 4 sec hold, both sides |
| ADIM in supine, bridge | 30 reps with 8 sec hold |
| ADIM in supine, SLS bridge | 30 reps with 8 sec hold, both sides |
| ADIM in supine, curl up, elbows at sides | 30 reps with 8 sec hold |
| ADIM in supine, curl up, elbows elevated | 30 reps with 8 sec hold |
| ADIM in supine, curl up, hands at head | |
| **Sidelying Progression** | |
| ADIM in sidelying | 30 reps with 8 sec hold |
| ADIM in sidelying, side plank, knees bent | 30 reps with 8 sec hold, both sides |
| ADIM in sidelying, side plank, knees extended | 30 reps with 8 sec hold, both sides |
| ADIM in sidelying, side plank with tilt | 30 reps with 4 tilts A/P, both sides |
| ADIM in sidelying, side plank with roll | |
| **Standing Progression** | |
| ADIM in standing | 30 reps with 8 sec hold |
| ADIM in standing, row | 30 reps with 8 sec hold |
| ADIM in standing, walking | |

**Table 7:** Gluteus Medius Strengthening Protocol

| Exercise | Progression Criterion |
|---|---|
| **Supine Progression** | |
| Bridge | 30 reps with 8 sec hold |
| Bridge with Arms Crossed | 30 reps with 8 sec hold |
| Bridge with Arms Crossed & Feet Together | 30 reps with 8 sec hold |
| SLS Bridge | |
| **Sidelying Progression** | |
| Clam at 45 degrees | 30 reps with 8 sec hold |
| Sidelying hip abduction, knees extended | 30 reps with 8 sec hold |
| Side plank, knees bent | 30 reps with 8 sec hold |
| Side plank, knees extended | 30 reps with 8 sec hold |
| **Squat Progression** | |
| Squat | 30 reps |
| SLS mini squat | 30 reps |
| SLS squat | |
| **Standing Progression 1** | |
| Standing abduction | 30 reps |
| Standing abduction, yellow band | 30 reps |
| Standing abduction, red band | 30 reps |
| Standing abduction, green band | 30 reps |
| Standing abduction, blue band | 30 reps |
| Standing abduction, black band | |
| **Standing Progression 2** | |
| Standing abduction with extension | 30 reps |
| Standing abduction with extension, yellow band | 30 reps |
| Standing abduction with extension, red band | 30 reps |
| Standing abduction with extension, green band | 30 reps |
| Standing abduction with extension, blue band | 30 reps |
| Standing abduction with extension, black band | |

## Dosage

Both programs were performed over an eight-week period with six clinic visits; an initial visit with follow up visits at one, two, four, and six weeks, and a final visit at eight weeks. This length of intervention and visit scheme was selected to be similar to other interventional studies and to mimic the clinical course of decreasing visit frequency typical of clinical practice.[37,38,125] All participants were prescribed a home exercise program to be performed daily. Home exercise logs were used to monitor adherence with prescribed home exercises and were reviewed at each clinic visit. At the end of the intervention participants were recommended to continue their exercise program. Both of the protocols used criterion-based progression of exercises, thus the exercise program

was customized to each individual participant based on their response and physical capacity as is done clinically.

## Assessments

Demographics were assessed at the initial visit. Outcome measures were assessed at the initial visit and at the end of exercise intervention. A researcher blinded to treatment assessed functional outcome measures since the treating physical therapist could not be blinded, as they needed to progress the exercise intervention. Participants were blinded to intervention. Exercise logs were used during the intervention period to monitor adherence. Adherence was determined as the percentage of days during the intervention period that at least some of the prescribed exercises were performed.

### Primary Outcome Measure

Average low back pain over the past week was rated using a 0-10 numerical rating scale with anchors of no pain and worst pain imaginable. This has been found to be a valid and responsive outcome measure for pain.[126]

### Secondary Outcome Measures

Perceived change was assessed with an 11-point Global Rating of Change (GRC) scale. Global Rating of Change has established validity in people with low back pain and has been reported reliable.[127] The minimum clinically important difference is two points on the 11-pont scale.[127]

Disability was assessed with the Oswestry Disability Index, a widely used low back pain disease-specific disability questionnaire. The Oswestry Disability Index is valid and reliable in the chronic low back pain population.[110]

Quality of life was assessed using the Medical Outcomes Study 36-item short-form health survey. It has well-developed validity and population norms.[128]

Function was assessed with the five-times sit-to-stand and six-minute walk tests. The five-times sit-to-stand test is a standard function test that measures the time it takes to move from sitting to standing five times from a chair without arms. It is widely used and is reliable in people with chronic low back pain.[113,129] In the six-minute walk test participants are asked to walk as far as they can over a period of six minutes and the distance walked is recorded. An analogous, five-minute walk test, has been demonstrated valid and reliable in people with low back pain.[113] These two functional tests were chosen since they appear to assess differing underlying factors: the five-time sit-to-stand test is a speed & coordination test whereas the walk test is an endurance & strength measure.[112]

Fear-avoidance was assessed with the Fear-Avoidance Beliefs Questionnaire (FABQ). The FABQ is valid and reliable in the chronic low back pain population.[104]

Gluteus medius strength was assessed using handheld dynamometry. Testing procedures used the protocol described by Hislop to assess gluteus medius strength.[79] Dynamometry was used to assess strength with greater resolution than manual muscle testing and is a reliable method to assess strength.[130]

Gluteus medius muscle dysfunction was assessed with two functional strength tests: the Active Hip Abduction Test and Single Limb Squat Tests.[68,78]

Tenderness throughout the lumbar and hip region was assessed with a physical exam. The greater trochanter, gluteal musculature, lumbar musculature were all assessed for pain to pressure. Pressure was standardized by pressing with the experimenter's thumb until the nail blanched, a commonly used criterion for controlling pressure application clinically, equal to approximately 4kg pressure. Tenderness was considered positive when palpation reproduced symptoms.

## Sample Size

A sample size of 20 per group was targeted after changing recruitment strategies to pilot the intervention and outcome assessments. An additional 16 participants were added to account for losses to exclusion after consent (estimated 20%) and drop out (estimated 20%). A total of 56 potential participants were screened and 38 randomized.

## Statistical Analysis

Participant demographics were compared with t-tests for continuous data and a Mann-Whitney U for ordinal data. The primary outcome of self-reported pain was assessed between groups with a generalized linear mixed model to account for all of the participant data. Effect size between groups was calculated based on outcome assessments. The secondary outcomes of GRC, ODI, SF-36, FABQ, five-times sit-to-stand, six-minute walk test, and torque assessed with dynamometry were also compared with a generalized linear mixed model to account for all participant data. Effect size between groups was calculated based on outcome assessments. The Active Hip Abduction test and Single Limb Squat test were compared between treatment groups with a Mann-Whitney U.

Finally, correlation coefficients were calculated between adherence and change in each of the outcome assessments on an intention to treat basis using the last value carried forward to assess the impacts of adherence on outcome.

## Quality Control

Quality control of the dynamometry and functional strength assessments was performed with inter-rater reliability in a separate sample of people with and without low back pain. Inter-rater reliability for dynamometry between the three assessors was substantial: ICC=0.732 for gluteus medius, ICC=0.718 for TFL, and ICC=0.618 for

gluteus maximus strength testing. Inter-rater reliability for the functional strength assessments was poor: paired weighted κ's ranged from 0.148 to 0.355 for the Active Hip Abduction Test and paired weighted κ's ranged from 0.207 to 0.377 for the Single Limb Squat Test.

Quality control of the dosage of exercise performed by the participants was assessed by review of home exercise logs at every study visit by the treating physical therapist. As part of the record logs, participants also recorded pain medication usage. Physical therapists kept records of exercise program prescribed and prescribed progression.

## Results

### Participants

Recruitment was performed using email to the University of Iowa community. Participant recruitment is detailed in Figure 4. Of those who were interested, 55% were lost and 30% were excluded. Of those who were consented, 68% met our inclusion criteria. Of those randomized to treatment, 24% dropped out. The participants who dropped out all cited not being able to keep up with the burden of a daily exercise program as their rationale for leaving the study. Those who dropped out were not significantly different from those who completed the interventions in any of the demographic or baseline assessments (Tables 9, 10, & 11).

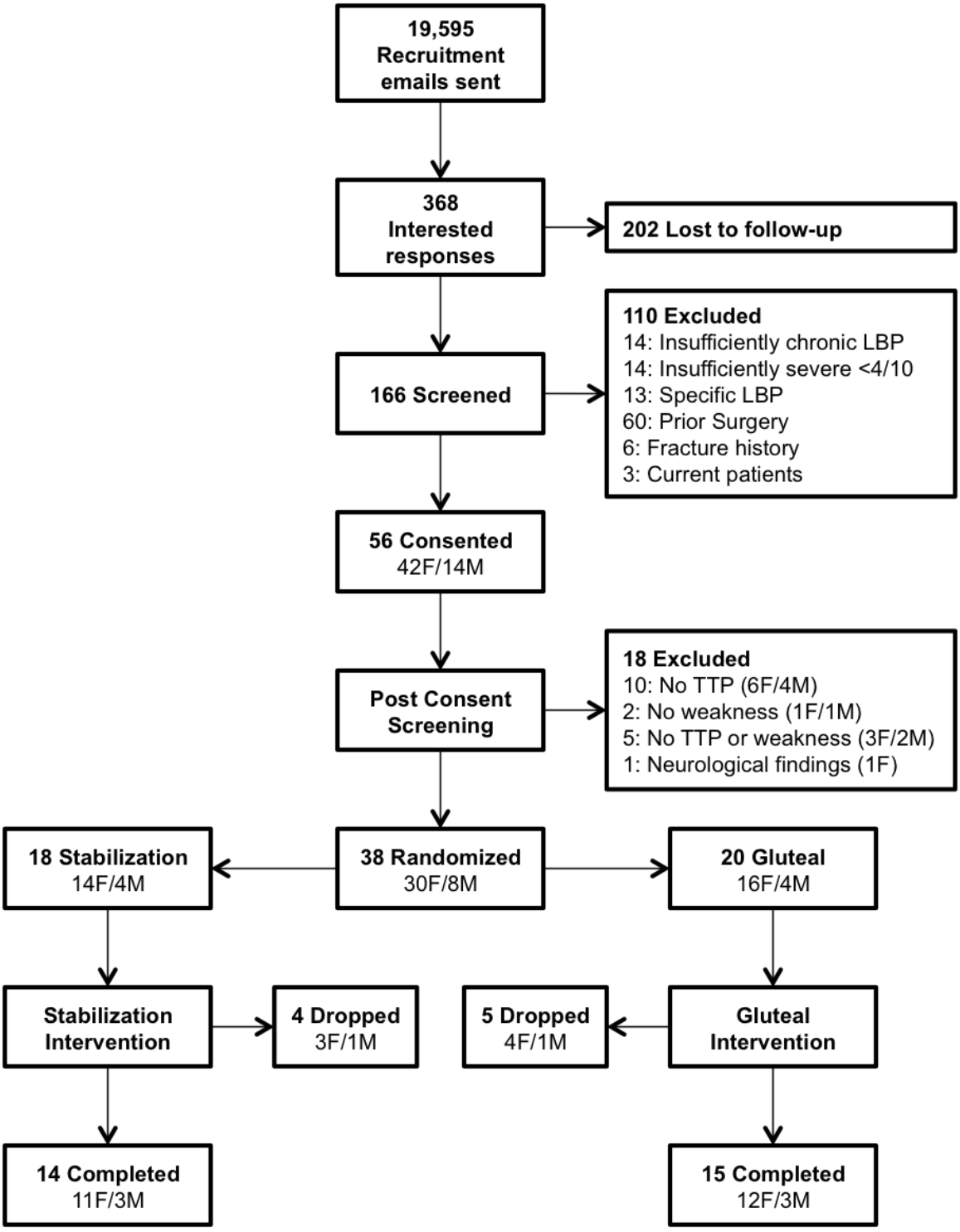


**Figure 3:** CONSORT Diagram. Of the potential participants who expressed interest in participating, 55% were lost to follow up and 30% were excluded. Of those who were consented and screened, 32% were excluded. During the intervention the total dropout rate was 24%. The dropout rates were similar between groups: 22% in the lumbar stabilization group and 25% in the gluteal strengthening group.

**Table 8:** Participant Demographics and Baseline Assessments. There were no differences between participants who completed the intervention and those who dropped out. Data are mean ± standard deviation (range).

| | Completed (n=29) | Dropped Out (n=9) | t-test |
|---|---|---|---|
| **Age (years)** | 51.0±14.1 (22-74) | 50.2±13.7 (23-65) | t=0.138 p=0.891 |
| **Height (cm)** | 166.8±7.5 (154.0-181.5) | 168.7±13.6 (151.5-188.5) | t=-0.373 p=0.718 |
| **Weight (kg)** | 73.3±14.2 (52.4-112.2) | 86.4±23.4 (57.1-116.5) | t=-1.516 p=0.166 |
| **BMI** | 26.4±5.3 (18.8-46.1) | 30.1±6.5 (22.2-41.8) | t=-1.662 p=0.106 |
| **Duration of LBP (mo)** | 83.7±92.5 (6-348) | 185.9±180.8 (5-480) | t=-1.530 p=0.163 |
| **Pain (0-10 NRS)** | 5.2±1.1 (4-7) | 5.8±0.8 (5-7) | t=-1.511 p=0.140 |
| **ODI** | 19.3±9.7 (0-38) | 20.2±9.0 (8-30) | t=-0.250 p=0.804 |
| **FABQ-PA** | 11.2±4.6 (1-20) | 10.0±5.1 (3-19) | t=0.686 p=0.497 |
| **FABQ-W** | 10.0±7.7 (0-23) | 9.3±10.8 (1-28) | t=0.195 p=0.847 |
| **SF-36 PCS** | 48.0±5.3 (35.7-56.2) | 49.0±4.9 (42.3-55.2) | t=-0.507 p=0.615 |
| **SF-36 MCS** | 50.8±5.8 (38.3-58.0) | 51.3±5.4 (42.0-58.5) | t=-0.258 p=0.798 |
| **5TSTS (s)** | 9.1±2.9 (4.58-14.68) | 10.6±2.2 (8.13-14.68) | t=-1.495 p=0.144 |
| **6MWT (m)** | 571.9±66.0 (430-661) | 544.6±63.2 (438-665) | t=1.096 p=0.280 |

**Table 9:** Strength Assessments. There were no strength differences between participants who completed the intervention and those who dropped out. Data are mean ± standard deviation (range).

| | Completed (n=29) | | Dropped Out (n=9) | | t-test | |
|---|---|---|---|---|---|---|
| | **Right** | **Left** | **Right** | **Left** | **Right** | **Left** |
| **G Medius (Nm)** | 136.6±52.8 (51.3-279.4) | 140.7±57.8 (58.4-311.7) | 142.8±63.5 (51.4-217.6) | 145.5±71.2 (40.0-239.7) | t=-0.293 p=0.772 | t=-0.207 p=0.837 |
| **TFL (Nm)** | 151.2±63.0 (42.8-293.0) | 150.2±58.9 (54.5-306.0) | 158.7±68.7 (44.5-238.5) | 148.0±69.1 (55.5-267.4) | t=-0.307 p=0.761 | t=0.094 p=0.926 |
| **G Maximus (Nm)** | 83.9±26.3 (50.9-155.9) | 80.9±27.0 (48.0-175.0) | 71.9±29.3 (33.3-111.1) | 74.1±31.2 (30.2-123.1) | t=1.166 p=0.251 | t=0.637 p=0.528 |

**Table 10:** Functional Strength Assessments. There were no functional strength differences between participants who completed the intervention and those who dropped out. Data are number of participants at each score.

| | Completed (n=29) | | Dropped Out (n=9) | | Mann-Whitney U | |
|---|---|---|---|---|---|---|
| | **Right** | **Left** | **Right** | **Left** | **Right** | **Left** |
| **Active Hip Abduction Test** | 0: 5<br>1: 9<br>2: 14<br>3: 1 | 0:4<br>1: 8<br>2: 16<br>3: 1 | 0: 3<br>1: 2<br>2: 3<br>3: 1 | 0: 0<br>1: 3<br>2: 5<br>3: 1 | p=0.686 | p=0.457 |
| **Single Limb Squat Test** | 1: 2<br>2: 1<br>3: 26 | 1: 2<br>2: 1<br>3: 26 | 1: 1<br>2: 0<br>3: 8 | 1: 0<br>2: 1<br>3: 8 | p=0.973 | p=1.000 |

Primary Outcome Measure

There was a significant main effect for time for self-reported pain ($F_{(5,165)}$=12.361, p<0.001, Figure 4), showing that the exercise intervention reduced pain ratings. However there was no main effect for group ($F_{(1,165)}$=0.248, p=0.619), Nor was there a significant interaction between time and treatment for the self-reported pain ($F_{(5,165)}$=0.115, p=0.989). Both groups achieved a clinically meaningful pain improvement: 2.6 in the stabilization group and 2.7 in the gluteal strengthening group. The effect size for differences in self-reported pain between treatment groups was very small (Cohen's d=0.048).

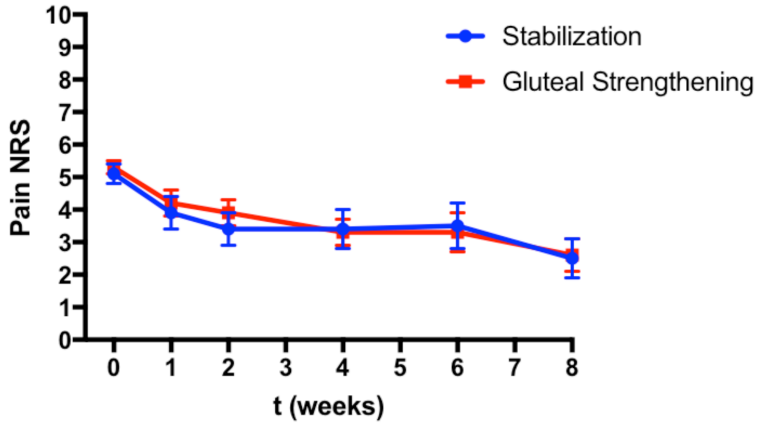


**Figure 4:** Pain vs. time. There was a significant main effect for time (p<0.001), but no treatment or interaction effects.

Secondary Outcome Measures

Although there were significant main effects for both time and treatment for GRC ($F_{(5,166)}$=16.262, p<0.001 & $F_{(1,166)}$=4.056, p=0.046 respectively, Figure 5) there was not a significant interaction effect: $F_{(5,166)}$=1.056, p=0.387. These data show that the exercise intervention increased the GRC, and that this increased over time. The gluteal strengthening group achieved a clinically important change of 2.5 points, while the stabilization group did not, achieving only a 1.6-point change, short of the minimum clinically important difference of 2. Effect size between groups was moderate: Cohen's d=0.497.

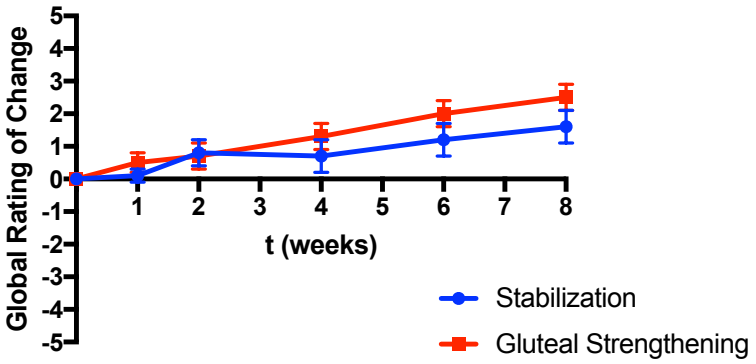


**Figure 5:** Global Rating of Change vs. time. There were significant main effects for time (p<0.001) and treatment (p=0.046) although no significant interaction effect.

There was a significant main effect for time for ODI ($F_{(1,63)}$=4.004, p=0.050), showing reductions in ODI after the exercise intervention. However there were not significant treatment or interaction effects for ODI: $F_{(1,63)}$=3.825, p=0.055 & $F_{(1,63)}$=0.029, p=0.865 respectively. The effect size between groups observed was moderate: Cohen's d=0.419.

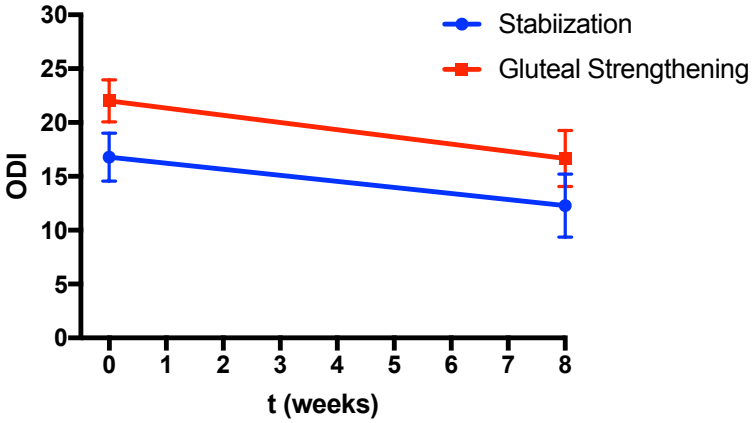


**Figure 6:** Oswestry Disability Index vs. time. There was a significant main effect for time (p=0.050), but there were no significant treatment or interaction effects.

There were no significant effects for time or treatment or interaction effect for either FABQ-PA or FABQ-W scales. There was a moderate effect size for FABQ-PA between groups: Cohen's d=0.581. However there was a small effect size for FABQ-W between groups: Cohen's d=0.012.

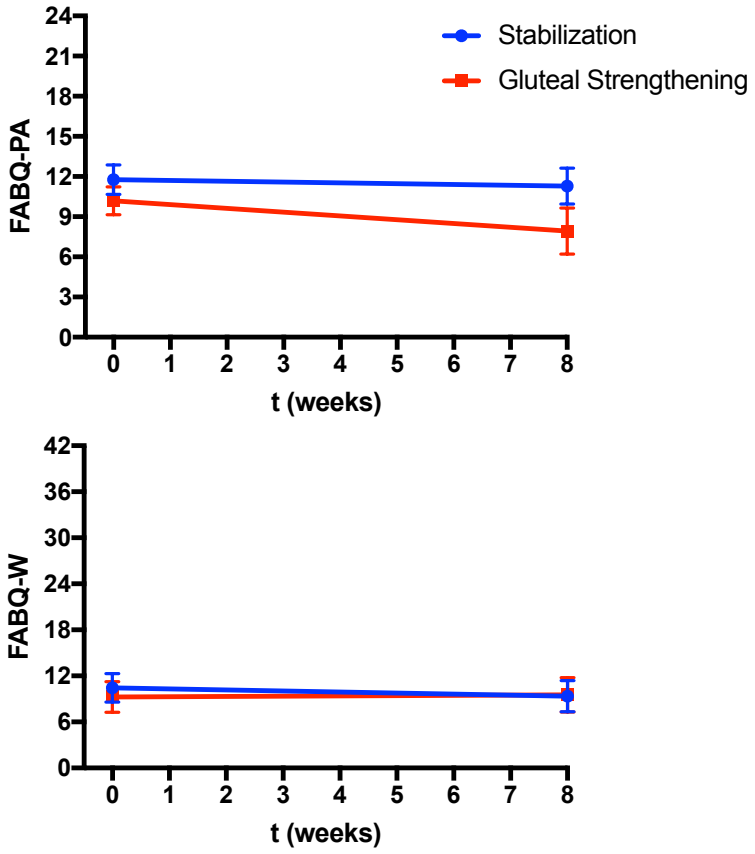


**Figure 7:** FABQ vs. time. There were no significant effects for time, treatment, or interaction for either FABQ-PA or FABQ-W subscales.

Scores on both the SF-36 PCS and MCS were very close to the normal value of 50 both before and after treatment. There was a significant main effect for time for SF-36 PCS score ($F_{(1,63)}$=4.216, p=0.044), showing improvements after the exercise intervention. There were no significant treatment or interaction effects for SF-36 PCS score. There were no significant time or treatment or interaction effects for SF-36 MCS

scores. Effect sizes between groups were small for both SF-36 PCS and MCS: 0.193 and 0.180 respectively.

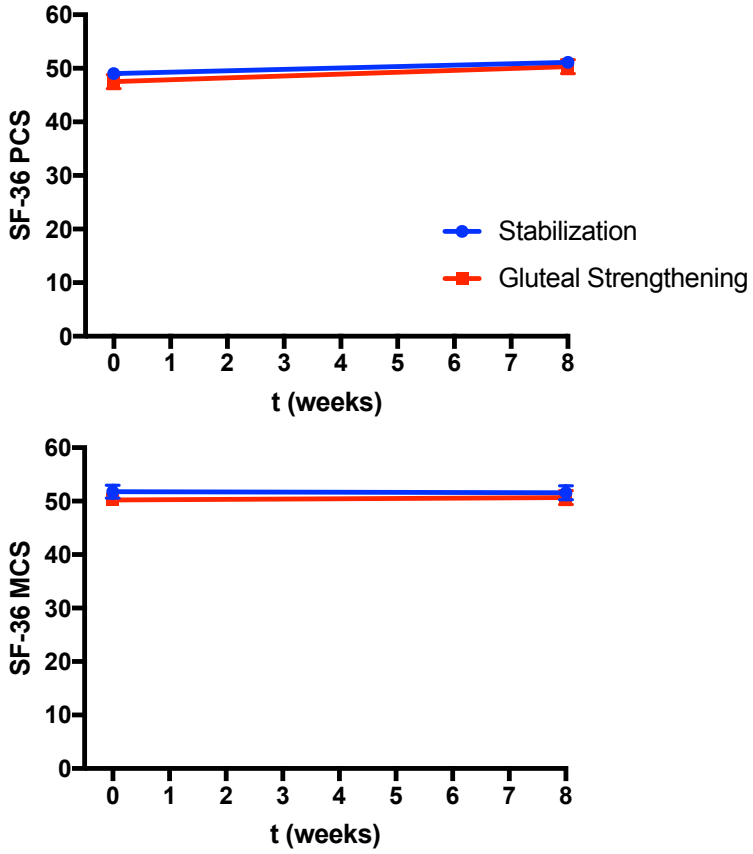


**Figure 8:** SF-36 vs. time. There was a significant main effect for time for SF-36 PCS. There were no significant treatment or interaction effects for SF-36 PCS. There were no significant time, treatment, or interaction effects for SF-36 MCS.

There was a significant time effect for the five-times sit-to-stand test ($F_{(1,63)}$=5.969, p=0.017) showing lower 5TSTS scores after the exercise intervention. There were no significant treatment or interaction effects. There was a small treatment effect for differences between groups: Cohen's d=0.287.

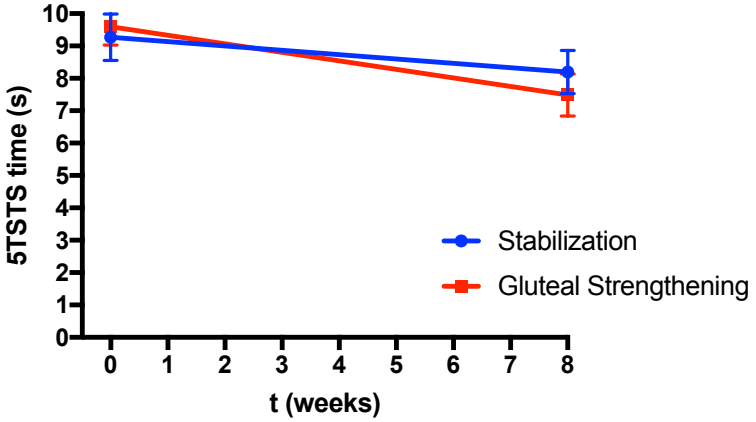


**Figure 9:** Five-times sit-to-stand test vs. time. There was a significant time effect (p=0.017), but no significant treatment or interaction effects.

There was a significant treatment effect for the six-minute walk test ($F_{(1,63)}$=8.660, p=0.005), suggesting the stabilization group walked a greater distance than the gluteal strengthening group. There were no significant time or interaction effects. There was a moderate effect size between groups: Cohen's d=0.682.

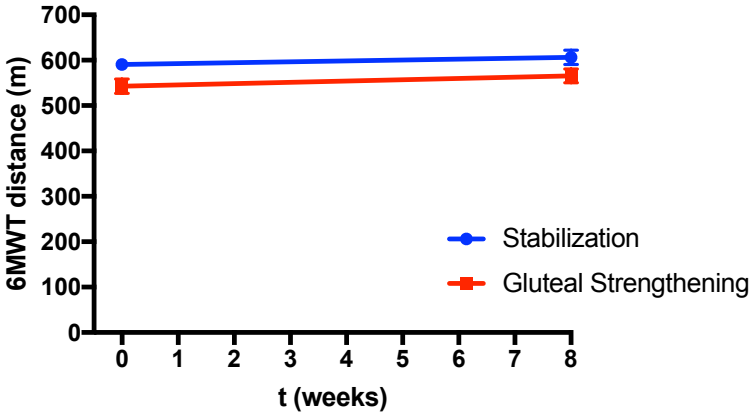


**Figure 10:** Six-minute walk test vs. time. There was a significant treatment effect (p=0.005), but no significant time or interaction effects.

Strength testing had inconclusive results. There were significant time effects for both gluteus medius and TFL strength ($F_{(1,130)}$=18.496, p<0.001 and $F_{(1,130)}$=13.646, p<0.001 respectively). However there were no significant treatment or interaction effects for gluteus medius or TFL strength. There were no significant effects for time or treatment or interaction for gluteus maximus strength. Effect sizes between groups were small to moderate, ranging from 0.109 to 0.463.

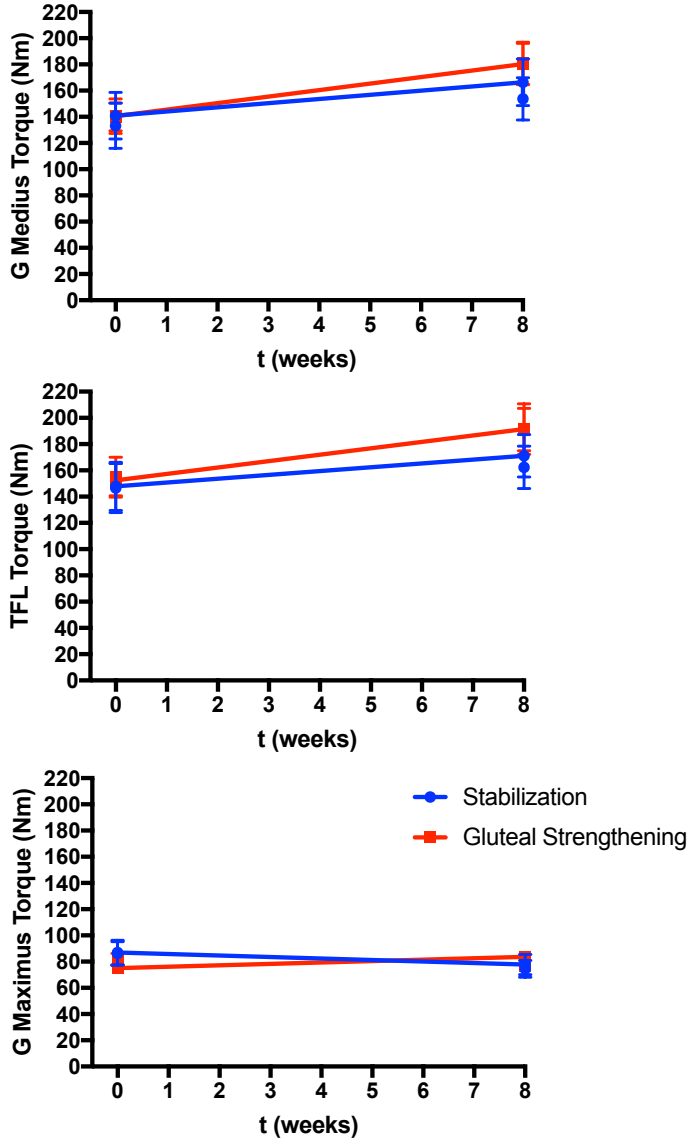


**Figure 11:** Dynamometry vs. time. There were significant time effects for gluteus medius and TFL strength. No other significant effects.

Active Hip Abduction Test and Single Limb Squat Test score distributions were not significantly different between groups before or after the exercise intervention.

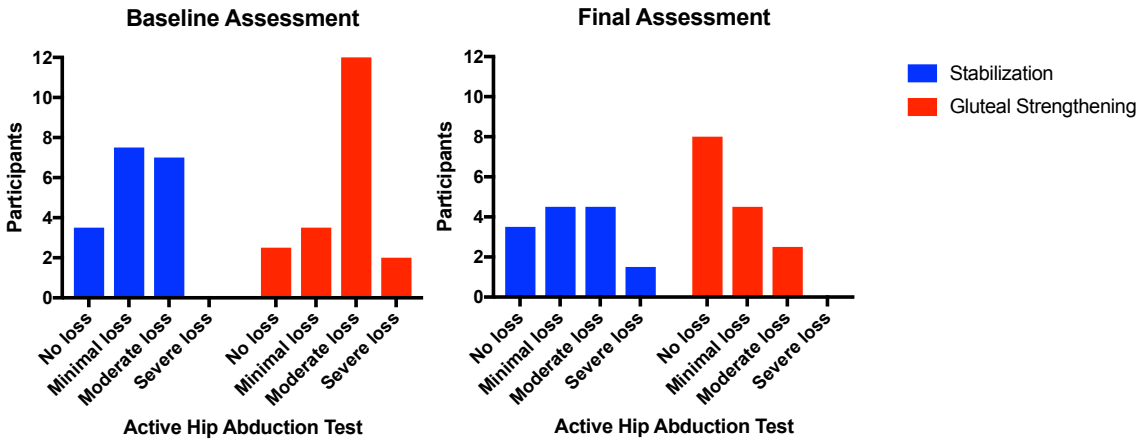


**Figure 12:** Active Hip Abduction Test Scores at Baseline and Final Assessments

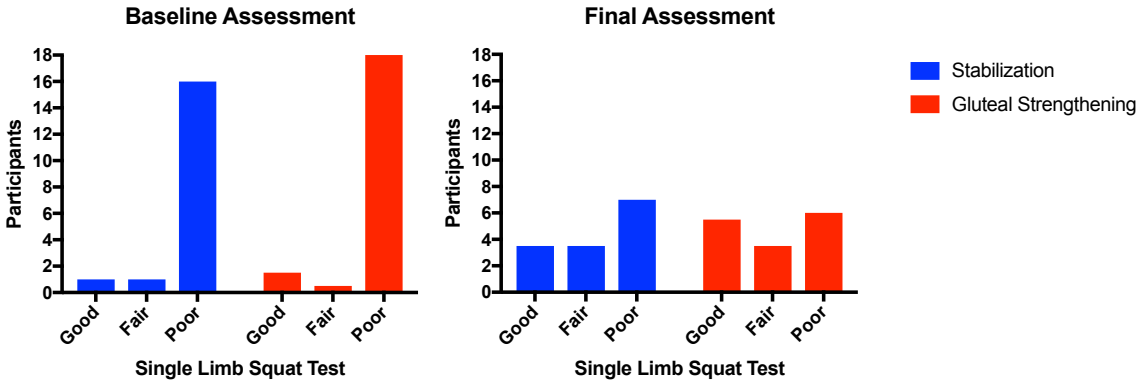


**Figure 13:** Single Limb Squat Test Scores at Baseline and Final Assessments.

## Secondary Analysis

Correlations between exercise program adherence and change in outcomes was a planned secondary analysis from this data. Adherence with the prescribed exercise program was 59.6±33.1% including all participants who were randomized to treatment. Adherence was not significantly different between groups: 56.8±30.1% for the

stabilization group and 60.2±36.2% for the gluteal strengthening group. Given that there were no significant differences between groups for the outcomes, nor for observed adherence, data are pooled in the correlations below (Table 26). Greater adherence was correlated with greater decrease in FABQ-PA scores in both analyses. In the intention to treat analysis, greater adherence was correlated with greater decrease in pain rating, greater perceived change, greater decrease in FABQ-PA scores, and faster times on the five-times sit-to-stand test. Adherence was correlated with greater improvement in right-sided gluteus medius strength in both analyses. In the intention to treat analysis, greater adherence was correlated with greater bilateral TFL strength increases.

**Table 11:** Correlations Between Adherence and Change in Outcome. FABQ-PA change was most strongly correlated with exercise adherence.

| | Adherence Correlation | |
|---|---|---|
| **Pain** | *r=-0.443*<br>*p=0.005* | |
| **GRC** | *r=0.554*<br>*p<0.001* | |
| **ODI** | r=-0.300<br>p=0.067 | |
| **FABQ-PA** | *r=-0.378*<br>*p=0.019* | |
| **FABQ-W** | r=0.084<br>p=0.616 | |
| **SF-36 PCS** | r=0.273<br>p=0.097 | |
| **SF-36 MCS** | r=0.177<br>p=0.288 | |
| **5TSTS** | *r=-0.321*<br>*p=0.049* | |
| **6MWT** | r=0.180<br>p=0.280 | |
| **G Medius (R, L)** | *r=0.458*<br>*p=0.004* | r=0.285<br>p=0.082 |
| **TFL (R, L)** | *r=0.341*<br>*p=0.036* | *r=0.331*<br>*p=0.042* |
| **G Maximus (R, L)** | r=-0.132<br>p=0.428 | r=-0.167<br>p=0.316 |

## Medication Usage

A total of 22 of the 38 participants enrolled reported using pain medications during the intervention period. Data was missing for six of the participants as they dropped out before returning any of their logs. Participants used over the counter (OTC) medications almost exclusively. OTC non-steroidal anti-inflammatory drugs (NSAIDs) were most commonly used: twelve people reported using ibuprofen, seven reported using naproxen, and two reported using aspirin. Four people reported using acetaminophen. Only four participants reported using prescription drugs. These included one participant using meloxicam, one using tramadol, one using cyclobenzaprine, and one using gabapentin and baclofen. During the first week of the interventions, participants took a mean of 8.8 pills/week. This decreased to 6.8 pills/week during the final week of the interventions. However a few participants who used large amounts of medications skewed these data. Median usage went from 5 pills/week to 3 pills/week of pain medication.

## Discussion

This pilot study failed to demonstrate a significant difference between treatments for the primary outcome of self-reported pain with a very small effect size ($d<0.05$). This small pilot study had power to detect an effect size of 1.134 based on the distribution of self-reported pain outcomes. Further pursuit of a large-scale clinical trial to examine differences between these treatments in this sample population is not justified due to the small effect sizes. These small effect sizes suggest equivalence of these two exercise interventions in this population of people with chronic low back pain. Given that clinically significant improvements in pain were seen in both groups suggests that either intervention is effective in managing chronic low back pain. However, the sample recruited in the current study may not be representative of the clinical population of

people seeking physical therapy intervention for chronic low back pain. Further, increasing adherence with exercise was significantly correlated with improvement in pain and perceived improvement in overall condition. Future work should focus on interventions to improve adherence rather than focus on choice of exercise intervention for people with chronic low back pain.

## Equivalence of Exercise Interventions

Recently there have been several trials assessing classification schemes in people with chronic low back pain that have not found utility in these classification schemes. Apeldoorn and colleagues found that using the Treatment Based Classification scheme was no more effective than usual physical therapy care in people with chronic low back pain.[22] Henry and colleagues did not find differences in outcomes using either the Treatment-Based Classification or Movement System Impairment schemes in people with chronic low back pain.[23] At long-term follow up there continued to be no difference between groups.[131] Other clinical trials comparing exercise interventions have failed to demonstrate a superior intervention.[132-135] Larger reviews of exercise interventions in chronic low back pain reiterate the lack of superiority of any particular exercise intervention.[11,24] A recent Cochrane review reported that motor control exercise were not superior to other exercise interventions in chronic low back pain.[136] Similarly Pilates and yoga were both found to be equivalent to other exercise interventions in chronic low back pain.[137,138] Given this equivalence in exercise interventions it may be better to move away from trying to identify subgroups for specific treatments to more empirical interventions focused on getting people to perform any exercise intervention. This is a challenge to the current thinking in physical therapy management of low back pain.

## Sample Representativeness

The chief concern with this pilot study is whether the population recruited accurately represents the population encountered clinically. Due to the extensive

exclusion criteria, essentially all of the clinically encountered population was excluded. Subsequently, the decision was made to recruit from the community rather than relax the exclusion criteria. Because this sample was recruited from a community population it may not necessarily generalize to a clinical population. Although pain ratings of this sample were similar to those reported in similar interventional trials, low back pain-related disability, and fear-avoidance belief were less severe than in similar interventional trials. Further quality of life was essentially normal. With regard to functional tests, this group was not as functional as a healthy population, but not as limited as previously described populations with chronic low back pain. After comparison to other reported clinical populations recruited for similar physical therapy exercise interventions supports this lack of generalizability.

The sample recruited for this pilot study had similarly severe pain as reported clinical populations. Although we used a minimum of 4/10 NRS pain rating as an inclusion criterion to capture people with more severe pain, this may not have been a strict enough criterion. In the studies underpinning the stabilization intervention used in this pilot Hicks and colleagues reported mean pain ratings of 4.5±2.4 for the whole of their clinically recruited sample.[37] This was similar to what we found in the present sample. However they reported generally better treatment outcomes with people with higher pain ratings.[37] Rabin and colleagues, in a validation study of Hicks et al., reported pain ratings of 4.9±1.7 and 5.3±1.7 in their clinical sample.[38] In another study using this stabilization intervention, Costa and colleagues reported pain ratings of 6.8±2.1 and 6.6±2.0 in a clinical sample from a physical therapy clinic in an academic medical center.[125] Henry and colleagues used a similar stabilization intervention and recruited participants via email as we did.[23] They reported much lower mean pain ratings than we found: 2.8/10 and 2.4/10 in their groups.[23] Pain ratings were similar in the current sample to other reported clinical samples and more like the clinical samples reported than the one community recruited sample.

Despite these similar pain ratings, low back pain related-disability was lower in the current sample. Hicks and colleagues and colleagues reported ODI scores of 29.7±13.7 at baseline in a population recruited from outpatient physical therapy clinics.[37] Rabin and colleagues reported even worse ODI scores: 37.8±10.6 and 37.6±12.5 in their groups.[38] Much like the current sample, Henry and colleagues found relatively lower disability scores: 20.6 and 18.7 for their groups. This suggests that the disability in the community-recruited sample is lower than that seen in clinical populations.

Fear-avoidance beliefs scores were lower in the present sample than in other clinical samples. Hicks and colleagues reported FABQ-PA scores of 14.6±5.9 and FABQ-W scores of 13.9±12.0; these are slightly higher than those in the present sample.[37] Rabin and colleagues reported even higher scores: 16.2±4.4 and 15.1±4.9 for the FABQ-PA and 18.1±9.9 and 19.4±10.3 for the FABQ-W for each treatment group.[38] Similar to the present sample, Henry and colleagues reported lower scores in their community-recruited sample: 13.4 and 13.0 for the FABQ-PA and 10.7 and 10.5 for the FABQ-W for each group.[23] This further supports that the community-recruited sample is different from the clinical population, particularly in the severity of their fear-avoidance.

Quality of life scores were essentially normal in this pilot study. These scores were almost identical to those reported by Henry and colleagues in their community sample: 46.7 and 48.9 for the SF-36 PCS and 52.8 and 52.6 for the SF-36 MCS.[23] These high scores suggest that this population has normal quality of life in spite of their chronic pain.

Functional tests in the present sample are better than those reported elsewhere. Simmons reported five times sit-to-stand results in people with CLBP recruited from an orthopaedic clinic of 12.75±7.36 seconds and 11.54±5.78 seconds on retest two weeks later.[113] This group added more participants to this sample and reported times by sex: 11.03±4.42 seconds for women with LBP and 12.75±8.67 seconds for men with LBP.[139] Later this group reported worse times of 14.05±7.93 seconds in a different sample

recruited from an orthopaedic spine clinic.[140] In another sample of people with CLBP recruited from an orthopaedic clinic and a physical therapy clinic, they report times of 13.00±6.29 seconds.[112] These are worse than the times observed in the present study. However these times are not a fast as those reported for healthy people. Simmonds and colleagues reported times of 7.36±1.42 seconds and 6.95±1.37 seconds on retest two weeks later in healthy people without low back pain.[113]

Similarly six-minute walk test distances were greater for the present sample compared to others reported. Simmonds, Novy, Lee, and colleagues have also reported walking test distances although they have utilized a five-minute test rather than a six-minute test.[112,113,139,140] We can approximate what a six-minute test distance would be by multiplying the reported distances by 6/5. After doing this, the approximate six-minute walk distances would be 513m and 530m on retest after two weeks.[113] The sample later recruited from the orthopaedic clinic would have walked about 475m in six minutes.[140] The sample recruited from both the orthopaedic clinic and physical therapy clinic would have walked about 479m in six minutes.[112] These distances are all shorter than the distance walked by participants in this project. The distances seen in the present population are more similar to the healthy controls they reported who would have walked about 620m in six minutes.[113]

Strength assessment and functional strength assessments are difficult to interpret. There is little data in the literature to interpret the handheld dynamometry assessments. Bohannon reported normative data for testing hip abduction in the frontal plane however he used a short lever make test in a gravity-eliminated position so these data may not accurately compare with the present data.[83] Based on Bohannon's regression equations, a mean normative value of 94.7 Nm would be expected in the assessed population. This calculation assumes female sex, as the majority of participants in the present study were female. Sutherlin and Hart reported hip abduction torques for people with and without low back pain.[141] They did not find a difference in hip abduction torque between

groups.[141] Based on their reporting we would expect a mean torque of 120 Nm. However, they used an isokinetic dynamometer using a short lever make test to do these assessments, so this may not be representative of the handheld dynamometry done in the present study.[141] These values are very different from the data observed in this study. To the best of my knowledge, dynamometry assessments of hip extension in a short lever knee flexed position have not been reported in the literature. Similarly, there do not exist any other studies reporting information about the Active Hip Abduction Test or the Single Limb Squat Test in low back pain populations. Given this lack of other data to aid in interpretation, these data from the current study are limited to assessing change in this sample only.

Global Rating of Change scores were similar to others reported. Utilizing an intention to treat analysis, Costa and colleagues reported GRC scores of 1.3±3.7 for their stabilization exercise group after the end of their intervention at two months using the same 11-point GRC scale.[125] This is essentially identical to the scores found in our intention to treat analysis.

In summary, while our population had similar pain ratings to prior studies, the severity of their chronic low back pain was different with respect to disability, quality of life, fear avoidance, and function. This suggests that the recruitment of a community population, willing to participate in an exercise program, results in a group of participants who better cope with their chronic low back pain. Future work should focus on clinical sample to assess the effectiveness of a gluteus medius strengthening program in a clinical population. As contrasted above, a clinical population would be more disabled, have worse quality of life, more fear avoidance, and more impaired function. Improvements in these assessments may be more dramatic as they are starting from a worse state. Participants recruited from a clinical population may also differ in terms of motivational factors to adhere to an exercise intervention.

## Exercise Adherence

Adherence to the prescribed exercise program was reasonable. The rate of 59.6% adherence was similar to the 68% adherence reported by Mannion and colleagues for a similar population.[142] Adherence to exercise was most strongly associated with decreased pain and greater perceived improvement in symptoms in this project. Both interventions were effective in treating the chronic low back pain experienced by the participants. If there is not a clear exercise intervention of choice than exercise selection should be made to maximize adherence. Multiple factors have been reported to impact adherence with exercise intervention including self-efficacy, locus of control, supervision, participation in an exercise program, and use of a motivational behavior change program.[142,143] Further work should assess the impact of utilizing strategies to maximize adherence to exercise interventions in chronic low back pain.

# CHAPTER 5: CONCLUSIONS

## Summary

These projects have supported that gluteus medius dysfunction occurs in chronic low back pain. The current study demonstrated that gluteus medius weakness and gluteal tenderness to palpation is common in people seeking physical therapy care for chronic low back pain. This weakness and tenderness is not seen in a healthy population. Despite the prevalence of gluteus medius weakness, an exercise intervention targeting this weakness is equally effective in producing clinically meaningful improvement in pain rating to an intervention using stabilization exercises. Further, exercise adherence was correlated with less pain and a greater perception of improvement in symptoms. Thus, these data suggest that performing an exercise program is more important than the type of exercise in treating chronic low back pain.

## Conclusions

The first hypothesis put forth in this thesis has been supported. We hypothesized that gluteus medius weakness and tenderness occurs in the majority of people with non-specific chronic LBP compared to people without LBP. We found that gluteus medius strength was significantly lower in patients with chronic low back pain compared to healthy people. We found that tenderness, especially over the gluteal muscle bellies, was more common in people with chronic low back pain than healthy controls. Gluteus medius weakness was strongly correlated with having low back pain. Further gluteus medius weakness was strongly predictive of the presence of low back pain. This identification of this subgroup led to the second hypotheses that an exercise program focused on treating this gluteus medius weakness would be more effective in treating chronic low back pain than a standard exercise intervention.

The hypothesis that a gluteus medius strengthening exercise intervention would be more effective than a standardized lumbar stabilization program in people with chronic low back pain with gluteal weakness and tenderness was mostly unsupported. The first specific aim, that outcomes would be superior in the gluteus medius strengthening group, was not supported. Although the gluteus medius strengthening exercise intervention was effective in treating these participants chronic low back pain, it was no more effective than the lumbar stabilization intervention. Changes in the primary outcome of self-reported pain were essentially identical. Changes in the secondary outcomes of global rating of change, low back pain-related disability, quality of life, and fear-avoidance were also not significantly different between groups. The second aim of this hypothesis, that the gluteus medius strengthening program will improve gluteus medius strength as measured with dynamometry and functional strength tests, was only partly supported. Gluteus medius strength was greater after participating in the gluteus medius strengthening intervention. However there was no difference between groups after treatment. Functional strength testing was not different between groups.

Together these projects support the idea that there is a clinically identifiable subgroup of people with chronic low back pain with gluteus medius weakness and associated tenderness. These people experience improvement in their chronic low back pain with a focused gluteus medius strengthening exercise intervention, but this intervention is no more effective than a lumbar stabilization intervention.

## Future Directions

This project reinforces two conflicting ideas: that although subgroups are observed in populations of people with chronic low back pain, using these subgroups to deliver matched treatments does not lead to superior outcomes. If subgrouping does not serve to improve outcome, then it should be abandoned. Given their equivalence, exercise

interventions should be selected to maximize adherence. Further, the role of interventions focused on improvement of adherence to exercise in the management of chronic low back pain should be further explored.

# APPENDIX A: OSWESTRY DISABILITY INDEX

Could you please complete this questionnaire it is designed to give us information as to how your back (or leg) trouble has affected your ability to manage in everyday life. Please answer every section. Mark **one box only** in each section that most closely describes you **today.**

**Pain Intensity**
- ☐ I can tolerate the pain I have without having to use pain medication.
- ☐ The pain is bad, but I can manage without having to take pain medication.
- ☐ Pain medication provides me with complete relief from pain.
- ☐ Pain medication provides me with moderate relief from pain.
- ☐ Pain medication provides me with little relief from pain.
- ☐ Pain medication has no effect on my pain.

**Personal Care (e.g. Washing, Dressing)**
- ☐ I can take care of myself normally without causing increased pain.
- ☐ I can take care of myself normally but it increases my pain.
- ☐ It is painful to take care of myself and I am slow and careful.
- ☐ I need help but I am able to manage most of my personal care.
- ☐ I need help every day in most aspects of my care.
- ☐ I do not get dressed, wash with difficulty and stay in bed.

**Lifting**
- ☐ I can lift heavy weights without increased pain.
- ☐ I can lift heavy weights but it causes increased pain.
- ☐ Pain prevents me from lifting heavy weights off the floor, but I can manage if the weights are conveniently positioned (e.g. on a table).
- ☐ Pain prevents me from lifting heavy weights but I can manage light to medium weights if they are conveniently positioned.
- ☐ I can lift only very light weights.
- ☐ I cannot lift or carry anything at all.

**Walking**
- ☐ Pain does not prevent me walking any distance.
- ☐ Pain prevents me walking more than 1 mile.
- ☐ Pain prevents me walking more than ½ mile.
- ☐ Pain prevents me walking more than ¼ mile.
- ☐ I can only walk with crutches or a cane.
- ☐ I am in bed most of the time and have to crawl to the toilet.

**Sitting**
- ☐ I can sit in any chair as long as I like.
- ☐ I can sit in my favorite chair as long as I like.
- ☐ Pain prevents me from sitting for more than 1 hour.
- ☐ Pain prevents me from sitting for more than ½ hour.
- ☐ Pain prevents me from sitting for more than 10 minutes.
- ☐ Pain prevents me from sitting at all

**Standing**
- ☐ I can stand as long as I want without increased pain.
- ☐ I can stand as long as I want but it increases my pain.
- ☐ Pain prevents me from standing more than 1 hour.
- ☐ Pain prevents me from standing more than ½ hour.
- ☐ Pain prevents me from standing more than 10 minutes.
- ☐ Pain prevents me from standing at all.

**Sleeping**
- ☐ Pain does not prevent me from sleeping well.
- ☐ I can sleep well only by using pain medication.
- ☐ Even when I take pain medication, I sleep less than 6 hours.
- ☐ Even when I take pain medication, I sleep less than 4 hours.
- ☐ Even when I take pain medication, I sleep less than 2 hours.
- ☐ Pain prevents me from sleeping at all.

**Social Life**
- ☐ My social life is normal and does not increase my pain.
- ☐ My social life is normal, but it increases my pain.
- ☐ Pain prevents me from participating in more energetic interests (e.g. sports, dancing).
- ☐ Pain prevents me from going out often.
- ☐ Pain has restricted my social life to my home.
- ☐ I have hardly any social life because of my pain.

**Traveling**
- ☐ I can travel anywhere without increased pain.
- ☐ I can travel anywhere but it increases my pain.
- ☐ My pain restricts my travel over 2 hours.
- ☐ My pain restricts my travel over 1 hour.
- ☐ My pain restricts my travel to short necessary journeys under ½ hour.
- ☐ My pain prevents all travel except for visits to the physician/therapist or hospital

**Employment/Homemaking**
- ☐ My normal homemaking/job activities do not cause pain.
- ☐ My normal homemaking/job activities increase my pain, but I can still perform all that is requires of me.
- ☐ I can perform most of my homemaking/job duties, but pain prevents me from performing more physically stressful activities (ex. lifting, vacuuming).
- ☐ Pain prevents me from doing anything but light duties.
- ☐ Pain prevents me from doing even light duties.
- ☐ Pain prevents me from performing any job or homemaking chores

## APPENDIX B: FEAR-AVOIDANCE BELIEFS QUESTIONNAIRE

Here are some of the things which other patients have told us about their pain. For each statement please circle any number from 0 to 6 to say how much physical activities such as bending, lifting, walking or driving affect or would affect your back pain.

| | Completely Disagree | | | Unsure | | | Completely Agree |
|---|---|---|---|---|---|---|---|
| 1. My pain was caused by physical activity | 0 | 1 | 2 | 3 | 4 | 5 | 6 |
| **2.** Physical activity makes my pain worse | 0 | 1 | 2 | 3 | 4 | 5 | 6 |
| **3.** Physical activity might harm my back | 0 | 1 | 2 | 3 | 4 | 5 | 6 |
| **4.** I should not do physical activities which (might) make my pain worse | 0 | 1 | 2 | 3 | 4 | 5 | 6 |
| **5.** I cannot do physical activities which (might) make my pain worse | 0 | 1 | 2 | 3 | 4 | 5 | 6 |

The following statements are about how your normal work affects or would affect your back pain.

| | Completely Disagree | | | Unsure | | | Completely Agree |
|---|---|---|---|---|---|---|---|
| **6.** My pain was caused by my work or by an accident at work | 0 | 1 | 2 | 3 | 4 | 5 | 6 |
| **7.** My work aggravated my pain | 0 | 1 | 2 | 3 | 4 | 5 | 6 |
| 8. I have a claim for compensation for my pain | 0 | 1 | 2 | 3 | 4 | 5 | 6 |
| **9.** My work is too heavy for me | 0 | 1 | 2 | 3 | 4 | 5 | 6 |
| **10.** My work makes or would make my pain worse | 0 | 1 | 2 | 3 | 4 | 5 | 6 |
| **11.** My work might harm my back | 0 | 1 | 2 | 3 | 4 | 5 | 6 |
| **12.** I should not do my normal work with my present pain | 0 | 1 | 2 | 3 | 4 | 5 | 6 |
| 13. I cannot do my normal work with my present pain | 0 | 1 | 2 | 3 | 4 | 5 | 6 |
| 14. I cannot do my normal work until my pain is tolerated | 0 | 1 | 2 | 3 | 4 | 5 | 6 |
| **15.** I do not think that I will be back to my normal work within 3 months | 0 | 1 | 2 | 3 | 4 | 5 | 6 |
| 16. I do not think that I will ever be able to go back to that work | 0 | 1 | 2 | 3 | 4 | 5 | 6 |

# APPENDIX C: SF-36

1. In general, would you say your health is:
   1 Excellent
   2 Very good
   3 Good
   4 Fair
   5 Poor

2. **Compared to one year ago**, how would you rate your health in general **now**?
   1 Much better now than one year ago
   2 Somewhat better now than one year ago
   3 About the same
   4 Somewhat worse now than one year ago
   5 Much worse now than one year ago

The following items are about activities you might do during a typical day. Does **your health now limit you** in these activities? If so, how much?

| | Yes, Limited a Lot | Yes, Limited a Little | No, Not limited at All |
|---|---|---|---|
| 3. **Vigorous activities**, such as running, lifting heavy objects, participating in strenuous sports | 1 | 2 | 3 |
| 4. **Moderate activities**, such as moving a table, pushing a vacuum cleaner, bowling, or playing golf | 1 | 2 | 3 |
| 5. Lifting or carrying groceries | 1 | 2 | 3 |
| 6. Climbing **several** flights of stairs | 1 | 2 | 3 |
| 7. Climbing **one** flight of stairs | 1 | 2 | 3 |
| 8. Bending, kneeling, or stooping | 1 | 2 | 3 |
| 9. Walking **more than a mile** | 1 | 2 | 3 |
| 10. Walking **several blocks** | 1 | 2 | 3 |
| 11. Walking **one block** | 1 | 2 | 3 |
| 12. Bathing or dressing yourself | 1 | 2 | 3 |

During the **past 4 weeks**, have you had any of the following problems with your work or other regular daily activities **as a result of your physical health**?

| | Yes | No |
|---|---|---|
| 13. Cut down the amount of time you spent on work or other activities | 1 | 2 |
| 14. **Accomplished less** than you would like | 1 | 2 |
| 15. Were limited in the **kind** of work or other activities | 1 | 2 |
| 16. Had **difficulty** performing the work or other activities (for example, it took extra effort) | 1 | 2 |

During the **past 4 weeks,** have you had any of the following problems with your work or other regular daily activities **as a result of any emotional problems** (such as feeling depressed or anxious)?

| | Yes | No |
|---|---|---|
| 17. Cut down the **amount of time** you spent on work or other activities | 1 | 2 |
| 18. **Accomplished less** than you would like | 1 | 2 |
| 19. Didn't do work or other activities as **carefully** as usual | 1 | 2 |

20. During the **past 4 weeks,** to what extent has your physical health or emotional problems interfered with your normal social activities with family, friends, neighbors, or groups?

1 Not at all
2 Slightly
3 Moderately
4 Quite a bit
5 Extremely

21. How much **bodily** pain have you had during the **past 4 weeks**?

1 None
2 Very mild
3 Mild
4 Moderate
5 Severe
6 Very severe

22. During the **past 4 weeks,** how much did **pain** interfere with your normal work (including both work outside the home and housework)?

1 Not at all
2 A little bit
3 Moderately
4 Quite a bit
5 Extremely

These questions are about how you feel and how things have been with you **during the past 4 weeks**. For each question, please give the one answer that comes closest to the way you have been feeling.
How much of the time during the **past 4 weeks** . . .

| | All of the Time | Most of the Time | A Good Bit of the Time | Some of the Time | A Little of the Time | None of the Time |
|---|---|---|---|---|---|---|
| 23. Did you feel full of pep? | 1 | 2 | 3 | 4 | 5 | 6 |
| 24. Have you been a very nervous person? | 1 | 2 | 3 | 4 | 5 | 6 |
| 25. Have you felt so down in the dumps that nothing could cheer you up? | 1 | 2 | 3 | 4 | 5 | 6 |
| 26. Have you felt calm and peaceful? | 1 | 2 | 3 | 4 | 5 | 6 |
| 27. Did you have a lot of energy? | 1 | 2 | 3 | 4 | 5 | 6 |

| | All of the Time | Most of the Time | A Good Bit of the Time | Some of the Time | A Little of the Time | None of the Time |
|---|---|---|---|---|---|---|
| 28. Have you felt downhearted and blue? | 1 | 2 | 3 | 4 | 5 | 6 |
| 29. Did you feel worn out? | 1 | 2 | 3 | 4 | 5 | 6 |
| 30. Have you been a happy person? | 1 | 2 | 3 | 4 | 5 | 6 |
| 31. Did you feel tired? | 1 | 2 | 3 | 4 | 5 | 6 |

32. During the **past 4 weeks,** how much of the time has your **physical health or emotional problems** interfered with your social activities (like visiting with friends, relatives, etc.)?
**(Circle One Number)**

1 All of the time
2 Most of the time
3 Some of the time
4 A little of the time
5 None of the time

How TRUE or FALSE is each of the following statements for you.
**(Circle One Number on Each Line)**

| | Definitely True | Mostly True | Don't Know | Mostly False | Definitely False |
|---|---|---|---|---|---|
| 33. I seem to get sick a little easier than other people | 1 | 2 | 3 | 4 | 5 |
| 34. I am as healthy as anybody I know | 1 | 2 | 3 | 4 | 5 |
| 35. I expect my health to get worse | 1 | 2 | 3 | 4 | 5 |
| 36. My health is excellent | 1 | 2 | 3 | 4 | 5 |

# APPENDIX D: MANUAL OF OPERATIONS

## Screening

### Screening Questions

Open screening database in RedCAP. Ask and record the answers to the following questions:

"How old are you?"

"Do you have low back pain?"

"Have you had low back pain for more than three months?"

"Has your low back pain been bothersome on more than half of the days of the past six months?"

"Have you been diagnosed with any specific back condition other than low back pain?"

"Do you have a history of any fractures in the back or legs?"

"Have you had any surgeries of the trunk or legs?"

"Have you had any injuries or do you have any conditions that affect your back or legs?"

If they do not meet inclusion/exclusion criteria:

"Thanks for your interest in our study, however you do not meet our criteria."

If they DO meet criteria thus far:

"You meet our criteria and we'd like to invite you to participate in our study."

### Consent

Give the potential participant a copy of the informed consent document and ask them to read through the document.

"This is the informed consent document. It describes the project and the associated risks and benefits. Please take a few minutes to read through is. Please ask if you have any questions or do not understand anything."

Sign and date both copies of the informed consent document. Give one copy to the participant and retain the other for our records.

Screening Physical Exam

"We need to check a few other things to make sure you meet all of the criteria for our study. I'm going to perform a neurological examination of your legs, press over the muscles and bones in your low back, and look at the strength in a couple of the muscles that cross your hips."

Have the participant sit on the exam table and remove their shoes.

"Have a seat on the exam table and take off your shoes. First we're going to look at the strength in several muscles in your legs. Pull your big toes up to the ceiling. Hold them up there."

Demonstrate the desired motion by lifting your thumbs to the ceiling. Test hallux extension on both sides. Grade and score this in RedCAP.

"Pull your feet up. Hold them up there."

Demonstrate the desired motion. Test ankle dorsiflexion. Grade and record this in RedCAP.

"Straighten out your [right or left] knee all the way."

Demonstrate the desired motion. Observe for any signs of discomfort.

"Bend your knee just a little bit."

With the knee unlocked, test knee extension strength. Grade and record this in RedCAP.

"Straighten out your other knee all the way"

Observe for signs of discomfort.

"Bend your knee just a little bit."

With the knee unlocked, test knee extension strength. Grade and record this in RedCAP.

"Lift your [right or left] knee up like you're marching."

Demonstrate the desired movement. Test hip flexion strength. Grade and record this in RedCAP.

"Lift your other knee."

Test hip flexion strength. Grade and record this in RedCAP.

"Next we're going to look at the sensation in both of your legs. I'm going to touch both sides. Let me know if they feel different side to side or if either feels numb or tingly. How does it feel here?"

Stoke the anterior thigh, over the L2 dermatome, bilaterally.

"How about here?"

Stroke the anterior knee, over the L3 dermatome, bilaterally.

"And here?"

Stroke the lateral calf ,over the L5 dermatome, bilaterally.

"How about in your feet, here?"

Stroke the medial aspect of the first MTP joint over the L4 dermatome bilaterally.

"Or here?"

Stroke the dorsal first web space, over the L5 dermatome, bilaterally.

"What about out here?"

Stroke the lateral aspect of the foot along the fifth metatarsal, over the S1 dermatome, bilaterally.

"And how about back here?"

Stroke the central posterior calf, over the S1 dermatome, bilaterally. Record the results of the sensory screening in RedCAP. Position the subject in supine on the exam table.

> "Go ahead and lay down on you back on the table. First I'm going to lift your legs one at a time. I want you to relax and let me do the lifting. Tell me when we need to stop."

Lift one lower extremity, flexing at the hip and keeping the knee extended and ankle dorsiflexed. Observe for signs of distress. Feel for resistance to hip flexion. Prompt the participant at any sign of distress or hamstring tension limiting continued flexion.

> "What are you feeling? Is there pain in the back or down into the leg? Or does it just pull in the back of the thigh?"

Lower the limb and repeat on the other side.

> "We're going to do the same thing over here. Let me do the lifting."

Lift the other lower extremity, flexing at the hip and keeping the knee extended and ankle dorsiflexed. Observe for signs of distress. Feel for resistance to hip flexion. Prompt the participant at any sign of distress or hamstring tension limiting continued flexion.

> "What are you feeling? Is there pain in the back or down into the leg? Or does it just pull in the back of the thigh?"

Position the participant in sidelying

Active Hip Abduction Test

The participant is positioned side lying with hips and knees extended and aligned with their trunk. The pelvis is in the frontal plane, perpendicular to the table. Direct the subject to abduct the top leg maintaining alignment in the frontal plane:

> "Please keep your knee straight and raise your top thigh and leg towards the ceiling, keeping them in line with your body, and try not to let your pelvis tip forwards or backwards."

Score the test 0-3 based on the criteria:

| Score | Criteria (Nelson-Wong et al, 2009) | Criteria (Davis et al, 2011) |
|---|---|---|
| 0: **No loss** of pelvis frontal plane<br>0, Able to **maintain position** of pelvis in the frontal plane | -Participant **smoothly** and **easily** performs the movement<br>-Lower extremities, pelvis, trunk, and shoulders **remain aligned** in the frontal plane | -**Smoothly** and **easily** performs movement; lower extremities, pelvis, trunk, and shoulders **remain aligned** in frontal plane. |
| 1: **Minimal loss** of pelvis frontal plane<br>1, **Minimal loss** of pelvis position in the frontal plane | -Participant may demonstrate a **slight wobble** at initiation of the movement, but quickly regains control.<br>-Movement may be performed with **noticeable effort** or with a slight **ratcheting** of the moving limb. | -**Slight wobble** at initiation or throughout movement; may show **noticeable effort** or **"ratcheting"** of moving limb. |
| 2: **Moderate loss** of pelvis frontal plane<br>2, **Moderate loss** of pelvis position in the frontal plane | -Participant has a **noticeable wobble**, **tipping of the pelvis**, **rotation of the shoulders or trunk**, **hip flexion**, and/or **internal rotation** of the abducting limb.<br>-Movement may be performed **too rapidly**, and participant may or may not be able to regain control of the movement once it has been lost. | -Has **at least 2** of the following: **noticeable wobble** through movement; **tipping of pelvis, trunk, or shoulder rotation**; increased **hip flexion** and/or **rotation** of the moving limb; **rapid or uncontrolled** movement. |
| 3: **Severe loss** of pelvis frontal plane<br>3, **Severe loss** of pelvis position in the frontal plane | -Participant demonstrates the same patterns as in a test score of 2, with **greater severity**.<br>-Participant is **unable to regain control** of the movement and may have to use a **hand or arm on the table** to maintain balance. | -Has **more than 3** of the above characteristics and/or **unable to regain control** of movement once lost or **may lose balance** (has to place hand on table) |

Single Limb Squat Test

The participant stands on one leg on a 20cm box with arms crossed over their chest. Direct the participant to squat down as far as possible and return to standing without losing their balance. Squats should be performed at a rate of about one squat per two seconds. They may take up to three practice attempts. For the test they will perform five squats consecutively. Observe their movement a score the squat as "good," "fair," or "poor" based on the following criteria:

| Criterion | Requirements for Good Rating |
|---|---|
| **Overall Performance Criterion** | |
| Balance | No loss of balance |
| Perturbations | Smooth performance |
| Squat depth | To at least 60deg knee flexion |
| Squat speed | Rate of 1 squat/2 seconds |
| **Trunk Posture Criterion** | |
| Trunk lateral deviation | No trunk lateral deviation |
| Trunk rotation | No trunk rotation |
| Trunk lateral flexion | No trunk lateral flexion |
| Trunk flexion | No trunk flexion |
| **Pelvis Position Criterion** | |
| Pelvic lateral deviation | No pelvis lateral deviation |
| Pelvic rotation | No pelvis rotation |
| Pelvic tilt | No pelvis tilt |
| **Hip Joint Criterion** | |
| Hip adduction | No hip adduction |
| Hip internal rotation | No hip internal rotation |
| **Knee Joint Criterion** | |
| Knee valgus | No knee valgus |
| Knee position | Knee remains over foot |

Participants are rated "Good" if they meet all of the requirements for 4/5 of the criteria.

Participants are rated "Fair" if they meet all the requirements of at least one of the criteria.

Participants are rated "Poor" if they fail to meet all of the requirements for at least one of the criteria.

Five Times Sit to Stand Test

Position participant in a 16-inch high, armless chair with their arms crossed over their chest. Instruct them to

> "Stand up and sit down as quickly as possible five times, keeping your arms folded across your chest. I'll be timing you with a stopwatch. After the test I will ask you to rate your pain on a zero to ten scale where zero is no pain and ten is the worst pain imaginable. We will do three trials of this test."

Begin timing as soon as the participant initiates the first transition to standing. Count each stand aloud so that the participant remains oriented. Stop the test when the participant achieves the standing position on the fifth repetition. Prompt the participant to rate their pain during the test:

> "How bad was your pain during the test on a zero to ten scale?"

Record the time to complete the five sit-to-stand transfers and their pain during the test.

Allow a brief pause before repeating the test.

Record the time to complete the five sit-to-stand transfers and their pain during the second test.

Allow a brief pause before repeating the test.

Record the time to complete the five sit-to-stand transfers and their pain during the third test.

Six Minute Walk Test

Instruct the participant as follows:

> "The object of this test is to walk as far as possible for six minutes. You will walk back and forth in this hallway. You are permitted to slow down, to stop, and to rest as necessary. You may lean against the wall while resting, but resume walking as soon as you are able. You will be walking back and forth around the cones. You should pivot briskly around the cones and continue back the other way without hesitation. Now I'm going to show you. Please watch the way I turn without hesitation."

Demonstrate by walking one lap yourself. Walk and pivot around a cone briskly.

> "Are you ready to do that? I am going to use this counter to keep track of the number of laps you complete. I will click it each time you turn around at this starting line. Remember that the object is to walk AS FAR AS POSSIBLE for six minutes, but don't run or jog."

Position the participant at the starting line. You should also stand near the starting line during the test. Do not walk with the participant.

> "Start now, or whenever you are ready."

As soon as the participant starts to walk, start the timer. Do not talk to anyone during the walk. Use an even tone of voice when using the standard phrases of encouragement. Watch the participant. Do not get distracted and lose count of the laps. Each time the participant returns to the starting line, click the lap counter once (or mark the lap on the worksheet). Let the participant see you do it. Exaggerate the click using body language, like using a stopwatch at a race.

After the first minute, tell the participant the following (in even tones):

> "You are doing well. You have 5 minutes to go."

When the timer shows 4 minutes remaining, tell the participant the following:

> "Keep up the good work. You have 4 minutes to go."

When the timer shows 3 minutes remaining, tell the participant the following:

> "You are doing well. You are halfway done."

When the timer shows 2 minutes remaining, tell the participant the following:

> "Keep up the good work. You have only 2 minutes left."

When the timer shows only 1 minute remaining, tell the participant:

> "You are doing well. You have only 1 minute to go."

Do not use other words of encouragement (or body language to speed up).

If the participant stops walking during the test and needs a rest, say this:

> "You can lean against the wall if you would like; then continue walking whenever you feel able."

Do not stop the timer. If the participant stops before the 6 minutes are up and refuses to continue (or you decide that they should not continue), wheel the chair over for the patient to sit on, discontinue the walk, and note on the worksheet the distance, the time stopped, and the reason for stopping prematurely.

When the timer is 15 seconds from completion, say this:

> "In a moment I'm going to tell you to stop. When I do, just stop right where you are and I will come to you."

When the timer rings (or buzzes), say this:

> "Stop!"

Walk over to the participant. Consider taking the chair if they look exhausted. Mark the spot where they stopped by placing a beanbag or a piece of tape on the floor. Measure the distance completed on the last partial lap. Calculate the total distance walked.

Stabilization Exercise Protocol

Physical Therapy Visit One:

The first visit will consist of training the participant in the abdominal drawing-in maneuver (ADIM) in different positions. No further progression is attempted on the first visit. Exercises in stage one are:

- ADIM in quadruped
- ADIM in supine
- ADIM in standing

Sidelying isometrics are not performed in stage one of the protocol.

Subsequent Physical Therapy Visits:

Each exercise progression is assessed. The exercise prescribed at the last visit is assessed first. If the participant meets the failure criteria, that exercise is prescribed. If a participant meets the progression criteria the next exercise in the progression is attempted. If they meet failure criteria, that exercise is prescribed; if they meet progression criteria, the next exercise is attempted. This is repeated until failure criteria are reached. If a participant progresses to the final exercise in the progression, that exercise is prescribed.

| Exercise | Progression Criterion |
|---|---|
| **Quadruped Progression** | |
| ADIM in quadruped | 30 reps with 8 sec hold |
| ADIM in quadruped, UE lifts | 30 reps with 8 sec hold, both sides |
| ADIM in quadruped, LE lifts | 30 reps with 8 sec hold, both sides |
| ADIM in quadruped, UE & LE lifts | 30 reps with 8 sec hold, both sides |
| ADIM in quadruped, dynamic UE & LE lifts | |
| **Supine Progression** | |
| ADIM in supine | 30 reps with 8 sec hold |
| ADIM in supine, heel slides | 20 reps with 4 sec hold, both sides |
| ADIM in supine, LE lift | 20 reps with 4 sec hold, both sides |
| ADIM in supine, bridge | 30 reps with 8 sec hold |
| ADIM in supine, SLS bridge | 30 reps with 8 sec hold, both sides |
| ADIM in supine, curl up, elbows at sides | 30 reps with 8 sec hold |
| ADIM in supine, curl up, elbows elevated | 30 reps with 8 sec hold |
| ADIM in supine, curl up, hands at head | |
| **Sidelying Progression** | |
| ADIM in sidelying, side plank, knees bent | 30 reps with 8 sec hold, both sides |
| ADIM in sidelying, side plank, knees extended | 30 reps with 8 sec hold, both sides |
| ADIM in sidelying, side plank with tilt | 30 reps with 4 tilts A/P, both sides |
| ADIM in sidelying, side plank with roll | |
| **Standing Progression** | |
| ADIM in standing | 30 reps with 8 sec hold |
| ADIM in standing, row | 30 reps with 8 sec hold |
| ADIM in standing, walking | |

Gluteus Medius Strengthening Exercise Protocol

Physical Therapy Visits:

Each exercise progression is assessed. The exercise prescribed at the last visit is assessed first. If the participant meets the failure criteria, that exercise is prescribed. If a participant meets the progression criteria the next exercise in the progression is attempted. If they meet failure criteria, that exercise is prescribed; if they meet progression criteria, the next exercise is attempted. This is repeated until failure criteria are reached. If a participant progresses to the final exercise in the progression, that exercise is prescribed.

| Exercise | Progression Criterion |
|---|---|
| **Supine Progression** | |
| Bridge | 30 reps with 8 sec hold |
| Bridge with Arms Crossed | 30 reps with 8 sec hold |
| Bridge with Arms Crossed & Feet Together | 30 reps with 8 sec hold |
| SLS Bridge | |
| **Sidelying Progression** | |
| Clam at 45 degrees | 30 reps with 8 sec hold |
| Sidelying hip abduction, knees extended | 30 reps with 8 sec hold |
| Side plank, knees bent | 30 reps with 8 sec hold |
| Side plank, knees extended | |
| **Squat Progression** | |
| Squat | 30 reps |
| SLS mini squat | 30 reps |
| SLS squat | |
| **Standing Progression 1** | |
| Standing abduction | 30 reps |
| Standing abduction, yellow band | 30 reps |
| Standing abduction, red band | 30 reps |
| Standing abduction, green band | 30 reps |
| Standing abduction, blue band | 30 reps |
| Standing abduction, black band | |
| **Standing Progression 2** | |
| Standing abduction with extension | 30 reps |
| Standing abduction with extension, yellow band | 30 reps |
| Standing abduction with extension, red band | 30 reps |
| Standing abduction with extension, green band | 30 reps |
| Standing abduction with extension, blue band | 30 reps |
| Standing abduction with extension, black band | |

REFERENCES


1. Walker BF. The prevalence of low back pain: a systematic review of the literature from 1966 to 1998. *Journal of spinal disorders.* 2000;13(3):205-217.
2. Dionne CE, Dunn KM, Croft PR, et al. A consensus approach toward the standardization of back pain definitions for use in prevalence studies. *Spine.* 2008;33(1):95-103.
3. Deyo RA, Rainville J, Kent DL. What can the history and physical examination tell us about low back pain? *JAMA.* 1992;268(6):760-765.
4. Pengel LH, Herbert RD, Maher CG, Refshauge KM. Acute low back pain: systematic review of its prognosis. *Bmj.* 2003;327(7410):323.
5. Deyo RA, Dworkin SF, Amtmann D, et al. Report of the NIH Task Force on Research Standards for Chronic Low Back Pain. *J Pain.* 2014.
6. Luo X, Pietrobon R, Sun SX, Liu GG, Hey L. Estimates and patterns of direct health care expenditures among individuals with back pain in the United States. *Spine.* 2004;29(1):79-86.
7. Dagenais S, Caro J, Haldeman S. A systematic review of low back pain cost of illness studies in the United States and internationally. *Spine J.* 2008;8(1):8-20.
8. Stewart WF, Ricci JA, Chee E, Morganstein D, Lipton R. Lost productive time and cost due to common pain conditions in the US workforce. *JAMA.* 2003;290(18):2443-2454.
9. Chou R, Qaseem A, Snow V, et al. Diagnosis and Treatment of Low Back Pain: A Joint Clinical Practice Guideline from the American College of Physicians and the American Pain Society. *Ann Intern Med.* 2007;147(7):478-491.
10. Koes BW, van Tulder M, Lin CW, Macedo LG, McAuley J, Maher C. An updated overview of clinical guidelines for the management of non-specific low back pain in primary care. *Eur Spine J.* 2010;19(12):2075-2094.
11. Hayden JA, van Tulder MW, Malmivaara A, Koes BW. Exercise therapy for treatment of non-specific low back pain. *The Cochrane database of systematic reviews.* 2005(3):CD000335.
12. Borkan JM, Cherkin DC. An agenda for primary care research on low back pain. *Spine.* 1996;21(24):2880-2884.
13. Borkan JM, Koes B, Reis S, Cherkin DC. A report from the Second International Forum for Primary Care Research on Low Back Pain. Reexamining priorities. *Spine.* 1998;23(18):1992-1996.
14. Karayannis NV, Jull GA, Hodges PW. Physiotherapy movement based classification approaches to low back pain: comparison of subgroups through review and developer/expert survey. *BMC Musculoskelet Disord.* 2012;13:24.
15. Hefford C. McKenzie classification of mechanical spinal pain: profile of syndromes and directions of preference. *Manual therapy.* 2008;13(1):75-81.
16. Delitto A, Erhard RE, Bowling RW. A treatment-based classification approach to low back syndrome: identifying and staging patients for conservative treatment. *Phys Ther.* 1995;75(6):470-485; discussion 485-479.
17. Fritz JM, Cleland JA, Childs JD. Subgrouping patients with low back pain: evolution of a classification approach to physical therapy. *J Orthop Sports Phys Ther.* 2007;37(6):290-302.
18. Petersen T, Olsen S, Laslett M, et al. Inter-tester reliability of a new diagnostic classification system for patients with non-specific low back pain. *Aust J Physiother.* 2004;50(2):85-94.
19. Sahrmann S. *Diagnosis and treatment of movement impairment syndromes.* St. Louis, Mo.: Mosby; 2002.

20. O'Sullivan P. Diagnosis and classification of chronic low back pain disorders: maladaptive movement and motor control impairments as underlying mechanism. *Manual therapy.* 2005;10(4):242-255.
21. Delitto A, George SZ, Van Dillen LR, et al. Low back pain. *J Orthop Sports Phys Ther.* 2012;42(4):A1-57.
22. Apeldoorn AT, Ostelo RW, van Helvoirt H, et al. A randomized controlled trial on the effectiveness of a classification-based system for subacute and chronic low back pain. *Spine.* 2012;37(16):1347-1356.
23. Henry SM, Van Dillen LR, Ouellette-Morton RH, et al. Outcomes are not different for patient-matched versus nonmatched treatment in subjects with chronic recurrent low back pain: a randomized clinical trial. *Spine J.* 2014.
24. van Middelkoop M, Rubinstein SM, Verhagen AP, Ostelo RW, Koes BW, van Tulder MW. Exercise therapy for chronic nonspecific low-back pain. *Best Pract Res Clin Rheumatol.* 2010;24(2):193-204.
25. Fairbank J, Gwilym SE, France JC, et al. The role of classification of chronic low back pain. *Spine.* 2011;36(21 Suppl):S19-42.
26. Machado LA, de Souza M, Ferreira PH, Ferreira ML. The McKenzie method for low back pain: a systematic review of the literature with a meta-analysis approach. *Spine.* 2006;31(9):E254-262.
27. Paatelma M, Kilpikoski S, Simonen R, Heinonen A, Alen M, Videman T. Orthopaedic manual therapy, McKenzie method or advice only for low back pain in working adults: a randomized controlled trial with one year follow-up. *J Rehabil Med.* 2008;40(10):858-863.
28. Garcia AN, Costa Lda C, da Silva TM, et al. Effectiveness of back school versus McKenzie exercises in patients with chronic nonspecific low back pain: a randomized controlled trial. *Phys Ther.* 2013;93(6):729-747.
29. Hosseinifar M, Akbari M, Behtash H, Amiri M, Sarrafzadeh J. The Effects of Stabilization and Mckenzie Exercises on Transverse Abdominis and Multifidus Muscle Thickness, Pain, and Disability: A Randomized Controlled Trial in NonSpecific Chronic Low Back Pain. *Journal of physical therapy science.* 2013;25(12):1541-1545.
30. Al-Obaidi SM, Al-Sayegh NA, Ben Nakhi H, Al-Mandeel M. Evaluation of the McKenzie intervention for chronic low back pain by using selected physical and bio-behavioral outcome measures. *PM R.* 2011;3(7):637-646; quiz 646.
31. Flynn T, Fritz J, Whitman J, et al. A clinical prediction rule for classifying patients with low back pain who demonstrate short-term improvement with spinal manipulation. *Spine.* 2002;27(24):2835-2843.
32. Childs JD, Fritz JM, Flynn TW, et al. A clinical prediction rule to identify patients with low back pain most likely to benefit from spinal manipulation: a validation study. *Ann Intern Med.* 2004;141(12):920-928.
33. Cleland JA, Fritz JM, Kulig K, et al. Comparison of the effectiveness of three manual physical therapy techniques in a subgroup of patients with low back pain who satisfy a clinical prediction rule: a randomized clinical trial. *Spine.* 2009;34(25):2720-2729.
34. Hancock MJ, Maher CG, Latimer J, Herbert RD, McAuley JH. Independent evaluation of a clinical prediction rule for spinal manipulative therapy: a randomised controlled trial. *Eur Spine J.* 2008;17(7):936-943.
35. Sutlive TG, Mabry LM, Easterling EJ, et al. Comparison of short-term response to two spinal manipulation techniques for patients with low back pain in a military beneficiary population. *Military medicine.* 2009;174(7):750-756.
36. Fritz JM, Magel JS, McFadden M, et al. Early Physical Therapy vs Usual Care in Patients With Recent-Onset Low Back Pain: A Randomized Clinical Trial. *JAMA.* 2015;314(14):1459-1467.

37. Hicks GE, Fritz JM, Delitto A, McGill SM. Preliminary development of a clinical prediction rule for determining which patients with low back pain will respond to a stabilization exercise program. *Arch Phys Med Rehabil.* 2005;86(9):1753-1762.
38. Rabin A, Shashua A, Pizem K, Dickstein R, Dar G. A clinical prediction rule to identify patients with low back pain who are likely to experience short-term success following lumbar stabilization exercises: a randomized controlled validation study. *J Orthop Sports Phys Ther.* 2014;44(1):6-B13.
39. Fritz JM, Lindsay W, Matheson JW, et al. Is there a subgroup of patients with low back pain likely to benefit from mechanical traction? Results of a randomized clinical trial and subgrouping analysis. *Spine.* 2007;32(26):E793-800.
40. Thackeray A, Fritz JM, Childs JD, Brennan GP. The Effectiveness of Mechanical Traction Among Subgroups of Patients With Low Back Pain and Leg Pain: A Randomized Trial. *J Orthop Sports Phys Ther.* 2016;46(3):144-154.
41. Trudelle-Jackson E, Sarvaiya-Shah SA, Wang SS. Interrater reliability of a movement impairment-based classification system for lumbar spine syndromes in patients with chronic low back pain. *J Orthop Sports Phys Ther.* 2008;38(6):371-376.
42. Vibe Fersum K, O'Sullivan P, Skouen JS, Smith A, Kvale A. Efficacy of classification-based cognitive functional therapy in patients with non-specific chronic low back pain: a randomized controlled trial. *European journal of pain.* 2013;17(6):916-928.
43. Harris-Hayes M, Sahrmann SA, Van Dillen LR. Relationship between the hip and low back pain in athletes who participate in rotation-related sports. *J Sport Rehabil.* 2009;18(1):60-75.
44. Offierski CM, MacNab I. Hip-spine syndrome. *Spine.* 1983;8(3):316-321.
45. Yoshimoto H, Sato S, Masuda T, et al. Spinopelvic alignment in patients with osteoarthrosis of the hip: a radiographic comparison to patients with low back pain. *Spine.* 2005;30(14):1650-1657.
46. Matsuyama Y, Hasegawa Y, Yoshihara H, et al. Hip-spine syndrome: total sagittal alignment of the spine and clinical symptoms in patients with bilateral congenital hip dislocation. *Spine.* 2004;29(21):2432-2437.
47. Radcliff KE, Orozco F, Molby N, et al. Is pelvic obliquity related to degenerative scoliosis? *Orthopaedic surgery.* 2013;5(3):171-176.
48. Sembrano JN, Polly DW, Jr. How often is low back pain not coming from the back? *Spine (Phila Pa 1976).* 2009;34(1):E27-32.
49. Ben-Galim P, Ben-Galim T, Rand N, et al. Hip-spine syndrome: the effect of total hip replacement surgery on low back pain in severe osteoarthritis of the hip. *Spine.* 2007;32(19):2099-2102.
50. Mellin G. Correlations of hip mobility with degree of back pain and lumbar spinal mobility in chronic low-back pain patients. *Spine.* 1988;13(6):668-670.
51. Ellison JB, Rose SJ, Sahrmann SA. Patterns of hip rotation range of motion: a comparison between healthy subjects and patients with low back pain. *Phys Ther.* 1990;70(9):537-541.
52. Chesworth BM, Padfield BJ, Helewa A, Stitt LW. A comparison of hip mobility in patients with low back pain and matched healthy subjects. *Physiother Can.* 1994;46(4):267-274.
53. Cibulka MT, Sinacore DR, Cromer GS, Delitto A. Unilateral hip rotation range of motion asymmetry in patients with sacroiliac joint regional pain. *Spine.* 1998;23(9):1009-1015.
54. Swezey RL. Pseudo-radiculopathy in subacute trochanteric bursitis of the subgluteus maximus bursa. *Arch Phys Med Rehabil.* 1976;57(8):387-390.
55. Collee G, Dijkmans BA, Vandenbroucke JP, Rozing PM, Cats A. A clinical epidemiological study in low back pain. Description of two clinical syndromes. *British journal of rheumatology.* 1990;29(5):354-357.

56. Collee G, Dijkmans BA, Vandenbroucke JP, Cats A. Greater trochanteric pain syndrome (trochanteric bursitis) in low back pain. *Scandinavian journal of rheumatology.* 1991;20(4):262-266.
57. Tortolani PJ, Carbone JJ, Quartararo LG. Greater trochanteric pain syndrome in patients referred to orthopedic spine specialists. *Spine J.* 2002;2(4):251-254.
58. Sayegh F, Potoupnis M, Kapetanos G. Greater trochanter bursitis pain syndrome in females with chronic low back pain and sciatica. *Acta orthopaedica Belgica.* 2004;70(5):423-428.
59. Simons DG, Travell JG. Myofascial origins of low back pain. 3. Pelvic and lower extremity muscles. *Postgrad Med.* 1983;73(2):99-105, 108.
60. Njoo KH, Van der Does E. The occurrence and inter-rater reliability of myofascial trigger points in the quadratus lumborum and gluteus medius: a prospective study in non-specific low back pain patients and controls in general practice. *Pain.* 1994;58(3):317-323.
61. Nourbakhsh MR, Arab AM. Relationship between mechanical factors and incidence of low back pain. *J Orthop Sports Phys Ther.* 2002;32(9):447-460.
62. Arab A, Nourbakhsh M. The relationship between hip abductor muscle strength and iliotibial band tightness in individuals with low back pain. *Chiropr Osteopat.* 2010;18(1):1.
63. Kendall KD, Schmidt C, Ferber R. The relationship between hip-abductor strength and the magnitude of pelvic drop in patients with low back pain. *J Sport Rehabil.* 2010;19(4):422-435.
64. Nadler SF, Malanga GA, DePrince M, Stitik TP, Feinberg JH. The relationship between lower extremity injury, low back pain, and hip muscle strength in male and female collegiate athletes. *Clinical journal of sport medicine : official journal of the Canadian Academy of Sport Medicine.* 2000;10(2):89-97.
65. Nadler SF, Malanga GA, Feinberg JH, Prybicien M, Stitik TP, DePrince M. Relationship between hip muscle imbalance and occurrence of low back pain in collegiate athletes: a prospective study. *American journal of physical medicine & rehabilitation / Association of Academic Physiatrists.* 2001;80(8):572-577.
66. Nadler SF, Malanga GA, Bartoli LA, Feinberg JH, Prybicien M, Deprince M. Hip muscle imbalance and low back pain in athletes: influence of core strengthening. *Med Sci Sports Exerc.* 2002;34(1):9-16.
67. Nelson-Wong E, Gregory DE, Winter DA, Callaghan JP. Gluteus medius muscle activation patterns as a predictor of low back pain during standing. *Clin Biomech.* 2008;23(5):545-553.
68. Nelson-Wong E, Flynn T, Callaghan JP. Development of active hip abduction as a screening test for identifying occupational low back pain. *J Orthop Sports Phys Ther.* 2009;39(9):649-657.
69. Nelson-Wong E, Callaghan JP. Is muscle co-activation a predisposing factor for low back pain development during standing? A multifactorial approach for early identification of at-risk individuals. *J Electromyogr Kinesiol.* 2010;20(2):256-263.
70. Nelson-Wong E, Callaghan JP. Transient low back pain development during standing predicts future clinical low back pain in previously asymptomatic individuals. *Spine.* 2014;39(6):E379-383.
71. Bewyer DC, Bewyer KJ. Rationale for treatment of hip abductor pain syndrome. *Iowa Orthop J.* 2003;23:57-60.
72. Bewyer KJ, Bewyer DC, Messenger D, Kennedy CM. Pilot data: association between gluteus medius weakness and low back pain during pregnancy. *Iowa Orthop J.* 2009;29:97-99.
73. Trendelenburg F. Trendelenburg's test: 1895. *Clin Orthop Relat Res.* 1998(355):3-7.
74. Hardcastle P, Nade S. The significance of the Trendelenburg test. *The Journal of bone and joint surgery British volume.* 1985;67(5):741-746.

75. Youdas JW, Madson TJ, Hollman JH. Usefulness of the Trendelenburg test for identification of patients with hip joint osteoarthritis. *Physiother Theory Pract.* 2010;26(3):184-194.
76. Kendall KD, Patel C, Wiley JP, Pohl MB, Emery CA, Ferber R. Steps toward the validation of the Trendelenburg test: the effect of experimentally reduced hip abductor muscle function on frontal plane mechanics. *Clinical journal of sport medicine : official journal of the Canadian Academy of Sport Medicine.* 2013;23(1):45-51.
77. Davis AM, Bridge P, Miller J, Nelson-Wong E. Interrater and intrarater reliability of the active hip abduction test. *J Orthop Sports Phys Ther.* 2011;41(12):953-960.
78. Crossley KM, Zhang WJ, Schache AG, Bryant A, Cowan SM. Performance on the single-leg squat task indicates hip abductor muscle function. *The American journal of sports medicine.* 2011;39(4):866-873.
79. Hislop HJ, Montgomery J. *Daniels and Worthingham's muscle testing : techniques of manual examination.* 7th ed. Philadelphia: W.B. Saunders; 2002.
80. Frese E, Brown M, Norton BJ. Clinical reliability of manual muscle testing. Middle trapezius and gluteus medius muscles. *Phys Ther.* 1987;67(7):1072-1076.
81. Kramer JF, Vaz MD, Vandervoort AA. Reliability of isometric hip abductor torques during examiner- and belt-resisted tests. *Journal of gerontology.* 1991;46(2):M47-51.
82. Jaramillo J, Worrell TW, Ingersoll CD. Hip isometric strength following knee surgery. *J Orthop Sports Phys Ther.* 1994;20(3):160-165.
83. Bohannon RW. Reference values for extremity muscle strength obtained by hand-held dynamometry from adults aged 20 to 79 years. *Arch Phys Med Rehabil.* 1997;78(1):26-32.
84. Krause DA, Schlagel SJ, Stember BM, Zoetewey JE, Hollman JH. Influence of lever arm and stabilization on measures of hip abduction and adduction torque obtained by hand-held dynamometry. *Arch Phys Med Rehabil.* 2007;88(1):37-42.
85. Krause DA, Neuger MD, Lambert KA, Johnson AE, DeVinny HA, Hollman JH. Effects of examiner strength on reliability of hip-strength testing using a handheld dynamometer. *J Sport Rehabil.* 2014;23(1):56-64.
86. Widler KS, Glatthorn JF, Bizzini M, et al. Assessment of hip abductor muscle strength. A validity and reliability study. *The Journal of bone and joint surgery American volume.* 2009;91(11):2666-2672.
87. Bolgla LA, Uhl TL. Electromyographic analysis of hip rehabilitation exercises in a group of healthy subjects. *J Orthop Sports Phys Ther.* 2005;35(8):487-494.
88. Ayotte NW, Stetts DM, Keenan G, Greenway EH. Electromyographical analysis of selected lower extremity muscles during 5 unilateral weight-bearing exercises. *J Orthop Sports Phys Ther.* 2007;37(2):48-55.
89. Ekstrom RA, Donatelli RA, Carp KC. Electromyographic analysis of core trunk, hip, and thigh muscles during 9 rehabilitation exercises. *J Orthop Sports Phys Ther.* 2007;37(12):754-762.
90. Boudreau SN, Dwyer MK, Mattacola CG, Lattermann C, Uhl TL, McKeon JM. Hip-muscle activation during the lunge, single-leg squat, and step-up-and-over exercises. *J Sport Rehabil.* 2009;18(1):91-103.
91. Distefano LJ, Blackburn JT, Marshall SW, Padua DA. Gluteal muscle activation during common therapeutic exercises. *J Orthop Sports Phys Ther.* 2009;39(7):532-540.
92. Boren K, Conrey C, Le Coguic J, Paprocki L, Voight M, Robinson TK. Electromyographic analysis of gluteus medius and gluteus maximus during rehabilitation exercises. *International journal of sports physical therapy.* 2011;6(3):206-223.

93. McBeth JM, Earl-Boehm JE, Cobb SC, Huddleston WE. Hip muscle activity during 3 side-lying hip-strengthening exercises in distance runners. *Journal of athletic training.* 2012;47(1):15-23.
94. Selkowitz DM, Beneck GJ, Powers CM. Which exercises target the gluteal muscles while minimizing activation of the tensor fascia lata? Electromyographic assessment using fine-wire electrodes. *J Orthop Sports Phys Ther.* 2013;43(2):54-64.
95. Philippon MJ, Decker MJ, Giphart JE, Torry MR, Wahoff MS, LaPrade RF. Rehabilitation exercise progression for the gluteus medius muscle with consideration for iliopsoas tendinitis: an in vivo electromyography study. *The American journal of sports medicine.* 2011;39(8):1777-1785.
96. Hamstra-Wright KL, Huxel Bliven K. Effective exercises for targeting the gluteus medius. *J Sport Rehabil.* 2012;21(3):296-300.
97. Reiman MP, Bolgla LA, Loudon JK. A literature review of studies evaluating gluteus maximus and gluteus medius activation during rehabilitation exercises. *Physiother Theory Pract.* 2012;28(4):257-268.
98. Fredericson M, Cookingham CL, Chaudhari AM, Dowdell BC, Oestreicher N, Sahrmann SA. Hip abductor weakness in distance runners with iliotibial band syndrome. *Clinical journal of sport medicine : official journal of the Canadian Academy of Sport Medicine.* 2000;10(3):169-175.
99. Sled EA, Khoja L, Deluzio KJ, Olney SJ, Culham EG. Effect of a home program of hip abductor exercises on knee joint loading, strength, function, and pain in people with knee osteoarthritis: a clinical trial. *Phys Ther.* 2010;90(6):895-904.
100. Ferber R, Kendall KD, Farr L. Changes in knee biomechanics after a hip-abductor strengthening protocol for runners with patellofemoral pain syndrome. *Journal of athletic training.* 2011;46(2):142-149.
101. Vlaeyen JW, Linton SJ. Fear-avoidance and its consequences in chronic musculoskeletal pain: a state of the art. *Pain.* 2000;85(3):317-332.
102. Nicholas MK, George SZ. Psychologically informed interventions for low back pain: an update for physical therapists. *Phys Ther.* 2011;91(5):765-776.
103. Sullivan MJL, Bishop SR, Pivik J. The Pain Catastrophizing Scale: Development and validation. *Psychol Assess.* 1995;7(4):524-532.
104. Waddell G, Newton M, Henderson I, Somerville D, Main CJ. A Fear-Avoidance Beliefs Questionnaire (FABQ) and the role of fear-avoidance beliefs in chronic low back pain and disability. *Pain.* 1993;52(2):157-168.
105. Chapman JR, Norvell DC, Hermsmeyer JT, et al. Evaluating common outcomes for measuring treatment success for chronic low back pain. *Spine.* 2011;36(21 Suppl):S54-68.
106. Vlaeyen JW, Kole-Snijders AM, Boeren RG, van Eek H. Fear of movement/(re)injury in chronic low back pain and its relation to behavioral performance. *Pain.* 1995;62(3):363-372.
107. Beck AT, Ward CH, Mendelson M, Mock J, Erbaugh J. An inventory for measuring depression. *Arch Gen Psychiatry.* 1961;4:561-571.
108. Zigmond AS, Snaith RP. The hospital anxiety and depression scale. *Acta psychiatrica Scandinavica.* 1983;67(6):361-370.
109. Radloff LS. The CES-D Scale: A Self-Report Depression Scale for Research in the General Population. *Appl Psychol Meas.* 1977;1(3):385-401.
110. Fairbank JC, Couper J, Davies JB, O'Brien JP. The Oswestry low back pain disability questionnaire. *Physiotherapy.* 1980;66(8):271-273.
111. Roland M, Morris R. A study of the natural history of back pain. Part I: development of a reliable and sensitive measure of disability in low-back pain. *Spine.* 1983;8(2):141-144.
112. Novy DM, Simmonds MJ, Lee CE. Physical performance tasks: what are the underlying constructs? *Arch Phys Med Rehabil.* 2002;83(1):44-47.

113. Simmonds MJ, Olson SL, Jones S, et al. Psychometric characteristics and clinical usefulness of physical performance tests in patients with low back pain. *Spine.* 1998;23(22):2412-2421.
114. Hoy D, March L, Brooks P, et al. The global burden of low back pain: estimates from the Global Burden of Disease 2010 study. *Annals of the rheumatic diseases.* 2014;73(6):968-974.
115. Chou R, Huffman LH. Nonpharmacologic Therapies for Acute and Chronic Low Back Pain: A Review of the Evidence for an American Pain Society/American College of Physicians Clinical Practice Guideline. *Ann Intern Med.* 2007;147(7):492-504.
116. van Middelkoop M, Rubinstein SM, Kuijpers T, et al. A systematic review on the effectiveness of physical and rehabilitation interventions for chronic non-specific low back pain. *Eur Spine J.* 2011;20(1):19-39.
117. Standaert CJ, Weinstein SM, Rumpeltes J. Evidence-informed management of chronic low back pain with lumbar stabilization exercises. *Spine J.* 2008;8(1):114-120.
118. Mayer J, Mooney V, Dagenais S. Evidence-informed management of chronic low back pain with lumbar extensor strengthening exercises. *Spine J.* 2008;8(1):96-113.
119. Johannes CB, Le TK, Zhou X, Johnston JA, Dworkin RH. The prevalence of chronic pain in United States adults: results of an Internet-based survey. *J Pain.* 2010;11(11):1230-1239.
120. Hoeger Bement M. Exercise-Induced Hypoalgesia: An Evidence-Based Review. In: Sluka KA, ed. *Mechanisms and Management of Pain for the Physical Therapist*. Seattle: IASP Press; 2009.
121. George SZ, Wittmer VT, Fillingim RB, Robinson ME. Comparison of graded exercise and graded exposure clinical outcomes for patients with chronic low back pain. *J Orthop Sports Phys Ther.* 2010;40(11):694-704.
122. Rasmussen-Barr E, Ang B, Arvidsson I, Nilsson-Wikmar L. Graded exercise for recurrent low-back pain: a randomized, controlled trial with 6-, 12-, and 36-month follow-ups. *Spine.* 2009;34(3):221-228.
123. Stanton TR, Fritz JM, Hancock MJ, et al. Evaluation of a treatment-based classification algorithm for low back pain: a cross-sectional study. *Phys Ther.* 2011;91(4):496-509.
124. Cooper NA, Scavo KM, Strickland KJ, et al. Prevalence of gluteus medius weakness in people with chronic low back pain compared to healthy controls. *Eur Spine J.* 2016;25(4):1258-1265.
125. Costa LO, Maher CG, Latimer J, et al. Motor control exercise for chronic low back pain: a randomized placebo-controlled trial. *Phys Ther.* 2009;89(12):1275-1286.
126. Ferreira-Valente MA, Pais-Ribeiro JL, Jensen MP. Validity of four pain intensity rating scales. *Pain.* 2011;152(10):2399-2404.
127. Kamper SJ, Maher CG, Mackay G. Global rating of change scales: a review of strengths and weaknesses and considerations for design. *J Man Manip Ther.* 2009;17(3):163-170.
128. Jenkinson C, Wright L, Coulter A. Criterion validity and reliability of the SF-36 in a population sample. *Qual Life Res.* 1994;3(1):7-12.
129. Smeets RJ, Hijdra HJ, Kester AD, Hitters MW, Knottnerus JA. The usability of six physical performance tasks in a rehabilitation population with chronic low back pain. *Clin Rehabil.* 2006;20(11):989-997.
130. Bohannon RW. Test-retest reliability of hand-held dynamometry during a single session of strength assessment. *Phys Ther.* 1986;66(2):206-209.

131. Van Dillen LR, Norton BJ, Sahrmann SA, et al. Efficacy of classification-specific treatment and adherence on outcomes in people with chronic low back pain. A one-year follow-up, prospective, randomized, controlled clinical trial. *Manual therapy.* 2016;24:52-64.
132. Cairns MC, Foster NE, Wright C. Randomized controlled trial of specific spinal stabilization exercises and conventional physiotherapy for recurrent low back pain. *Spine (Phila Pa 1976).* 2006;31(19):E670-681.
133. Macedo LG, Latimer J, Maher CG, et al. Effect of motor control exercises versus graded activity in patients with chronic nonspecific low back pain: a randomized controlled trial. *Phys Ther.* 2012;92(3):363-377.
134. Unsgaard-Tondel M, Fladmark AM, Salvesen O, Vasseljen O. Motor control exercises, sling exercises, and general exercises for patients with chronic low back pain: a randomized controlled trial with 1-year follow-up. *Phys Ther.* 2010;90(10):1426-1440.
135. Ferreira ML, Ferreira PH, Latimer J, et al. Comparison of general exercise, motor control exercise and spinal manipulative therapy for chronic low back pain: A randomized trial. *Pain.* 2007;131(1-2):31-37.
136. Saragiotto BT, Maher CG, Yamato TP, et al. Motor control exercise for chronic non-specific low-back pain. *The Cochrane database of systematic reviews.* 2016(1):CD012004.
137. Yamato TP, Maher CG, Saragiotto BT, et al. Pilates for low back pain. *The Cochrane database of systematic reviews.* 2015(7):CD010265.
138. Wieland LS, Skoetz N, Pilkington K, Vempati R, D'Adamo CR, Berman BM. Yoga treatment for chronic non-specific low back pain. *The Cochrane database of systematic reviews.* 2017;1:CD010671.
139. Novy DM, Simmonds MJ, Olson SL, Lee CE, Jones SC. Physical performance: differences in men and women with and without low back pain. *Arch Phys Med Rehabil.* 1999;80(2):195-198.
140. Lee CE, Simmonds MJ, Novy DM, Jones S. Self-reports and clinician-measured physical function among patients with low back pain: a comparison. *Arch Phys Med Rehabil.* 2001;82(2):227-231.
141. Sutherlin MA, Hart JM. Hip-abduction torque and muscle activation in people with low back pain. *J Sport Rehabil.* 2015;24(1):51-61.
142. Mannion AF, Helbling D, Pulkovski N, Sprott H. Spinal segmental stabilisation exercises for chronic low back pain: programme adherence and its influence on clinical outcome. *Eur Spine J.* 2009;18(12):1881-1891.
143. Beinart NA, Goodchild CE, Weinman JA, Ayis S, Godfrey EL. Individual and intervention-related factors associated with adherence to home exercise in chronic low back pain: a systematic review. *Spine J.* 2013;13(12):1940-1950.