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The Effect of Functional Movement Control on Patient-Reported Outcomes in Individuals with Non-Arthritic Hip Pain

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THE EFFECT OF FUNCTIONAL MOVEMENT CONTROL ON PATIENT-REPORTED OUTCOMES IN INDIVIDUALS WITH NON-ARTHRITIC HIP PAIN

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ABSTRACT

THE EFFECT OF FUNCTIONAL MOVEMENT CONTROL ON PATIENT-REPORTED OUTCOMES IN INDIVIDUALS WITH NON-ARTHRITIC HIP PAIN

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Ryan P. McGovern

May 2019

Dissertation supervised by RobRoy L. Martin, PhD, PT, CSCS

Purpose: Both the single leg squat test and step-down test assess for deficiencies relating to the hip and surrounding musculoskeletal structures and could be useful in the evaluation of functional movement control for individuals with non-arthritic hip pain. The purpose of this study is to determine if individuals with non-arthritic hip pain that improve functional movement control during the single leg squat test and step-down test have better patient-reported outcomes than those that do not improve, following the implementation of a rehabilitation intervention and a standardized home-exercise program.

Subjects: Forty-six individuals (31 females; 15 males) with a mean age of 30 years (range = 14-61; SD = 12) were included in this retrospective study. These individuals were

patients of an orthopaedic surgeon who were clinically diagnosed and conservatively treated for non-arthritic hip pain from chondrolabral lesions caused by FAI, dysplasia and/or structural abnormalities. Participants must have had evaluations for both the initial and follow-up test performance of the single leg squat test and step-down test, following the implementation of a rehabilitation intervention and a standardized home-exercise program.

Materials/Methods: The following information was retrospectively collected from an outcomes registry: age, gender, height, weight, body mass index (BMI), side of involved hip, duration of symptoms, intra-articular diagnosis, current pain level (VAS), hip outcome score for limitations in activities of daily living (HOS-ADL) and sports-related activities (HOS-SRA), percent global rating for activities of daily living (% - ADL) and sports-related activities (% - SRA), the categorical assessment of function, patient satisfaction, the individual's decision to proceed with surgical intervention or not, and evaluations of test performance for the single leg squat test and step-down test from both the initial and follow-up clinical evaluations. The research data for the current study was de-identified so that subjects could not be identified, directly or through identifiers linked to the subjects. A one-tail, independent t-test and a one-way analysis of covariance (ANCOVA) with a pre-determined alpha set of 0.05 were performed for each continuous patient-reported outcome (VAS, HOS-ADL, HOS-SRA, % - ADL, % - SRA). A Fisher's exact test with a pre-determined alpha set of 0.05 was performed for each categorical patient-reported outcome (categorical rating of function, patient satisfaction, and choice for surgical intervention or not).

Results: There was a statistically significant difference ($p \leq .022$) between individuals that improved and those that did not improve their functional performance for the following measures: VAS for SLST and SDT, HOS-ADL for the SLST and SDT, HOS-SRA for the SLST and SDT, % - ADL for the SLST and SDT, and % - SRA for the SLST. There was not a statistically significant difference for the % - SRA for the SDT ($p = .094$). There was a statistically significant relationship ($p \leq .004$) between those individuals that improved and those that did not improve their functional performance for both the SLST and SDT with patient satisfaction and surgery. There was not a statistically significant relationship between those individuals that improved and those that did not improve their functional performance for both the SLST and SDT with their categorical rating of function ($p \geq .117$).

Conclusions: Individuals that improved their functional movement control during performance of the SLST and SDT reported less pain, higher scores for functional ability in their daily and sports-related activities, higher scores for their global rating of functional ability in their daily and sport-related activities, higher patient satisfaction with the prescribed rehabilitation intervention and standardized home-exercise program, and lower rates of surgical intervention, than those that did not improve.

Clinical Relevance: The results of this study suggest that individuals who improved their functional movement control are more likely to report less pain and greater functional ability in their daily and sports-related activities following a prescribed rehabilitation intervention and standardized home-exercise program. A significant number of

individuals who improved their functional movement control reported greater satisfaction with the prescribed rehabilitation intervention as well as lower rates of surgical intervention, than those that did not improve. There is potential significance for the routine addition of the SLST and SDT into the clinical assessment of non-arthritic hip pain and dysfunction as measures of function. This study also supports the use of a rehabilitation intervention and a standardized home-exercise program to acutely improve outcomes for those with non-arthritic hip pain.

DEDICATION

To my parents, Nancy and Michael, for instilling the importance of an education at a young age. To my son, Shane, may this encourage you to pursue all your goals in life. Most importantly to my wife, Ashley, your love and support inspires me every day. You are the best thing. Hi-Two.

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Chapter 1

Introduction

1.1 Background

Healthcare providers utilize functional performance testing to evaluate individuals for injury prevention, management of athletic injuries, and return-to-play decisions.[1-3] Functional performance tests combine the assessment of range of motion, strength, and proprioception to evaluate functional movement patterns that are associated with more complex activities.[2,4] These tests are used to identify neuromuscular deficiencies that limit the functional movement control of an individual during dynamic activity.[2] In a healthy active population, those who were able to improve their movement control had an improvement in functional performance testing.[5,6] However, for individuals with non-arthritic hip pain, there are no studies demonstrating whether those that have improved functional movement control will differ in outcome assessment from those that do not improve.

An area of limited research is the evaluation of functional performance testing in the young, athletic population with non-arthritic hip pain.[2] Non-arthritic hip pain is defined as pathologies associated with the intra-articular structures of the hip in the absence of severe degenerative joint disease that can cause pain including femoroacetabular impingement (FAI), dysplasia, structural instability, acetabular labral tears (LT), chondral lesions, and ligamentum teres tears.[7-9] These non-arthritic hip pathologies have been associated with abnormal hip motion and muscle function.[7,9,10] Arthroscopic surgical interventions to treat these conditions have increased in the United

States by 365% between 2004-2009[11] and 600% between 2006-2010.[12] While surgical outcomes are generally good it is unknown whether improvements in hip motion and muscle function with non-operative or conservative treatment can also produce positive outcomes. It may be possible to decrease intra-articular stresses and have good outcomes even in the presence of structural abnormalities through conservative treatment of neuromuscular deficiencies.

Non-arthritic hip pain is diagnosed from a combination of diagnostic imaging (i.e. x-ray, magnetic resonance imaging, magnetic resonance arthrogram) and a comprehensive clinical examination.[7,8,13] Patient-reported outcome measures (PRO's) and functional performance testing are included in the clinical examination.[7,13] Two commonly performed lower extremity functional performance tests are the single leg squat test (SLST) and step-down test (SDT).[14,15] The SLST and SDT account for several deviations in hip, pelvis, and trunk performance that are considered important when assessing individuals for neuromuscular deficiencies associated with non-arthritic hip pain.[16,17] While clinicians commonly utilize the SLST and SDT in the evaluation process for those with lower extremity pathologies, their use in individuals with non-arthritic hip pain has not been specifically defined.

Both the SLST and SDT assess for deficiencies relating to the hip and surrounding musculoskeletal structures and could be useful in the evaluation of functional movement control for individuals in this population. The purpose of this study is to determine if individuals with non-arthritic hip pain that improve functional movement control during the SLST and SDT have better PRO's than those that do not

improve, following the implementation of a rehabilitation intervention and a standardized home-exercise program.

1.2 Problem Statement

There are no current studies that demonstrate whether individuals with non-arthritic hip pain who improve their functional movement control from an initial evaluation (pre-test) to follow-up evaluation (post-test) of the SLST and SDT differ in PRO's than those that do not improve, following the implementation of a rehabilitation intervention and a standardized home-exercise program.

1.3 Independent Variables

The independent variable of the current study was the evaluation of functional movement control by performance of the SLST and SDT.

1. Improvement from initial evaluation (pre-test) to follow-up (post-test) evaluation following rehabilitation that includes a standardized home-exercise program.

1.4 Dependent Variables

The current study evaluated PRO's before and after rehabilitation intervention and a standardized home-exercise program. Patient outcomes will be determined by the evaluation of eight dependent variables:

1. Visual analog scale (VAS) for evaluation of current pain level.
2. Hip outcome score for limitations in activities of daily living (HOS-ADL).

3. Hip outcome score for limitations in sports-related activities (HOS-SRA).
4. Percent global rating for activities of daily living (% - ADL).
5. Percent global rating for sports-related activities (% - SRA).
6. Categorical rating of function.
7. Patient satisfaction.
8. Choice of surgical intervention or not.

1.5 Hypothesis

1. Individuals that improve functional movement control during performance of the SLST and SDT will have better PRO's than those that do not improve.
    a. Individuals who improve functional movement control during performance of the SLST and SDT will have a lower reported pain level (0-10) than those that do not improve.
    b. Individuals who improve functional movement control during performance of the SLST and SDT will score higher on the HOS-ADL (0-100) than those that do not improve.
    c. Individuals who improve functional movement control during performance of the SLST and SDT will score higher on the HOS-SRA (0-100) than those that do not improve.
    d. Individuals who improve functional movement control during performance of the SLST and SDT will report a higher % - ADL (0-100), than those that do not improve.

e. Individuals who improve functional movement control during performance of the SLST and SDT will report a higher % - SRA (0-100), than those that do not improve.
f. Individuals who improve functional movement control during performance of the SLST and SDT will report a better categorical rating of function (improved or did not improve), than those that do not improve.
g. Individuals who improve functional movement control during performance of the SLST and SDT will report a higher level of satisfaction (yes or no), than those that do not improve.
h. Individuals who improve functional movement control during performance of the SLST and SDT will choose surgery at a lower rate (yes or no), than those that do no improve.

Chapter 2

Literature Review

A review of the literature was conducted to provide an overview of non-arthritic hip pain (section 2.1) as well as outline the current treatment strategies (section 2.2) and define the evaluation process (section 2.3) for individuals with intra-articular hip pathologies.

2.1 Non-Arthritic Hip Pain

Non-arthritic hip pain is defined as pathologies associated with the intra-articular structures of the hip in the absence of severe degenerative joint disease. The most common cause of non-arthritic hip pain is chondrolabral pathologies, specifically labral tears and chondral lesions.[7] Deformities that lead to chondrolabral pathology include FAI, dysplasia, and structural instability.[7-9] These pathologies commonly are inter-related and can occur concurrently, with cam and pincer FAI being the most common deformities.[11,12,18] Cam impingement is caused by an asphericity of the femoral head and/or a protrusion of excess bone at the femoral head/ neck junction,[7,19] while pincer impingement is caused by an excessive protrusion of the anterolateral rim of the acetabulum.[7,19] Although most of the current focus has been dedicated to FAI,[20] dysplasia and structural instability are also prevalent bony abnormalities that can lead to acetabular labral tears and chondral lesions, due to excessive femoral head movement relative to the acetabulum.[7,10,21-25] Dysplasia typically causes instability from an

undercoverage of the anterior and superolateral acetabulum over the femoral head.[25,26] While dysplasia is the most common type of structural instability, excessive acetabular anteversion and retroversion as well as femoral anteversion are also prevalent conditions that can cause excess hip motion. Femoroacetabular impingement, dysplasia, and structural instability cause symptomatic chondrolabral lesions due to the repetitive impact and rotational loading associated with sports related activities.[7,25,27-30]

Individuals with symptomatic chondrolabral lesions commonly report pain in the groin or anterior hip, however symptoms can also present in the lateral or posterior hip region.[25,31] Pain is often associated with mechanical symptoms that present as catching, clicking, locking, and/or an unstable feeling in the hip joint.[19,25] The onset of symptoms in individuals can occur from an acute traumatic incident but have primarily been reported as atraumatic with intermittent sharp pain.[19,25,31] A decrease in hip flexion, adduction, abduction, and internal rotation range of motion (ROM) are the most consistently identified limitations in patients with chondrolabral pathologies.[25,31] While limitations in hip ROM are common in this population, increased pelvic and lumbosacral motions can compensate causing further pathomechanical adaptations.[19] These adaptations can lead to functional limitations during daily and sports-related activities, diminished strength in the musculature of the hip, and impaired kinematic and kinetic movements during weight-bearing activities.[31,32] Individuals have shown a decrease in hip and pelvis ROM in the frontal and sagittal planes as well as altered balance and proprioceptive control during dynamic movements.[16,33,34] Significant muscle weakness with hip flexion, abduction, adduction, and external rotation has been shown in individuals with non-arthritic hip pain compared to healthy controls.[16,33,35] The loss of

strength, functional motion, and proprioception during weight-bearing activities combine to cause neuromuscular deficiencies that can decrease the dynamic stability of the hip, pelvis, and trunk.[32]

Neuromuscular control is the detection and utilization of perceived sensory information attained during performance of specific movements.[36] Deficiencies in neuromuscular control during dynamic weight-bearing activities have been shown to notably change movement patterns and increase the risk for musculoskeletal injuries.[33,36] The assessment of deficiencies in individuals with non-arthritic hip pain during dynamic movements should be evaluated before a rehabilitation intervention or conservative treatment is initiated.[37] Functional performance testing is commonly utilized to evaluate the basic dynamic movement patterns of the lower extremity and may combine ROM, flexibility, balance, proprioception, motor control, as well as muscle strength, power, and/or endurance.[2,37,38] Identification of deficiencies in neuromuscular control during functional performance testing could improve the individualized rehabilitation intervention utilized to increase muscular strength around the hip, decrease joint instability, and improve proprioceptive control during dynamic activities.

2.2 Treatment of Non-Arthritic Hip Pain

The current standard of care for treatment of individuals with non-arthritic hip pain include conservative care, rehabilitation, and/or surgical intervention. Open and arthroscopic surgeries are utilized to address structural abnormalities as well as the associated intra-articular pathologies.[31] Prior to consideration of surgical intervention, a trial of non-operative or conservative management is commonly recommended to address

neuromuscular deficiencies in the surrounding hip musculature through a rehabilitation intervention.[7,31,32]

2.2.1 Operative Management

Open surgical dislocation and hip arthroscopy are the two commonly performed operative techniques to treat non-arthritic hip pain.[20,39] While the use of an open dislocation procedure was first reported to access the hip joint in 2001[40] and treat individuals with FAI in 2003,[41] hip arthroscopy has become the most commonly performed procedure in the past decade.[11,12,18,42] Arthroscopic interventions to treat intra-articular conditions have increased in the United States by 365% between 2004-2009[11] and 600% between 2006-2010.[12] The increased use of the less invasive arthroscopic procedure is associated with having better overall recovery of function, reducing non-arthritic hip pain, and having a lower re-operation rate than the open surgical dislocation procedure.[39]

Both open dislocation and hip arthroscopy techniques are utilized to address structural abnormalities, relieve pain, improve the functional ability of patients during activity, and preserve the hip joint from further structural damage.[43] Commonly performed procedures utilized to address intra-articular pathologies during surgical intervention include: debridement, repair, refixation, or reconstruction of labral tears;[44,45] femoroplasty for decompression of cam morphologies;[45,46] acetabuloplasty for acetabular rim resection of pincer morphologies;[47,48] pelvic osteotomies to treat dysplasia and acetabular retroversion (ie. shelf osteotomy, periacetabular osteotomy, Birmingham interlocking periacetabular osteotomy);[45,49] acetabular and femoral chondroplasty for

repair of damaged cartilage;[50,51] acetabular and femoral microfracture procedures for addressing chondral defects;[52,53] and debridement or reconstruction for tears of the ligamentum teres.[44,54] The open dislocation and arthroscopic surgeries for management of non-arthritic hip pain have both been reported to positively affect PRO's.[55,56] Studies demonstrate that individuals who underwent surgical interventions for chondrolabral pathologies relating to FAI and dysplasia reported a decrease in pain, improvements in function, and a high level of satisfaction with the surgical procedure.[39,57-59] However, despite the increase in the frequency of surgery and the positive PRO's, there are limitations that are not addressed in the current literature. These limitations include: a precise examination procedure to determine which individuals warrant surgical intervention; a lack of robust evidence-based research describing long-term outcomes of surgery; and a lack of high quality studies comparing operative to non-operative treatment.[20,60-62]

2.2.2 Non-Operative Management

While surgical interventions are generally thought to be successful in treating non-arthritic hip pain,[39,57-59] a recent systematic review found that FAI morphological deformities and labral injuries are common in asymptomatic individuals.[63] Structural deformities commonly addressed during surgical intervention may not be the only influences on pain in individuals with non-arthritic, intra-articular hip conditions.[32] Neuromuscular deficiencies in the surrounding hip musculature can lead to joint instability and excessive motion causing structural damage over time.[23,32,64] It may be possible to decrease intra-articular stresses even in the presence of structural

abnormalities through improving neuromuscular control of the surrounding structures and possibly avoid the need for surgical correction.

A trial of non-operative management is commonly recommended before consideration of surgical intervention, however specific rehabilitation protocols have not been thoroughly established in the current literature. A literature review that identifies and provides available evidence for the use of non-operative or conservative management of individuals with non-arthritic hip pain from the current, peer-reviewed literature is presented in Chapter 3.

2.3 Evaluation of Non-Arthritic Hip Pain

With the recent increase in awareness of non-arthritic hip pathologies,[20,65] identification and diagnosis of these conditions has become more common, especially in the young, athletic population. Non-arthritic hip pain is diagnosed from a combination of diagnostic imaging (section 2.3.1) and comprehensive clinical examination (section 2.3.2).[7,8,13] The use of imaging and the clinical exam should focus on the intra-articular structures of the hip, surrounding musculotendinous structures, as well as the spine, pelvis and lower extremities.[13,66,67] The primary objective for the evaluation of individuals with non-arthritic hip pain is to not only identify the severity of specific pathologies but also identify associated neuromuscular deficiencies and functional limitations.

2.3.1 Diagnostic Imaging

The combined use of a standard set of plain radiographs (section 2.3.1.1) with either magnetic resonance imaging (MRI) (section 2.3.1.2) or magnetic resonance arthrography (MRA) (section 2.3.1.3) allow for a thorough evaluation of intra-articular pathologies of the hip.[66,68]

2.3.1.1 Radiographs

A standard set of plain radiographs are attained to assess the bony structures of the intra-articular hip joint.[66,69] Common radiographic views utilized to evaluate intra-articular pathologies of the hip include the superior anteroposterior (AP) view of the pelvis, lateral view of the proximal femur (Dunn 45° or 90° view, frog-leg lateral view, and/or cross-table lateral view), and a standing false profile view of the pelvis.[8,13,66,69] The full, contralateral hip joint and proximal femur should be included in the AP view to allow for the proper evaluation of all angles and structures. Valuation of these views are commonly assessed with automated software, allowing for the direct measurement of angles associated with non-arthritic hip pain.[66]

Femoral morphologies associated with cam impingement are commonly assessed using the AP, lateral (specifically the Dunn), or modified false-profile views for the alpha angle.[13,66,70] An alpha angle greater than 55°-60° is considered abnormal, while angles less than 55° are defined as normal.[13,41,66] Acetabular over-coverage associated with pincer impingement is assessed using the AP view for the crossover sign, Wiberg's lateral center-edge-angle (LCEA), and the Tönnis angle as well as the false profile view

for anterior center-edge-angle (CEA).[8,13,66] The AP views for LCEA, the acetabular index, and Tönnis angle as well as the false profile view for CEA are also utilized to assess for acetabular under-coverage associated with dysplasia.[13,66] Normal LCEA and CEA are 22°-42°, while angles <40° are considered to be pincer morphologies and > 26° are measured as dysplastic.[66] Tönnis angle's between -10° and 10° are considered normal, however, an angle <10° can be considered dysplastic while an angle of >10° can be indicative of a pincer morphology.[66] Acetabular retroversion can be evaluated using the AP view assessing for LCEA, the crossover sign, the posterior wall sign, the ischial spine sign and the acetabular index.[8] A positive crossover sign with LCEA >35° is indicative of acetabular retroversion.[66] The femoral neck to shaft angle is also measured in the AP view for evaluation of abnormal femoral neck orientation in the acetabulum. Normal femoral neck-shaft angles range from 125° to 145°, with a femoral neck-shaft angle >145° indicative of coxa valga, and a neck-shaft angle of >125° indicating the occurrence of coxa vara.[66] These conditions can lead to abnormal stresses on the hip joint causing irregular hip development, biomechanics, and secondary soft-tissue pathologies.[66]

Radiographs have been shown to be reliable and valid in identifying bony abnormalities associated with cam and pincer FAI, dysplasia, and structural instability.[71-76] Several studies have demonstrated the diagnostic accuracy of non-radiologists correctly diagnosing cam and pincer FAI.[71,72] Specifically, Ratzlaff et al.[71] demonstrated intra-rater reliability with a kappa value of 0.72 and prevalence-adjusted bias-adjusted Kappa of 0.76, while validity was shown with a sensitivity of 0.83 and specificity of 0.87 compared to an experienced musculoskeletal radiologist. Measurements indicative of

dysplasia have demonstrated intraclass correlation coefficients (ICC) for intra-rater and inter-rater reliabilities as 0.85 and 0.51 respectively,[77] as well as 0.67 for inter-rater reliability for observers who were experienced in evaluating the hip.[72,78] Acetabular retroversion was also shown to be accurately assessed with kappa values of 0.63 and 0.70 for inter-rater reliability and 0.67 and 0.70 for intra-rater reliability.[75]

In order to classify individuals with non-arthritic hip pain, osteoarthritic changes should be evaluated radiographically utilizing the Tönnis classification of osteoarthritis.[79] The Tönnis grade is usually assessed on the AP view and gives an objective evaluation for the severity of degeneration. The Tönnis grade evaluates the joint space between the femoral head and acetabulum of the hip on a 4-point scale, from 0 to 3 with: 0 representing no signs of osteoarthritis; 1 representing mild osteoarthritis with an increased subchondral sclerotic change, slight narrowing of the joint space, and/or slight loss of head sphericity; 2 representing moderate osteoarthritis with small cysts, moderate narrowing of the joint space, and/or a moderate loss of head sphericity; and 3 representing severe osteoarthritis with large cysts, severe narrowing or obliteration of the joint space, severe deformity of the femoral head, and/or evidence of necrosis.[72,79] The classification of hip osteoarthritis is commonly defined as a 50% narrowing of joint space (< 2 mm) and/or a Tönnis grade of 2-3.[8,43] Therefore, non-arthritic hip pain can be graded as either a Tönnis 0 or 1 due to the overall preservation of joint space with no or mild sclerotic change.[7,43,80] Kappa values for Tönnis grading have been reported for inter-observer reliability (0.74) and intra-observer reliability (0.73) in a 20-year follow-up study on periacetabular osteotomies.[81]

2.3.1.2 Magnetic Resonance Imaging

Magnetic resonance imaging techniques have been specifically developed for evaluating FAI and soft-tissue conditions of the hip joint and surrounding musculoskeletal structures.[68,82] The use of MRI has recently been shown as highly accurate in the evaluation of intra-articular pathologies of the hip in the presence of FAI.[68,83] MRI techniques include imaging in an oblique plane along the femoral neck as well as standard coronal, sagittal, and axial plane views of the hip and pelvis.[13,68] Addition of the contralateral hip can be included in the coronal view to allow for comparison of bone marrow charactersistics.[68] Evaluation of these views are commonly assessed with automated software, allowing for the visualization of structures and direct measurement of angles associated with non-arthritic hip pain.

MRI can be used to identify structural morphologies associated with cam and pincer impingement. Similar to the evaluation of radiographs, the alpha angle is quantified from the axial oblique series for cam impingement and the LCEA is quantified from the coronal sequence for pincer impingement.[68] Fibrocystic lesions that are caused by impingement can also be identified by MRI to show changes in the femoral head-neck junction.[68] MRI's have been shown to accurately assess for chondrolabral pathologies associated with FAI, demonstrating high levels of both specificity (50%-100%) and sensitivity (85%-100%) when compared to hip arthroscopy.[83] While the acetabular labrum can be identified on the coronal, sagittal, and/or axial oblique views, higher strength MRI's (3T) have better outcomes than lower strength (1.5T) for identifying labral tears.[68] Subchondral changes, extra-articular tendinopathies, and capsular defects are also commonly assessed by healthcare providers when evaluating an MRI for FAI

and intra-articular, soft-tissue pathologies.[68] The diagnostic accuracy of conventional 3T MRI has been shown to be equivalent to 1.5T MRA for diagnosing labral tears and cartilage delamination, while it is has been shown superior in diagnosing acetabular cartilage defects.[84,85]

2.3.1.3 Magnetic Resonance Arthrography

Magnetic resonance arthrography is the direct injection of a contrast material into the hip joint followed by the standard MRI evaluation reviewed in the previous section. The injection is either given directly into the hip joint under ultrasound sonography or fluoroscopy, or indirectly into the bloodstream.[86] The sensitivity of a 1.5T MRA has been shown equivalent to the conventional 3T MRI for diagnosing labral tears and cartilage delamination, but it has been shown less effective in diagnosing acetabular cartilage defects.[84,85] While MRA techniques are still commonly utilized by healthcare providers, the inclusion of intra-articular contrast is an unnecessary invasive procedure that is not needed to accurately evaluate the intra-articular structures of the hip.[68]

While radiographs are the most commonly utilized imaging method for diagnosing and assessing the progression of osteoarthritis, MRI and MRA can also be used to identify pre-arthritic changes in the hip by assessing for chondrolabral pathologies associated with increased Tönnis grade.[80,87] Individuals with higher Tönnis grades (2 and 3) have been shown to cause increased chondral damage as evaluated by MRI with a higher reversion to total hip arthroplasty following arthroscopic surgery than individuals with mild osteoarthritis.[43] Larger labral tears have also been shown in

individuals with higher Tönnis grades, specifically in females with diagnosed coxa vara.[88]

2.3.2 Comprehensive Clinical Examination

A comprehensive clinical examination should be combined with a standard set of plain radiographs and high-resolution MRI study to accurately assess for non-arthritic hip pain.[66-68] A comprehensive clinical exam should include a directed and thorough patient history (section 2.3.2.1) and physical examination (section 2.3.2.2) based on the best current evidence available.

2.3.2.1 History

Prior to the physical examination, a subjective history should be obtained in order to provide detail on the individuals pathological condition.[67] This detailed, patient history should begin with patient demographics, the date of onset, the presence or absence of trauma, location of pain, mechanism of injury, reporting of mechanical symptoms (snapping, clicking, popping) in the hip, and current functional limitations.[13,89] The individuals history of recreational and sports-related activities can help define the type of injury as well as establish realistic goals and expectations following treatment.[89] Other commonly utilized questions that provide needed information for the clinician are: previous consultations (with the treating and/or other healthcare providers), past orthopaedic surgical interventions (contra-lateral hip/ ipsilateral hip and lower extremity), previous orthopaedic injuries, prior physical therapy or rehabilitation interventions, and the presence of childhood hip disease, osteoarthritis, and risk factors related to

osteonecrosis.[13,67,89] The history of pain and trauma should be established to aid in the determination of intra-articular versus extra-articular pathologies as well as identify possible differential diagnoses that may be related to the trunk, spine, pelvis, and lower extremities.[13,67,89] Quantification of hip pain, daily and sports-related function, and severity of symptoms should be addressed through the use of outcome measures.[89,90] The specific use of PRO's in the evaluation of non-arthritic hip pain will be discussed in section 2.3.2.2.3.1.

2.3.2.2 Physical Examination

Following the subjective history, a physical examination should be performed as quickly and efficiently as possible to establish pathology associated with the hip, pelvis, trunk, abdominal, neurovascular, and neurologic systems.[89] Individuals should be in loose fitting clothes for proper evaluation of the lower extremity. Several studies recommend that a standardized procedure should be incorporated for an efficient evaluation including an examination beginning in the standing position followed by sitting, supine, lateral, and prone testing.[13,67,89,91] Evaluation tools utilized in these positions include impairment measures, special testing, and functional measures.[89]

2.3.2.2.1 Impairment Measures

Individuals with bony abnormalities that cause symptomatic chondrolabral lesions commonly report pain in the groin or anterior hip, however symptoms can also be present in the lateral or posterior hip region.[25,31] Pain is often associated with mechanical symptoms such as catching, clicking, locking, and/or an unstable feeling in the hip

joint.[19,25] A decrease in hip flexion, adduction, abduction, and internal rotation are the most consistently reported limitations in patients with chondrolabral pathologies.[25,31] Significant muscle weakness with hip flexion, abduction, adduction, and external rotation has been shown in individuals with non-arthritic hip pain in comparison to healthy controls.[16,33,35] Healthcare providers evaluate non-arthritic hip pain by utilizing specific impairment measures to assess the extent of injury caused by the bony abnormality and associated chondrolabral pathology.[92,93] These impairment measures should include visual observation, palpation, ROM, and strength testing.[13,67,89,91]

The examination in standing should begin with a general assessment of the individuals overall appearance, body composition, mood, posture, and gait.[67] Gait should be assessed for specific limitations associated with antalgic gait (shortened stride length on affected side), Trendelenburg gait (abductor stagger), excessive internal or external rotation at the hip, pelvic tilt or rotation, decreased stride length, and an abnormal foot progression.[67,89] Hypermobility of other joints should be assessed in the standing position if there is a concern for dysplasia of the hip.[67]

The examination in the seated position assesses the vascular and neurological integrity of the lower extremity through the evaluation of pulse, sensation, motor control, and deep tendon reflexes.[89] Range of motion for hip flexion, internal and external rotation, abduction, and adduction can be evaluated first in the seated position before evaluating in the supine exam position.[67,89]

The examination in supine should begin with visual observation of the lower extremity for leg length discrepancy, quadriceps atrophy, and pelvic obliquity.[67,89] Anterior capsule laxity and hip retroversion can be evaluated by the amount of hip

external rotation (toe out) an individual has in a relaxed, supine position.[13,67] Palpation of the hip and surrounding structures is primarily used for extra-articular symptoms including abdominal soreness, hip flexor tendinosis, hip abductor and adductor soreness, and "C" sign soreness for trochanteric pain.[67,89] Palpation of surrounding bony landmarks including the anterior superior iliac spine, pubic symphysis, and ischial tuberosity should be performed as well.[67,89] Range of motion for hip forward flexion, internal and external rotation (with the hip and knee flexed at 90°), abduction, and adduction can be evaluated in the supine position.[50] Individuals with non-arthritic hip pain commonly have limitations in hip flexion, abduction, and external and internal rotation range of motion.[13]

The examination in the lateral position begins with further palpation of the sacroiliac joint, abductors, iliotibial band, and greater trochanteric regions.[67,89] Irritation to the trochanteric bursa and the gluteus medius/minimus can often be associated with intra-articular conditions of the hip.[89] Abductor strength can be evaluated by resisted abduction and extension of the hip in the side-lying position.[89]

The examination in the prone position should begin with palpation at the ischial tuberosity to evaluate the insertion of the proximal hamstring tendons.[67] The sacroiliac joint, lumbar spine, and greater trochanter should also be evaluated for point tenderness.[67,89] Gluteus maximus and hamstring strength can be evaluated in the prone position with palpation of tendons during resisted hip extension to evaluate for contracture.[67] Internal and external rotation can also be evaluated in the prone position with the knee bent to 90°. Excessive internal rotation can indicate increased femoral

anteversion while an excess of both internal and external rotation could indicate a dysplastic hip joint.[67,89] A significant limitation in internal rotation can signify FAI.[67]

Eighty-one percent of individuals with surgically confirmed non-arthritic hip pain have reported groin pain as the most common clinical presentation of symptoms.[67,94] Limitations in flexion-internal rotation have been shown sensitive (96%) in the diagnosis of non-arthritic hip pain, specifically FAI.[67,95] Several clinical examination measures have been shown to have strong evidence for use in identifying individuals with hip osteoarthritis compared to those with non-arthritic hip pain.[80] Impairment and mobility deficits that will help distinguish arthritic hip pain from non-arthritic hip pain include: individuals over the age of 50 with moderate anterior or lateral hip pain during weight-bearing activities;[87] morning stiffness that lasts less than 1 hour in duration after waking up;[87] hip internal rotation range of motion less than 24° or internal rotation and hip flexion 15° less than the nonpainful side;[96,97] and/or increased hip pain associated with passive hip internal rotation.[87]

2.3.2.2.2 Special Testing

While limitations in hip ROM are common in individuals with non-arthritic hip pain, increased pelvic and lumbosacral motions can compensate for these limitations during strength testing and in turn cause further pathomechanical issues.[19] Orthopaedic special tests are often utilized to isolate specific structures during the evaluation process in order to assess for specific pathologies.[98] Several special testing techniques should be used when evaluating individuals for non-arthritic hip pain in order to provide critical, objective feedback on the diagnostic condition.[98] These special tests should be utilized in

all patient positions and incorporate techniques to confirm as well as rule out conditions related to non-arthritic hip pain.[67,98]

Special testing should begin during the standing examination with the Trendelenburg sign. This test is evaluated to rule out osteoarthritic and gluteal tendinopathies, by assessing contralateral hip and pelvis alignment of individuals in a single leg stance bilaterally for 30 seconds.[91] Functional performance testing is a measure utilized to assess movement in weight bearing.[13,91,99] The specific use of functional performance testing in the evaluation of non-arthritic hip pain will be discussed in section 2.3.2.2.2.3.2.

Special testing in the supine position includes a log roll test to evaluate the bilateral comparison of hip external rotation. Increased external rotation on one side can indicate an incompetent iliofemoral ligament or structural instability.[67] The flexion, abduction, external rotation test (FABER) is commonly used to differentiate for pain between hip (posterior FAI, ligament integrity, trochanteric pain) and sacroiliac pathologies.[67,89] The flexion, internal rotation, and adduction (FADDIR) test evaluates for anterior rim FAI, with a significant decrease in internal rotation demonstrating increased severity of cam impingement.[67,91] The dynamic internal rotatory impingement (DIRI) and dynamic external rotatory impingement (DEXRI) tests are used to assess for anterior femoroacetabular impingement and superolateral and posterior impingement, respectively.[89] The resisted straight leg raise (RSLR) is performed against resistance at 45° of hip flexion and a positive is indicative of hip flexor or capsular irritation.[67] The dial test can be performed to evaluate capsular laxity in the hip[67] while the posterior

impingement test assesses the congruence of the posterior wall and femoral neck as well as anterior instability with a positive apprehension sign.[89]

Special testing in the lateral position should begin with a modified Ober's test for passive adduction can be performed to evaluate for gluteus and tensor fascia latae contractures.[67] The FADDIR test can be dynamically utilized in this position to evaluate for FAI.[89] The lateral rim impingement is utilized to passively abduct and externally rotate the hip for evaluation of anterior instability or posterior impingement.[89] An apprehension test is also utilized in the lateral position to force the hip into an antero-inferior position to test for capsular instability and ligamentum teres pathology.[89]

The diagnostic accuracy for special tests utilized in the evaluation of non-arthritic hip pain has not been thoroughly established in the current literature.[67,100] Several tests are commonly performed, however only a few have shown evidence for reliability and validity in the evaluation of individuals with FAI and/or chondrolabral pathologies.[67] Specifically, the FADDIR test (anterior impingement test) demonstrated moderate to high sensitivity (0.59-1.0)[95,100-106], but a broad range for specificity (0.10-1.0)[100,101,106] in diagnosing intra-articular hip pathologies. The FABER test also demonstrated moderate to high sensitivity (0.41-0.97)[100,101,103,105-107] and a broad range for specificity (0.18-1.0)[101,106,107] in identifying FAI and chondrolabral pathologies. The RSLR demonstrated a broad range for both sensitivity (0.06-0.75)[103,106,107] and specificity (0.38-1.0)[106,107] in the evaluation of non-arthritic hip pain. The DIRI test (referred to here as the internal rotation over pressure test) was also shown to be sensitive (0.88-0.91) in the diagnosis of individuals with FAI.[107,108] While these tests have been shown to successfully assess for non-arthritic hip pain, a recent systematic review found that not all individuals with intra-

articular hip conditions report any symptoms.[63] Structural deformities and chondrolabral pathologies may not be the only influences on pain in individuals with non-arthritic, intra-articular hip conditions.[32] Neuromuscular deficiencies in the surrounding hip musculature could lead to joint instability and excessive motion causing chondrolabral pathologies sustained over time.[23,32,64]

Several functional performance tests have evidence for reliability and validity in distinguishing individuals with osteoarthritis from those with non-arthritic hip pain.[80] These functional performance measures include: the 30-second chair stand (ICC = 0.88, a standardized error of measurement (SEM) = 1.5);[109] timed single-leg stance for inter-rater (ICC = 0.89, SEM = 3.46) and intra-rater (ICC = 0.82, SEM = 4.62) reliability;[110] 4-square step test for inter-rater (ICC = 0.86, SEM = 0.77) and intra-rater (ICC = 0.83, SEM = 0.86) reliability;[110] and the step test for inter-tester (ICC = 0.94, SEM = 1.06) and intra-rater (ICC = 0.91, SEM = 1.37) reliability for standing on the side of the painful hip.[110]

2.3.2.2.3 Functional Measures

Adaptations to pathomechanical deficiencies can lead to functional limitations during daily and sports-related activities, diminished strength in the musculature of the hip, and impaired kinematic and kinetic movements during weight-bearing activities.[31,32] Individuals have shown altered balance and proprioceptive control during dynamic movements associated with functional control.[16,33,34] The effects of these changes to function should be assessed in the comprehensive clinical evaluation for individuals with non-arthritic hip pain. Assessments should examine all aspects of the individual's

capabilities to provide a thorough determination of present function as well as assess and treat all individuals within their own setting of function regardless of injury.[2,111] In order to do so, clinicians should integrate an evaluation process that incorporates several measures of function to accurately assess for neuromuscular limitations and dysfunction.[38,99] Two clinical measures of function that are commonly recommended for use in evaluation of non-arthritic hip pain are PRO's and functional performance testing. The combined use of PRO's and functional performance testing in the assessment of function is recommended to properly evaluate each individual's perceived levels of dysfunction as well as their actual functional performance limitations.[99,112]

2.3.2.2.3.1 Patient-Reported Outcomes

Patient-reported outcomes are clinical measures utilized by healthcare providers to collect an individual's perception of symptoms, their self-reported functional limitations, health-related quality of life, and satisfaction levels relating to quality of care.[113] Patient-reported outcomes used in the assessment of function must be based on high quality research that establishes appropriate measurement properties.[113,114] The use of PRO's in the evaluation of non-arthritic hip pain should incorporate both hip specific outcome measures as well as generic outcome measures that assess pain and quality of life.[115] Patient-reported outcomes should be included in the initial assessment as well as all follow-up evaluations to monitor any change in functional deficiencies and/or limitations.[13] The PROs used in this study will include the following: 1) VAS 2) HOS-ADL, 3) HOS-SRA, 4) % - ADL, 5) % - SRA, 6) categorical rating of function, and 7) patient satisfaction.

2.3.2.2.3.1.1 Visual Analog Scale

Most PRO's utilized in the assessment of non-arthritic hip pain do not assess for pain.[116] The most commonly used PRO for evaluation of pain is the VAS which can also be referenced as the numeric pain rating scale. This is an 11-point scale that is evaluated from 0 to 10, with 0 being no pain and 10 being the worst imaginable pain.[116,117] The VAS has been shown to be a reliable and valid psychometric response scale for pain in patients with spine fractures and dislocations[118] and is increasingly being used to assess for outcomes after hip arthroscopy. High test-retest reliability was shown with a strong correlation coefficient of 0.976 ($p<0.001$), and validity was demonstrated with a high internal consistency (Cronbach-α of 0.9117) between healthy controls and individuals with thoracolumbar spine injuries.[118] Responsiveness of testing for the VAS score was shown with minimal clinically important differences (MCID) values of 1.4 and 2.4 for individuals treated for rotator cuff disease of the shoulder after 6 weeks of non-operative care and in individuals with chronic low back pain, respectively.[119,120]

2.3.2.2.3.1.2 Hip Outcome Score

The HOS is a commonly used self-reported outcome measurement that accounts for limitations in activities of daily living (HOS-ADL) and sports-related activities (HOS-SRA). The HOS-ADL subscale contains 17 items that addresses function as it relates to routine activities that individuals participate on a normal, everyday basis, while the HOS-SRA contains 9 questions that are specific to their chosen athletic activities.[121-124] Each question is scored on a scale from 0 to 4, with 0 being "unable to do", 1 being "extreme difficulty," 2 being "moderate difficulty," 3 being "slight difficulty," and 4 being "no

difficulty at all."[121,124] There is also a "non-applicable" option that is available for each question but not included when quantifying the scores.[121-124] An individual's score for both the HOS-ADL and HOS-SRA is divided by the highest possible score then multiplied by 100 to get a percentage.[7,122,124] An individual's highest possible score is the total number of questions with a response, excluding blanks or "non-applicable" submissions, multiplied by 4. [7,122] The higher the score, the higher an individual's level of function is assessed for each subscale.[7,121-124]

The HOS has been shown to have high reliability and responsiveness of testing as well as a high correlation to measures of physical function in individuals with acetabular labral tears who are undergoing operative or non-operative management.[121-123] The HOS was also shown to demonstrate test-retest reliability, internal consistency, construct validity, responsiveness, lack of floor/ceiling effect, and an appropriate measure individuals with FAI and labral pathologies.[125] Test-retest reliability for the HOS-ADL and HOS-SRA were defined by ICC values of 0.98 and 0.92, respectively.[122] Validity was shown through internal consistency for the HOS-ADL (α-value = .96, SEM of 2.8 and a 90% CI of ± 4.6 points) and HOS-SRA (α-value = .95, an SEM of 2.3 and a 90% CI of ± 3.8).[121] Convergent and divergent validity was demonstrated through correlation coefficients between both the HOS-ADL and HOS-SRA and the Short Form-36 physical function subscale, physical component summary score, mental health subscale, and mental component summary score.[121] These correlations were 0.76, 0.74, 0.27, and 0.18 for the HOS-ADL and 0.72, 0.68, 0.23, and 0.1 for the HOS-SRA, respectively.[121] Responsiveness was shown with large effect sizes[126] for the HOS-ADL and HOS-SRA as 1.2 and 1.5, respectively.[122] The area under the receiver operating curves (ROC) for the

HOS-ADL and HOS-SRA were shown as 0.88 (95% confidence interval [CI], 0.80 to 0.95) and 0.90 (95% CI, 0.83 to 0.97), respectively.[122] From the area under the ROC curves the HOS-ADL was determined to have an MCID value of 9 points and was shown to have a sensitivity of 0.82 and specificity of 0.89, while HOS-SRA demonstrated an MCID value of 6 points with a sensitivity of 0.85 and specificity of 0.87.[122]

2.3.2.2.3.1.3 Generic Ratings of Function

Along with the HOS-ADL and HOS-SRA subscales, individuals completing the HOS are asked to generically rate their current level of function. This includes asking an individual to globally rate their percentage for performance of activities of daily living (% - ADL) on a scale from 0-100, with 100 being their level of function prior to their hip problem and 0 being the inability to perform any of their usual daily activities.[122,124] Individuals can also globally rate their percentage for performance of sports-related activities (% - SRA) on a scale from 0-100, with 100 being their level of function prior to their hip problem and 0 being the inability to perform any of their usual sports-related activities.[122,124] Generic rating of function can also include a categorical rating of function as "normal," "nearly normal," "abnormal," or "severely abnormal."[122,123] Although the quantification for global percentage of function and the categorical rating of function are commonly performed in the clinical setting, information regarding their psychometric properties are not currently available.

2.3.2.2.3.1.4 Patient Satisfaction

Another commonly used PRO measure is the assessment of patient satisfaction with treatment outcome. It is commonly measured separately as a response of "yes" or "no" or on a 11-point scale of 0 - 10, with 0 being not satisfied and 10 being completely satisfied.[116] Patient satisfaction should be included in all clinical evaluations, particularly with the recent emphasis on reporting patient's perspectives on improvements in their overall quality of life.[115,127] Pearson correlation coefficients have been shown as significant between patient satisfaction and VAS outcomes with changes in the HOS-ADL (patient satisfaction = 0.45 and VAS = 0.49) and HOS-SRA (patient satisfaction = 0.42 and VAS = 0.46) commonly used in the evaluation of hip arthroscopic surgery.[116] This significant, moderate correlation suggests that the inclusion of patient satisfaction along with the administration of the HOS-ADL and HOS-SRA could add to the overall assessment of non-arthritic hip pain.

2.3.2.2.3.2 Functional Performance Testing

Functional performance testing is a collection of tests that are utilized to determine the performance abilities and/or functional limitations of the individual being tested.[37] Reiman and Manske[37] defined functional performance testing as the ability to determine 1) an individual's ability to participate at their desired level without limitations and 2) that individual's ability to do so in all three planes of movement (frontal, sagittal, and transverse) as determined by non-traditional tests.[37,99] These functional performance tests are used to evaluate basic dynamic movement patterns that are commonly part of a more complex activity and combine range of motion, flexibility, balance, proprioception,

motor control, and muscle strength, power, and endurance.[2,37,38] The use of these tests are beneficial in sports medicine to screen for injury prevention, evaluate athletic injuries, and help in return-to-play decisions.[1-3] The use of functional performance testing in the clinical setting can provide healthcare professionals with quantitative and qualitative feedback for individualized movement control.[37,38,99]

Functional performance testing should be utilized with the goal of recognizing any fundamental musculoskeletal limitations present that might predispose an individual to injury.[1] An individual's physical performance during multi-dimensional dynamic movements can be defined as their functional movement control. Screening functional movement control throughout the kinetic chain while emphasizing lower-extremity force characteristics, specifically eccentric loading should be targeted.[37,38,99] Functional performance testing should be utilized to evaluate the functional movement control of individuals with non-arthritic hip pain, despite a lack of quality assessment evidence.[2,7,13] The SLST and SDT are two well-known tests that have been used in the evaluation of individuals with lower extremity dysfunction, most commonly among patients with knee pathologies.[128-137] However, these tests also account for several deviations in hip, pelvis, and trunk performance that are considered important when assessing individuals with hip pain. [16,17] A literature review that identifies and provides psychometric evidence to support the use of and the best methods for administration of SLST and SDT in evaluation of patients with non-arthritic hip pain is presented in Chapter 4.

2.3.2.2.4 Quality of Assessment

Healthcare providers should incorporate evidence-based practice, using assessment strategies and measures that have established psychometric properties whenever possible. The most appropriate assessment strategies and measures will therefore have evidence for validity, reliability, and responsiveness to support their use.

Reliability demonstrates the repeatability of measurement between single or multiple raters. There are several ways to establish reliability including internal consistency, test-retest or intra-rater, and inter-rater reliability.[113,138] Validity demonstrates the accuracy with which the phenomenon under observation is measured by a standard reference procedure or most commonly the recognized gold standard.[113,138] Validity establishes whether a measurement tool actually assesses what it proposes to measure. There are several ways to establish validity including content, construct, and criterion validity.[113] Responsiveness of testing is the ability of the measurement tool to detect clinically relevant changes in status of the underlying construct over time. [113,138] This is commonly described as a longitudinal measure of validity that assesses correlations between changes in measures or expected differences in groups.[113,138] Responsiveness testing is commonly reported as MCID values, which are the smallest change in a measurement score of interest that patients perceive to be beneficial.[120,139] MCID's are evaluated by either distribution-based methods that measure change alone or anchor-based methods that measure clinically meaningful change.[120] Distribution-based methods utilize the SEM to demonstrate the statistical significance of the change scores in the measure.[120] The anchor-method demonstrates the smallest difference in a

measurement instrument that relates to a corresponding change in a reference or gold-standard measure.[120]

All aspects of the evaluation process for individuals with non-arthritic hip pain should be established in standardization and responsiveness. While measures of assessment establish the foundation for the evaluative and diagnostic process,[113] there is limited research evaluating the quality of functional performance testing in the evaluation of individuals with non-arthritic pain. Specifically, there are no current studies establishing the use of the SLST and SDT in assessment of deficiencies in the hip and surrounding musculoskeletal structures. Evidence for reliability and validity of the SLST and SDT in evaluating individuals with non-arthritic hip pain is presented in Chapter 5.

2.4 Summary

Structural pathologies commonly associated with non-arthritic hip pain are FAI, dysplasia, and structural instability in the absence of moderate to severe degenerative joint disease. The most common cause of non-arthritic hip pain is chondrolabral pathologies, specifically labral tears and chondral lesions. A comprehensive clinical examination consisting of a thorough history, physical exam, and diagnostic imaging protocol has been shown to accurately differentiate between osteoarthritic and non-arthritic hip pain. During the physical exam, the combined use of PRO's and functional performance testing is necessary to properly evaluate for perceived levels of dysfunction as well as functional movement limitations. By identifying deficiencies in neuromuscular control during functional performance testing, an individualized rehabilitation intervention could be utilized to improve muscular strength around the hip, decrease joint

instability, and improve proprioceptive control. Through improvements in neuromuscular control of the surrounding hip structures, it may be possible to decrease intra-articular stresses and avoid the need for surgical correction.

Chapter 3

Non-Operative Management of Individuals with Non-Arthritic Hip Pain: A Literature Review

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3.1 Abstract

Background: Non-arthritic hip pain is defined as being related to pathologies of the intra-articular structures of the hip that can be symptomatic. A trial of non-operative management is commonly recommended before consideration of surgery for individuals with non-arthritic hip conditions. There is a need to describe a non-operative or conservative treatment plan for individuals with non-arthritic hip pain.

Purpose: The purpose of this literature review was to systematically examine the literature in order to identify and provide evidence for non-operative or conservative management of individuals with non-arthritic hip pain. A proposed home exercise program will be provided for individuals with non-arthritic hip pain.

Study Design: Review of the Literature.

Materials/Methods: A literature search of PubMed, Medline, SPORTSDiscus, and CINAHL was conducted. Keywords included: "hip" AND "femoroacetabular impingement" OR "labral tear." Studies were included if they described non-operative

management for individuals with non-arthritic hip pain. Studies were excluded if they recommended a trial of conservative treatment without specific management or interventions and/or activity modification without specific details for intervention.

Results: A total of 49 studies met the eligibility criteria and were included in the review. Rehabilitation recommendations were identified from manuscripts including clinical trials, case series, discussion articles, or systematic reviews related to the non-operative or conservative management of non-arthritic hip pain. Rehabilitation interventions focused on patient education, activity modification, limitation of aggravating factors, an individualized physical therapy protocol, and use of a home exercise program.

Conclusions: Rehabilitation should address biomechanical deficiencies with neuromuscular training of the hip and lumbopelvic regions. While the current literature on non-operative management is limited, future randomized control trials will establish the effectiveness of specific physical therapy protocols for individuals with non-arthritic hip pain.

Level of Evidence: 2b

Key Words: FAI, acetabular labral tears, dysplasia, structural instability, movement system

3.2 Introduction

Non-arthritic hip pain is described as pathologies to the intra-articular structures of the hip that can cause pain including femoroacetabular impingement (FAI), dysplasia, structural instability, acetabular labral tears, chondral lesions, and ligamentum teres tears.[7-9] These conditions primarily occur from microtrauma associated with dynamic

movement between the proximal femur and the acetabulum.[7,140] When left unaddressed, FAI, dysplasia, and structural instability can lead to the progression of acetabular labral tears, chondropathy, and potentially osteoarthritic change.[22,41,141-145]

Arthroscopic surgical procedures to address structural abnormalities, decrease pain, and improve function have significantly increased over the past decade.[11,12,18,20,43] However, a recent systematic review found that there is a high prevalence of structural deformities in asymptomatic individuals.[63] Additionally, musculoskeletal impairments such as strength deficits associated with non-arthritic pathology are not necessarily addressed with surgery.[32] Deficiencies in the surrounding hip region musculature may lead to joint instability and excessive motion contributing to structural damage, pain, and decreased function.[23,32,64] It may be possible to decrease intra-articular stresses in the presence of structural abnormalities, through management of muscular deficiencies and avoid the need for surgical correction. An evaluation algorithm and treatment classification has been outlined to identify those with non-arthritic hip conditions that might benefit for a prioritized non-operative treatment program.[67,89]

A trial of non-operative management is commonly recommended before consideration of surgery, however specific interventions remain a point of controversy. Considering that not all individuals will benefit from surgical intervention and the possibility for management of extra-articular deficiencies to relieve symptoms, a non-operative or conservative treatment plan needs to be described for non-arthritic hip pain. The purpose of this literature review was to systematically examine the literature in order to identify and provide evidence for non-operative or conservative management of individuals with non-arthritic hip pain. A proposed home exercise program will be

provided for individuals with non-arthritic hip pain. The information attained will assist clinicians in making treatment decisions based on the current standard of care for management of non-arthritic hip conditions.

3.3 Methods

A search of the PubMed, Medline, SPORTSDiscus, and CINAHL databases was conducted to include articles from 1997 until July 2017. Manuscripts were identified that presented clinical trials, case series, discussion articles, or systematic reviews for non-operative or conservative management of non-arthritic hip pain. The search excluded single series case reports, abstract-only publications, and editorial commentary. The following key words were used in combination for searching the electronic databases: "hip" AND "femoroacetabular impingement" OR "labral tear."

The literature search included research articles if they met the following criteria: 1) written in English, 2) published in a peer-reviewed journal from 1997 until August 2017, and 3) described non-operative or conservative management for individuals with non-arthritic hip pain. Studies were excluded if they recommended a trial of conservative treatment without specific management or physical therapy interventions and/or activity modification to avoid extreme ranges of motion without specific details for intervention. The primary author reviewed the abstracts of all references retrieved from the search and duplicates were removed. From this search, full length publications were retrieved, and the reference lists of these articles were reviewed for any additional relevant manuscripts.

3.4 Results

The initial search identified a total of 2,147 research articles. After applying the inclusion/exclusion criteria and independent search of reference lists, a total of 49 studies met the eligibility criteria. Overall, there were 35 articles addressing FAI, four articles addressing acetabular labral tears, one article addressing dysplasia or structural instability, and nine articles addressing a combination of FAI, acetabular labral tears, dysplasia, structural instability, chondral lesions, and/or ligamentum teres tears as shown in Figure 3.1.

Thirty-two of the articles were review and/or discussion studies, seven were experimental studies, and ten addressed feasibility (pilot studies) and protocol studies for future randomized controlled trials. These articles were categorized for level of evidence based on the 2009 guidelines from the Oxford Center of Evidence-Based Medicine.[146] Further evaluation of each article was performed for quality of evidence based on the established Grading of Recommendations Assessment, Development and Evaluation (GRADE) system with classification of studies as: “high quality”, “moderate quality”, “low quality”, or “very low quality.”[147] The discussion and review articles were principally constructed on expert opinion Level 5 evidence, with the systematic reviews utilizing Level 2a and 3a evidence in order to analyze the experimental studies performed on individuals with non-arthritic hip pain.[146] The expert opinions established in these discussion and review articles were classified as “very low quality” due to the uncontrolled nature of clinical observations.[147]

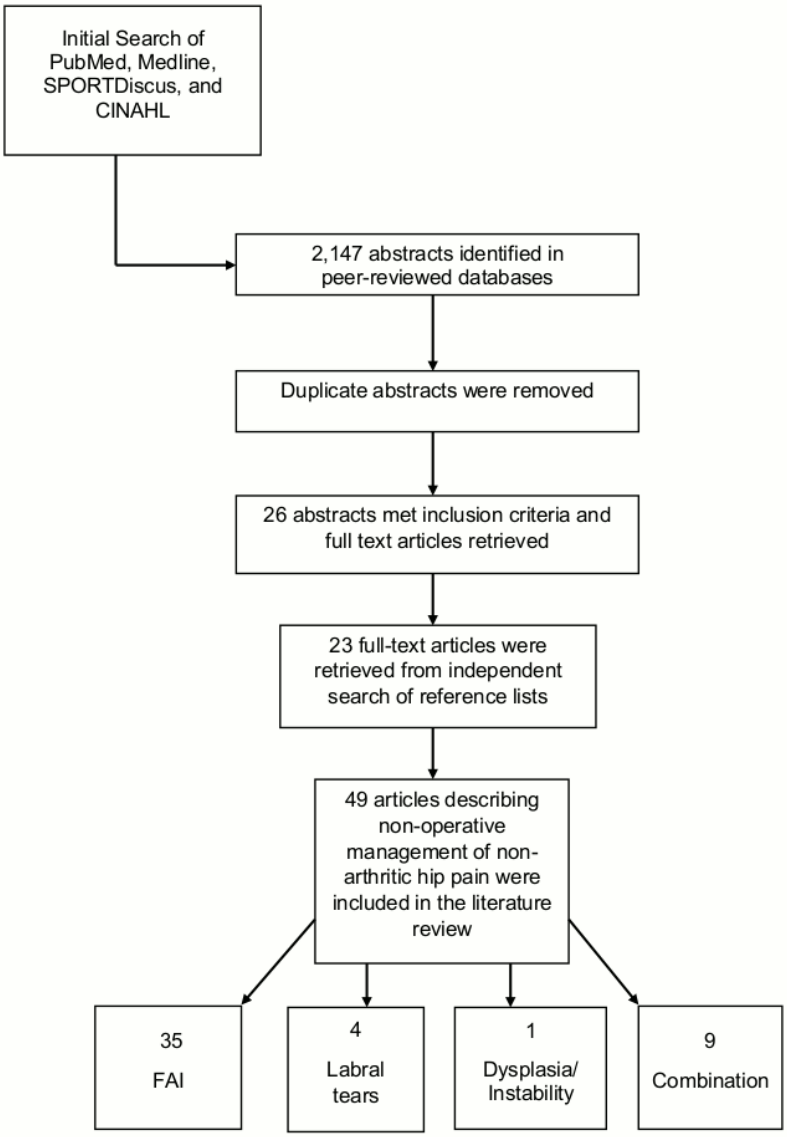

Figure 3.1: Search results of the PubMed, Medline, SPORTSDiscus, and CINAHL databases

Of the 32 review and discussion articles: 24 addressed FAI, three addressed acetabular labral tears, one addressed dysplasia or structural instability, and four addressed a combination of FAI, acetabular labral tears, and dysplasia or structural instability. These articles provided comprehensive non-operative management recommendations, a synthesis of which is provided in Table 3.1. Of the seven experimental studies: three addressed FAI and four addressed a combination of FAI, acetabular labral tears, dysplasia or structural instability, chondral lesions and/or ligamentum teres tears. Of these four were case series (three prospective and one retrospective), one was a prospective clinical outcomes study, one was a retrospective matched analysis study, and one a descriptive epidemiological study. Detailed descriptions of these studies are found in Table 3.2. Of the 10 articles addressing future randomized controlled trials: eight were established for patients with symptomatic FAI and two were established for patients with intra-articular hip pain, including FAI, acetabular labral tears, and structural instability/dysplasia. Details pertaining to the specific study design, methodology, and results for the six protocol studies and four feasibility studies are provided in Table 3.3. No randomized control trials were identified.

Therapeutic Interventions	Number of Articles (out of 32)
Hip musculature strengthening	22
Pelvic stability/posture (pelvic inclination)	16
Core muscle strengthening	14
Neuromuscular training	13
Hip muscular stretching/flexibility	12
Manual therapy interventions	12
Dynamic biomechanical control	10
Gait training	4

Table 3.1: Recommended therapeutic interventions from review and discussion articles.

Rehabilitation interventions throughout the identified studies including patient education, activity modification, limitation of aggravating factors, performance of an individualized physical therapy protocol, and performance of a home exercise program, have been shown to decrease pain and improve function in patients with non-arthritic hip pain. Interventions should focus on addressing neuromuscular deficits with rehabilitation of the hip and lumbopelvic regions. Exercise suggestions gleaned from the included studies were used to generate a proposed home exercise program for individuals with non-arthritic hip pain in Appendix A.[148]

Study	Type of Study (quality of study)*	Number of Patients	Age of Patients mean ± SD, (range)	Diagnosis	Non-Operative Management	Outcome
Emara et al. 2011	Prospective case series (Low)	37	33 ± 5, (23-47)	FAI – cam morphology	4 Stages: 1. Avoidance of excessive physical activity and NSAIDs for 2-4 wk during the acute attack. 2. Physiotherapy for 2-3 weeks. Stretching exercises (20-30 min daily) to improve hip ER and ABD in EXT and FLEX, and to avoid the "W" sitting position. 3. Assessment of the normal range of hip IR and FLEX after acute pain subsided. 4. Modification of activities of daily living predisposing to FAI.	33 patients treated nonoperatively showed improvement: • Mean HHS improved significantly from 72 before treatment to 91 at the 6-month follow-up and 91 at the 24-month follow-up. • The mean non-arthritic hip scores improved from 72 to 90 to 91. • Mean VAS for hip pain improved from 6 to 3 to 2. 4 required surgery following nonoperative management.

Feeley et al. 2008	Descriptive epidemiology study – NFL athletes (Very Low)	678 athletes (738 injuries) 13 FAI and LT (8 non-op, 5 surgically)	Not defined	FAI and LT	Not defined	8 players returned to playing after physical therapy.
Hunt et al. 2012	Prospective observational clinical outcomes study (Low)	52 (6 lost to follow-up from 58)	35 ± 11, (18–50)	Pre-arthritic, intra-articular hip disorders (FAI, LT, dysplasia) 32 subjects with only LT, 8 subjects with mild hip dysplasia, and 18 subjects with mild FAI	Goals of therapy: 1. Improve precision of hip motion 2. Prevent hip hyperextension with active or passive motion 3. Prevent rotation of acetabulum on femur under load 4. Prevent dominance of quadriceps and/or hamstrings 5. Improve performance of abdominal muscles and hip flexors, abductors, and short external rotators 6. Muscle retraining during active motions and	After 3 months of conservative care, subjects with continued limitations, reduction of symptoms with a diagnostic intra-articular hip injection, and a surgically amenable lesion found on a magnetic resonance arthrogram proceeded to surgery. 23 subjects reported satisfaction with conservative care. 29 subjects chose to have surgery. Both groups demonstrated equally significant improvement in all outcome measures from baseline to 1-year follow-up.

					sustained postures 7. Education on day-to-day activity modification. Perform home exercise program which was not defined.	
Jager et al. 2004	Prospective case series (Very Low)	17 (9 treated non-operatively, 6 FAI surgery, 2 arthroplasty)	33.6 ±14.4 (14-60)	FAI – cam morphology	Not defined	9 non-operative patients complained of pain and hip dysfunction. 8 surgical patients were pain free.
Reynolds et al. 1999	Retrospective case series (Very Low)	22 (11 non-operatively, 11 surgically)	28 ± 10, (15-50)	FAI – pincer morphology	Not defined	Not defined. Proper diagnosis could allow patients to modify activities and posture to decrease symptoms and possibly alleviate problems related to FAI.
Spencer-Gardner et al. 2017	Retrospective matched paired analysis (Low)	72 (36 waitlisted, non-operative & 36 operative)	Non-operative: 40 (18-58) Operative: 40 (18-58)	Intra-articular pathologies (FAI, LT-cam morphology, chondral lesion, ligamentum teres tear)	All patients in both groups had undertaken at least 3-month's conservative treatment, including community physiotherapy, before being considered for surgery, and had failed to improve with that treatment.	HA may lead to significant improvements when compared to non-operative management of waitlisted patients with intra-articular pathology of the hip at 18-month follow-up.

					There was no additional management provided to the non-operative group following initial 3-month conservative care.	
Yazbek et al. 2011	Prospective case series (Low)	4	24.8 ± 1.5 (24 -27)	1 FAI – pincer morphology; 1 LT; 1 LT, chondral lesion; 1 LT, partial ligamentum teres tear	3 phases: 1. Emphasized pain control, education in trunk stabilization, and correction of abnormal joint movement. 2. Focused on muscular strengthening, recovery of normal range of motion (ROM), and initiation of sensory motor training. 3. Emphasized advanced sensory motor training, with sport-specific functional progression.	All patients demonstrated decreased pain, functional improvement, and correction of muscular imbalance. Increased muscle strength for the hip flexors (1%-39%), abductors (18%-56%), and extensors (68%-139%) was shown.

M – male; F – female; FAI – femoroacetabular impingement; ER – external rotation; ABD – abduction; EXT – Extension; FLEX – flexion; IR – internal rotation; HHS – harris hip score; VAS – visual analog scale; LT – acetabular labral tear; CT - computed tomographic; BMI – body mass index; HA – hip arthroscopy; * - Quality of evidence based on the GRADE classification system.

Table 3.2: Experimental studies for conservative management of individuals with non-arthritic hip pain.

Study	Type of Study	Number of Patients (population)	Diagnosis	Proposed, Randomized Group Comparison	Results	Outcome
Boye et al. 2015	Feasibility (pilot study)	75 (53 and 22 from two separate orthopaedic centers)	FAI	Arthroscopic surgery vs. non-surgical management	28% indicated absolute willingness to participate in the trial. 40% were probably willing or unsure. 32% were not willing. 18.7% had a strong preference for surgery. 2.7% strongly preferred nonsurgical treatment. 78.6% no strong preference for either.	Sufficient patient accrual for a randomized trial of FAI treatment is currently feasible while equipoise still exists among patients and surgeons.
Coppack et al. 2016	Protocol	100 (male military participants)	Intra-articular non-arthritic hip pain	7-day residential (in-patient) intervention vs. 8 PT led, out-patient treatments (over 6 weeks) combined with home exercise program	**Hypothesis:** A 7-day multidisciplinary residential intervention will result in greater improvement in treatment outcomes compared to individualized outpatient treatment in young adults.	Presents the protocol for a RCT that will compare the effects of a residential intervention with conventional outpatient care on pain and physical function in young patients with non-arthritic hip pain.

Griffin et al. 2016 (1)	Feasibility (pilot study)	42 out of 60 eligible (from 9 hospital centers) Identified 120 surgeons, 1908 patients with FAI treated in 2011-2012 throughout UK NHS	FAI	Arthroscopic surgery vs. conservative care	-84 diagnostic and recruitment consultations in 60 patients were used to develop a model for an optimal recruitment consultation. -The International Hip Outcome Tool (iHOT) at 12 months was identified as an appropriate outcome measure. -Estimated the sample size 344 participants (from 25 centers/18 months).	-It is feasible to obtain ethics approval for this research question and to obtain support from a variety of hospitals. -Clinicians were prepared to take part, with surgeons agreeing to follow a defined operative protocol, and physiotherapists attending a training workshop and agreeing to deliver physical therapy protocol.
Griffin et al. 2016 (2)	Protocol	344 (over a 26-month recruitment period in 24 hospital centers)	FAI	Arthroscopic surgery vs. conservative care (clinical and cost effectiveness)	**Hypothesis:** Arthroscopic surgery is superior to conservative care at 12 months for self-reported hip pain and function for patients with FAI syndrome.	**Primary Outcome**: Pain and function assessed by iHOT-33 measured at 1-year. **Secondary outcomes**: General health (SF-12), quality of life

						(EQ5D-5L) & pt. satisfaction.
Harris-Hayes et al. 2016	Feasibility (pilot study)	35 (18 treatment, 17 control from Washington University)	Chronic hip joint pain (intra-articular non-arthritic hip pain)	-Movement pattern training (MPT) vs. wait-list control (no treatment) -MPT: Six, 1-hour supervised sessions for task specific training for functional tasks and symptom provoking tasks. Strengthening of hip. Daily home program.	-Retention rates did not significantly differ between MPT (89%) and control groups (94%). -16/18 patients (89%) in the MPT group attended at least 80% of the treatment sessions and reported performing their home program at least once per day.	**Primary Outcomes:** Retention and adherence rates show that a larger RCT is warranted to assess treatment effects. **Secondary Outcomes:** PRO's, kinematics, and muscle strength will be utilized in the proposed RCT.
Mansell et al. 2016	Protocol	80 (from Madigan Army Medical Center over 2 years) All 80 surgical candidates who have failed 6 weeks ofnon-op care.	FAI (with and without LT tears)	-Arthroscopic surgical decompression vs. non-surgical rehabilitation -Rehabilitation will follow impairment based physical therapy program consisting of 2x per week for 6 weeks.	**Primary Purpose:** Determine if there is a difference in self-reported functional outcomes between arthroscopic surgery and a supervised physical therapy program 2 years out from intervention. **Secondary Purpose:** Evaluate the differences in hip-related healthcare utilization and associated costs.	**Primary Outcome:** HOS. **Secondary Outcomes:** IHOT-33, GROC, and NPRS. Self-Motivation Inventory and Pain Catastrophizing Scale will be taken at baseline and 24 months. Collect healthcare

						utilization and associated costs that occurred for the duration of the study, and compare.
Palmer et al. 2014	Protocol	120 (over 24 months from NHS clinics in at least 3 hospitals)	FAI	Surgical management vs. non-surgical management Rehabilitation will follow a goal-based program with up to 8 sessions over 5 months.	**Primary Objective:** Determine whether arthroscopic surgery or PT and activity modification is more effective in improving symptoms and preventing the development and progression of osteoarthritis in patients with symptomatic FAI. **Secondary Objective:** Compare cost effectiveness of physiotherapy and activity modification with arthroscopic surgery.	**Primary Outcomes:** Improvement of symptoms: HOS with ADL and sports subscales. Prevention of osteoarthritis: radiographic with 3-year follow-up. **Secondary Outcome:** Improvement of symptoms: NAHS, iHOT-33, HAGOS, OHS, and HADS.
Smeatham et al. 2017	Feasibility (pilot study)	23 out of 30 eligible (from a single NHS acute hospital in Devon, England)	FAI	-PT vs. routine care -PT is 3-months of specialist physiotherapist led care. -Routine is analgesia and continuation of	-NAHS for the intervention group was 12.7 and 1.8 in the control group. Median change in LEFS was 11.5 vs. −1.0 in control group. -Improvement in LEFS was beyond minimal clinically important difference in the intervention group.	**Main Outcomes:** Conservative treatment can change symptoms of FAI even in the presence of

				self-management advice.	-Pain scores improved in both groups.	structural abnormalities.
Wall et al. 2016 (3)	Final Protocol (Personalized Hip Therapy, PHT)	13 (from 21 randomized out of 42)	FAI	Protocol for the non-operative group in the UK FASHIoN trial.	Rehabilitation led by physiotherapist: (1) Detailed patient assessment (2) Education and advice (3) Help with pain relief (4) Individualized exercise program. PHT is delivered over 12–26 weeks in 6–10 physiotherapist and patient contacts. Home exercise program.	**Main Outcome:** PHT provides a structure for the non-operative care of FAI and offers guidance to clinicians and researchers.
Wright et al. 2016	Feasibility (pilot study)	15 out of 18 eligible (from a single surgeon practice from the Department of Orthopaedic Surgery, Wake Forest Baptist Medical Center)	FAI	-Combination manual therapy and supervised exercise (with advice and home exercise) vs. advice and home exercise. -Both groups over a 6-week period.	-No significant between-group differences were observed in pain and function, 1-week after completion of 6-week period. -Both groups showed statistically significant improvements in pain: the manual therapy group improved a mean of 17.6 mm and 18.0 mm for the advice and home group.	**Main Outcome:** -Evidence that FAI may be amenable to conservative treatment strategies. -Supervised manual therapy and exercise did not result in greater improvement in pain or function compared to advice and home exercise.

FAI – femoroacetabular impingement; UK – United Kingdom; NHS – National Health Service; iHOT – International Hip Outcome Tool; iHOT-33 - International Hip Outcome Tool 33; RCT – randomized control trial; PRO's – patient reported outcomes; LT – acetabular labral tears; HOS – Hip Outcome Score; GROC – Global rating of change ;

NPRS – Numeric pain rating scale; ADL – activities of daily living; NAHS – non-arthritic hip score; HAGOS – hip and groin outcome score; OHS – Oxford hip score; HADS – hospital and anxiety depression scale; MRI – magnetic resonance imaging; VAS – visual analog scale; LEFS – lower extremity functional score; PT – physical therapy

(1) Phase 1 of the FASHIoN randomized control trial, (2) Phase 2 of the FASHIoN randomized control trial, (3) Phase 3 of the FASHIoN randomized control trial. UK FASHIoN trial (ISRCTN64081839).

Table 3.3: Studies addressing future randomized controlled trials in individuals with non-arthritic hip pain.

3.5 Discussion

This literature review identified studies related to non-operative or conservative care in the treatment of individuals with non-arthritic hip pain. Discussion and/or review articles, experimental studies, and randomized control feasibility and protocol studies addressing management of individuals with FAI, acetabular labral tears, dysplasia, structural instability, chondral damage, and ligamentum teres tears were evaluated. From these studies, several concepts were identified that should be considered when beginning all non-operative management plans including: patient education,[149-151] symptom control (with the use of non-steroidal anti-inflammatory drugs),[19,152-154] identification of aggravating activities,[19,155] modification of these activities with a focus on limiting extreme ranges of motion,[19,152,153,156,157] and initiation of therapeutic interventions within a physical therapy protocol.[155,158,159] These therapeutic interventions should consist of addressing neuromuscular deficits with training of the hip and lumbopelvic regions.

Physical therapy interventions that were described in the discussion and/or review articles included: hip musculature strengthening (specifically the hip abductors and deep external rotators);[9,25,31,65,149,152-154,156,158,160-171] pelvic positioning and stability related to posture;[25,31,65,102,152,153,155,156,158,164,165,167-170,172] core muscle strengthening;[19,31,102,152,153,155,156,159,161,164,166,167,173,174] neuromuscular training focused on hip and lumbopelvic stability;[9,31,156,157,159,163,166-172] stretching and flexibility for the surrounding hip musculature;[9,153-155,158,160,165-167,170,173,175] inclusion of manual therapy interventions focusing on soft-tissue mobilization of surrounding structures of the hip;[25,154,156,162,163,166,167,169,170,172,175,176] dynamic biomechanical control including proprioception, balance, and coordination training;[9,25,31,159,162,163,166-168,171] and gait

training to address pathological adaptations with use of orthotics if necessary.[25,168,169,171] It is recommended that all physical therapy interventions should be performed on an individualized basis.

The goal of rehabilitation should be to establish dynamic stabilization of the surrounding hip musculature and concurrent core and pelvic control to prevent accessory motion of the hip joint during complex activities.[156,169] Neuromuscular training of the hip and lumbopelvic regions is important for establishing motor control during sports-related activities.[169,170] Of note, the discussion and review articles were principally constructed on expert opinion Level 5 evidence, with the systematic reviews utilizing Level 2a and 3a evidence in order to analyze the experimental studies performed on individuals with non-arthritic hip pain.[146] Recommendations in the current literature review are based on "low" or "very low quality" evidence due to the uncontrolled nature of the clinical observations.[147]

The experimental studies included in this literature review include Level 4 (case series & descriptive epidemiological study), Level 2b (retrospective matched analysis), and Level 2c (clinical outcomes study) evidence, for the use of non-operative management of individuals with FAI, dysplasia, and structural instability. Three case series (two prospective[177,178] and one retrospective[179]) specifically addressed management of individuals with the diagnosis of FAI. While two of these studies[178,179] did not specifically define the non-operative management plan that was utilized, Emara et al.[177] demonstrated a successful plan utilizing four stages of conservative treatment that included: avoidance of physical activity with symptom control during the acute stage, physical therapy with stretching exercises for two to three weeks, assessment of normal

hip ROM, and modification/adaptation of ADL's. Prolonged sitting during this time frame was avoided, but if necessary it was recommended that individuals lean backwards periodically to decrease hip flexion and elicitation of impingement causing posture.[177] Thirty-three of the 37 patients (89%) had positive results from the conservative management plan with both the mean Harris Hip Score and non-arthritic hip scores improving from 72 to 91 (out of 100) over a 24-month period and visual analog scores for hip pain decreasing from 6 to 2 over the same timeframe.[177] The results of this case control study suggests that an intervention focused on activity modification and physical therapy can significantly improve hip function and decrease symptoms in individuals with FAI.

Three experimental studies addressed non-operative management of intra-articular disorders including FAI, acetabular labral tears, dysplasia, chondral lesions and ligamentum teres partial tears.[150,151,180] Two of these studies provided specifics of non-operative management including Yazbek et al.'s[151] case series demonstrating a decrease in pain, improvement in functional movement, and increased lower extremity muscular balance in four individuals. This was achieved by correcting abnormal joint movement by emphasizing muscular strengthening and sensory motor training. When the muscle imbalance was corrected, the participants were progressed to a sports-specific functional training regimen and successfully returned to activity over a 12-week period.[151] The case series performed by Hunt et al.[150] demonstrated a successful management plan in 23 of 52 (44%) individuals with FAI, LT, and dysplasia over a 12-week period. All participants were taken through an individualized physical therapy protocol that emphasized femoral head motion by decreasing the anterior glide within the acetabulum

through muscle training and postural positioning of the pelvis.[150] This study included a home exercise program but did not comment on the specifics beyond modification and avoidance of everyday aggravating activities. As shown in Table 3.2, four of the experimental studies were classified as having "low quality" and three as having "very low quality" of evidence.

Level 1 randomized controlled trials (RCT) are the type of study that will establish "high quality" evidence for the cause and effect analysis of non-operative management for individuals with non-arthritic hip pain. While the current literature review did not identify any completed RCT's to date, several feasibility and protocol studies were available in the literature. The five feasibility studies provided in this review demonstrate that a sufficient accumulation of patients, physical therapists, and surgeons willing to participate in future RCTs comparing: surgical vs. non-surgical management of FAI,[181,182] movement pattern training (MPT) vs. no treatment for intra-articular, non-arthritic hip pain,[183] physical therapy vs. self-management of FAI,[184] and a combination of manual therapy, physical therapy, and home exercise vs. advice and home exercise for FAI.[185] While feasibility studies demonstrate the willingness for participation; protocol studies serve to define the intended treatment and control populations, methodology, and study design. They also establish the intended hypothesis or objectives that the future RCTs would pursue. Four protocol studies were identified in this review, with three describing the comparison of surgical vs. non-surgical management of FAI[186-188] and a seven-day in-patient intervention vs. physical therapist led, outpatient intervention with home exercise program, for individuals with intra-articular, non-arthritic hip pain.[189]

A study conducted by Wall et al.[148] established a suggested rehabilitation protocol based off of a prior feasibility[182] and protocol study.[186] The Personalized Hip Therapy (PHT) protocol provides the specific non-operative management that will be utilized in the FASHIoN RCT.[148] The authors identified four rehabilitation components that were to be utilized in their future RCT including: a detailed patient assessment, education and professional advice, symptom control and pain relief, and an individualized exercise-based program.[148] Optional, individualized management was also included for treatment of coexisting symptoms, use of orthotics for biomechanical abnormalities, use of corticosteroid injections for patients with severe pain, and manual therapy interventions.[148] A home exercise program will be provided for each individual participating in the non-operative group of the RCT.

This literature review has attempted to assimilate the current evidence for use of non-operative or conservative care for individuals with non-arthritic hip pain and suggest an exercise program. The information provided herein may benefit clinicians in making treatment decisions based on the current peer-reviewed literature. The provided home exercise program reflects the author's compilation of exercises utilized within the peer-reviewed literature and could be performed along with an individualized rehabilitation protocol. There are limitations to this proposed home exercise program that need to be considered when applying the information presented. The proposed rehabilitation interventions and compiled home exercise program are based on the authors interpretation of the current peer-reviewed literature. These recommendations may not be the only viable options for non-operative management of individuals with non-arthritic

hip pain. No cause and effect relationships between the proposed exercises and outcomes can be inferred.

3.6 Conclusion

In general, the results of this literature review indicate that rehabilitation intervention focused on patient education, activity modification, limitation of aggravating factors, an individualized physical therapy protocol, and a home exercise program, can decrease pain and improve function in patients with non-arthritic hip pain. Interventions should focus on addressing neuromuscular deficits with training of the hip and lumbopelvic regions. While the current literature on non-operative management is limited, future randomized control trials will establish the effectiveness of specific physical therapy protocols for individuals with non-arthritic hip pain.

Chapter 4

Evidence-Based Procedures for Performing the Single Leg Squat and Step-Down Tests in Evaluation of Non-Arthritic Hip Pain: A Literature Review

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4.1 Abstract

Background: Functional performance tests are commonly utilized in screening for injury prevention, evaluating for athletic injuries, and making return-to-play decisions. Two frequently performed functional performance tests are the single leg squat and step-down tests.

Purpose: The purpose of this study was to systematically review the available psychometric evidence for use of the single leg squat and step-down tests for evaluating non-arthritic hip conditions and construct an evidence-based protocol for test administration.

Study Design: Review of the Literature

Materials/Methods: A search of the PubMed and SPORTSDiscus databases was performed. Psychometric evidence of reliability, validity, and responsiveness to support

the use of the both tests were collected. The protocols used for administering these tests were extracted, summarized, and combined.

Results: Of the 3,406 articles that were reviewed, 56 total articles met the inclusion criteria and were included in the review. Evidence for reliability and validity was available to support the use of the single leg squat and step-down tests. Both tests assess for neuromuscular control of the hip and surrounding muscular structures. Evaluation of these functional movement patterns enable the clinician to assess for limitations that may cause an increase in hip pain and dysfunction.

Conclusions: The single leg squat and step-down tests can assess for kinematic and biomechanical deficiencies and may be useful in the evaluation process for individuals with non-arthritic hip pain. The authors of this study present a comprehensive evidence-based protocol for standardized performance of these tests.

Level of Evidence: 3b

Keywords: Functional performance testing, non-arthritic hip pain, standardized protocol

4.2 Introduction

Functional performance tests are used to evaluate basic dynamic movement patterns that are commonly part of more complex activity. Such tests typically combine range of motion, strength, and proprioceptive assessment. They allow for the simultaneous evaluation of movement in all three (frontal, sagittal, and transverse) planes of motion. These functional performance tests can be useful in sports medicine to screen for injury prevention, evaluate athletic injuries, and help in return-to-play decisions.[1-3] The single leg squat test (SLST) (Figure 4.1) and step-down test (SDT) (Figure 4.2) are

two well-known tests described in the published literature and used in clinical practice.[14,15] The SLST and SDT have been used in the evaluation of individuals with lower extremity dysfunction, most commonly among patients with knee pathology.[128-137] However, these tests also assess for several deviations in hip, pelvis, and trunk performance that are considered important when assessing individuals with hip pain. [16,17]

Figure 4.1: The single leg squat test. A – initial test position. B – squat position

Figure 4.2: The step-down test. A – initial test position. B – step-down position

The overall movement pattern during descent for both the SLST and SDT include hip and knee flexion with anterior pelvic tilt, flexion at the trunk, and hip adduction with knee internal rotation and abduction.[17,190,191] While these two tests are similar, they have been shown to produce different patterns of movement and stresses at the hip.[192,193] Therefore, both the SLST and SDT could potentially be used to assess for kinematic and biomechanical deficiencies and be useful in the evaluation process of individuals with hip-related dysfunction. Static measures of range of motion performed standing or supine may not accurately depict the biomechanical demands of dynamic movements. It is currently unclear how the implementation of the SLST and SDT in clinical evaluation of non-arthritic hip patients is best accomplished, but there is promise regarding the potential of routine addition of these tests for advancing the understanding of non-

arthritic hip dysfunction. Additional examination of strength, flexibility, and endurance could be necessary to specifically identify the underlying pathologies, however, the inclusion of the SLST and SDT in clinical practice may be particularly helpful in the examination of patients with non-arthritic sources of hip pain. There is a need for an evidence based standardized protocol for administering the SLST and SDT in individuals with non-arthritic hip pain.

The purpose of this study was to systematically review the literature to identify the psychometric evidence to support the use of and the best methods for administration of SLST and SDT in evaluation of patients with non-arthritic hip pain. The results of this study will allow for the development of a standardized protocol for administering the SLST and SDT in clinical practice and future research studies involving non-arthritic hip conditions.

4.3 Methods

4.3.1 Search Strategy for Identification of Studies

A search of the PubMed and SPORTSDiscus databases was performed to include articles from January 1997 to March 2017. Articles were identified that offered psychometric evidence for reliability, validity, and responsiveness regarding the administration of the SLST and SDT for examination of trunk and lower extremity function. The following key words were used in combination for searching the electronic databases: “single leg squat” AND “step down.” The primary author reviewed the abstracts of all references retrieved from the search and duplicates were removed. From

this search, full length articles were retrieved and reference lists for these articles were also reviewed for additional relevant articles.

Research articles were included if they met the following criteria: 1) written in English, 2) published in a peer-reviewed journal after 1997, and 3) described the use of the SLST and/or SDT test in evaluation of strength, balance, postural control, or range of motion in the trunk, pelvis, hip, or knee. Studies were excluded if they assessed only the ankle or foot during performance of the tests, or the performance of testing was completed on patients with degenerative disorders (i.e. osteoarthritis).

4.3.2 Data Extraction – Reliability & Validity

Statistical analysis of reliability including test-retest, intra-rater, and inter-rater, and was recorded from each evaluated research article.[2,194,195] Reliability was recorded as an interclass correlation coefficient (ICC) for interval or continuous data and the Cohen's Kappa statistic for categorical or nominal data.[196-198] Both the ICC and Kappa coefficient are valued on a scale of 0.0 to 1.0, with values closer to 1 showing higher reliability.[199] A value for either the ICC or Kappa that is equal to or greater than 0.75 is considered excellent, between 0.40 and 0.74 is considered moderate, and less than 0.40 is considered poor.[196]

Validity for the SLST and SDT was assessed by comparing the performance of individuals with a documented lower extremity condition to healthy individuals and/or comparing performance on another test that shares similar characteristics with the SLST and SDT.[200] This relationship is commonly expressed through correlation coefficients,

comparing the performance of each clinical test with other values, such as muscle strength and lower extremity range of motion.

4.4 Results

A total of 3,406 research articles were identified in the initial search. After applying the inclusion/exclusion criteria and subsequent evaluation of reference lists, a total of 56 studies were included in the review. Search results included 37 articles describing the SLST, 14 describing the SDT, and 5 articles describing a combination of the SLST and SDT as shown in Figure 4.3. A total of 27 articles addressed validity, 15 articles addressed reliability, and 14 addressed both reliability and validity. There were no articles that addressed the responsiveness of testing for either the SLST or SDT.

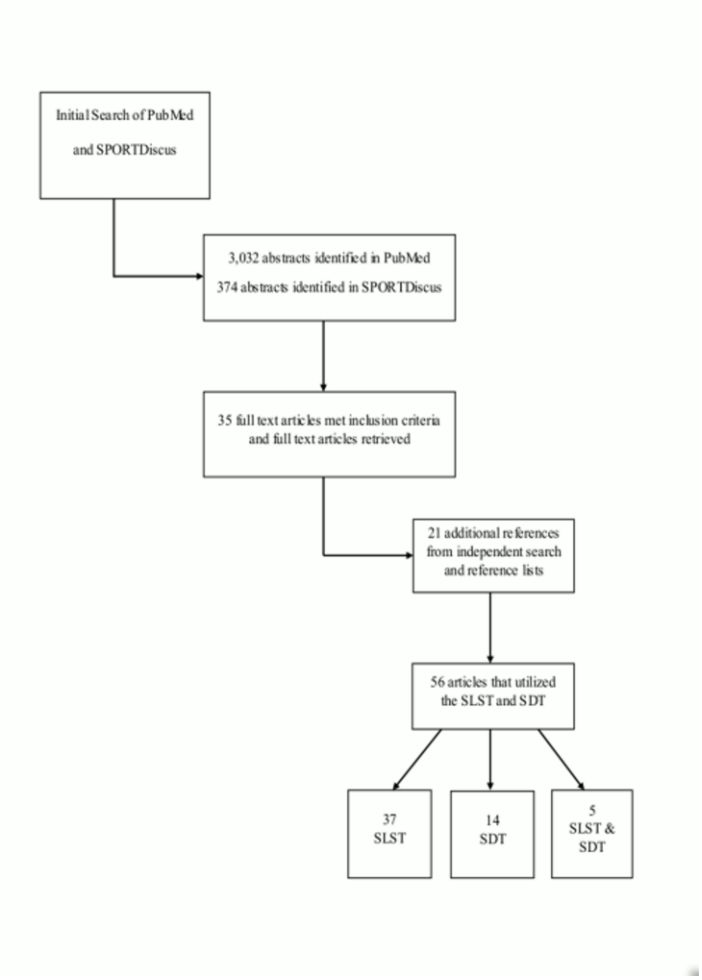

Figure 4.3: Results of literature search for single leg squat and step-down tests

There was no evidence of reliability in administration or evaluation procedures for either the SLST or SDT specifically in patients with documented hip dysfunction. Evidence of reliability for the visual assessment of overall quality of movement for both the SLST and SDT in both healthy subjects and those with documented knee injuries is shown in Table 4.1. Both the SLST and SDT were found to be reliable when the evaluation was based on the evaluators overall impression of test performance as well as evaluation of specific biomechanical deviations for posture and/or movement of the trunk, pelvis, hip, and knee.[201-204]

Study	Test	Evidence of Reliability	Normative Values for Evaluation of Participants
Crossley (2011)	SLST	Inter-rater (Kappa = 0.6 – 0.8, 73% - 87% agreement) Intra-rater (Kappa = 0.61 -0.8, 73%-87% agreement)	Quality of movement rated as "poor", "fair" or "good", based on 5-point criteria
Junge (2012)	SLST	Inter-rater (Kappa = 0.54 – 0.86, 86%-97% agreement)	Postural orientation of knee, hip, and trunk, based on a 4-point scale
Kennedy (2010)	SLST	Intra-rater (ICC = 0.85 & 0.95, 0.74-0.97; Kappa = 0.31 & 0.53) Inter-rater (ICC = 0.8 & 0.92, 0.71-0.95; Kappa = 0.37 & 0.26)	Evaluation of trunk, hip, knee, lower leg, and overall pattern on repetitions (ICC) and limiting factor (Kappa) for left and right leg.
Loudon (2002)	SDT	Intra-rater (ICC = 0.94, SEM = 0.53)	Overall quality of movement
Park (2013)	SDT	Inter-rater (Kappa = 0.80, 85% agreement)	Quality of movement based on 5-point criteria
Piva (2006)	SDT	Inter-rater (Kappa = 0.67, 80% agreement)	Quality of movement based on 5-point criteria
Rabin (2014)	SDT	Inter-rater Overall (Kappa = 0.81, 0.68 – 0.94) Trunk (Kappa = 0.72, 0.57 – 0.87) Pelvis (Kappa = 0.71, 0.52 – 0.90) Knee (Kappa = 0.87, 0.75 – 0.99)	Overall quality of movement & individual rating criteria for trunk, pelvis, and knee rated as "good" or "moderate"
Herman (2016)	SDT	Inter-rater Overall (ICC = 0.61, 73.83% agreement) <1 year (ICC = 0.61, 66.67% agreement) 1 -5 years (ICC = 0.59, 78.33% agreement) >5 years (ICC = 0.59, 73.40% agreement)	Overall quality of movement rated as "good", "fair", "poor" for a cohort of physical therapists with varying levels of experience.
Chmielewski (2007)	SLST/SDT	Inter-rater (Overall method) SLST (Kappa = 0.01, (-0.27) – 0.25) SDT (Kappa = 0.19, (-0.15) – 0.53) Inter-rater (Specific method) SLST (Kappa = 0.18, 0.04 – 0.32) SDT (Kappa = 0.22, 0.07– 0.36)	Overall vs. specific methods for quality of movement

Table 4.1: Studies offering evidence of reliability in overall quality of movement for SLST and SDT

There was no evidence of validity in administration of the SDT specifically in patients with documented hip dysfunction. One study for the SLST demonstrated evidence of validity in administration for patients with hip dysfunction.[16] Both tests demonstrated evidence of validity in kinematic and muscle function assessment in healthy patients. Table 4.2 presents the evidence related to validity in evaluation of hip function for both the SLST and SDT.

Study	Test	Evidence of Validity
Claiborne (2006)	SLST	Hip abduction and internal rotation strength are strong predictors for control of valgus motion at the knee.
Crossley (2011)	SLST	Individuals graded as "good" on test performance had greater hip abduction torque and trunk side flexion force in comparison to those graded as "poor."
DiMattia (2005)	SLST	Weak, positive correlation between hip-abduction strength and hip-adduction angle during test performance.
Hatton (2014)	SLST	Individuals with documented hip chondropathy had decreased balance during test performance. Increased range of motion for hip external rotation may predict balance impairments.
Hollman (2014)	SLST	Individuals graded as "good" had less hip flexion and adduction during test performance than those graded as "poor" performers. Increased medial hip rotation and adduction occurred with an increased knee valgus angle.
Khuu (2016)	SLST	Mechanics of the trunk, pelvis, and lower extremity during test performance was affected by the positioning of the non-stance leg. The SLST-Back positioning caused the most kinematic changes at the hip and pelvis during testing.
Mauntel (2013)	SLST	Increased hip abductor and external rotator strength influences decreasing medial knee deviation during test performance.
Shirey (2012)	SLST	The intentional core activation of individuals during test performance had significantly smaller hip frontal plane displacement ($p=0.01$) and a larger angle of knee flexion ($p=0.009$).
Stickler (2015)	SLST	The hip abductors, external rotators, extensors, and core musculature have an impact on the frontal plane projection angle of the knee during test performance. Specifically, strength of the hip abductors was the greatest indicator of valgus deviation at the knee.
Burnham (2016)	SDT	Hip abduction, external rotation, and extension strength, as well as trunk endurance were positively correlated with repetitions of SDT.
Hollman (2009)	SDT	Recruitment of the gluteus maximus muscle may have a greater effect on test performance than muscle strength. Hip adduction is positively correlated to knee valgus in the frontal plane.
Oliver (2016)	SDT	Both the hamstring and gluteus medius muscles were classified as "strong" during test performance.
Hatfield (2016)	SLST & SDT	The SDT and SLST were shown to have similar kinematic requirements with high hip flexion and adduction muscle impulses. The SDT was shown to have a higher hip adduction angle as well as frontal plane excursion angle of the hip.
Lewis (2015)	SLST & SDT	The SLST and SDT were kinematically different with the SLST having less hip adduction but more hip external rotation and knee abduction ($p \leq 0.03$) than the SDT.

Table 4.2: Studies offering evidence of validity for kinematic evaluation of the trunk, pelvis, hip, and knee

Results attained from studies on the SLST[2,190,201,205-213] (Table 4.3) and SDT[128,135,201,205,211,212,214-216] (Table 4.4) were used to create a standardized protocol and scoring criteria for both functional performance tests for evaluating individuals with non-arthritic hip pain. Evaluation for the proposed protocol was based on an overall impression of the trials (including balance and evaluation of the arm strategy), posture or movement of the trunk, posture of the pelvis, hip joint movement and posture, and knee joint movement and posture.[201-204]

Each individual must wear shorts that enables the evaluator to observe their knee position throughout the entire SLST. A "T" (6" horizontal and 10" vertical) will be marked with 1 ½" white athletic tape on the floor. Patients will be instructed to stand barefoot with both legs shoulder width apart and parallel to each other, with arms positioned at their side. They are instructed to place their unaffected foot on the long axis of the "T" shape with the second metatarsal aligned perpendicular to the stem but not touching the line. The individuals will then transition to a single leg-stance on the unaffected leg with the non-stance knee flexed to 90° and thigh vertically aligned with the stance leg. While maintaining a straight trunk the participants are then instructed to squat down until they can no longer see the line in front of their toes (~45-60 degrees of flexion), while maintaining a balanced and controlled motion at a rate of 1 squat per 2 seconds. After completion of each repetition the individuals will return to their original standing position before beginning another squat. The SLST will be performed a total of 3 times. The participants then will complete 3 repetitions on the affected side. A single investigator will demonstrate the entire procedure before the participation of an individual.

The evaluator assessed the overall test performance of the individuals affected side. Along with an overall impression, each repetition was graded as "positive" or "negative" for the five criteria listed below. For the individual to pass, the evaluator must first grade the overall impression of test performance as passing. Second, a total of 4 out of the 5 specific criteria must be negative for deviation. A passing grade of at least 1 out of the 3 tests are needed for evaluation. Therefore, failing 2 out of 3 tests still elicits a passing assessment.

Scoring Criteria

Overall impression (balance, gross arm deviation, ability to perform test)

1. Trunk movement (forward lean, lateral rotation, lateral flexion, thoracic rotation)
2. Posture of the pelvis (tilt or rotation)
3. Posture of the hip joint (adduction or internal rotation)
4. Posture of the knee (knee valgus or tremor)
5. Depth of squat (compared bilaterally, orientation with T)

Table 4.3: Single leg squat test protocol

Each individual must wear shorts that enable the evaluator to observe their knee position throughout the entire SDT. They are instructed to stand barefoot with both legs shoulder width apart and parallel to each other with arms positioned at their side on a standardized step that is 20-25 cm high. They are then asked to transition to a single leg-stance on the unaffected leg with the non-stance knee extended out from the step and foot in dorsiflexion. The stance leg is positioned so that the toes are even with the front edge of the step. While maintaining a straight trunk, individuals are then instructed to bend their knee on the stance leg until the heel of the contralateral leg touches the floor. Without putting weight on the heel, they must return to the starting position at a rate of 1 squat per 2 seconds. After completion of each repetition the participants will return to their original standing position before beginning the next repetition. Individuals will perform the SDT a total of 3 times. They will then complete 3 repetitions on the affected side. A single investigator will demonstrate the entire test performance before the participation of an individual.

The evaluator assessed the overall test performance of the individuals affected side. Along with an overall impression, each repetition was graded as "positive" or "negative" for the five criteria listed below. For the individual to pass, the evaluator must first grade the overall impression of test performance as passing. Second, a total of 4 out of the 5 specific criteria must be negative for deviation. A passing grade of at least 1 out of the 3 tests are needed for evaluation. Therefore, failing 2 out of 3 tests still elicits a passing assessment.

Scoring Criteria

Overall impression (balance, balance or acceleration provided by heel contact, gross arm deviation, ability to perform test)

1. Trunk movement (forward lean, lateral rotation, lateral flexion, thoracic rotation)
2. Posture of the pelvis (tilt or rotation)
3. Posture of the hip joint (adduction or internal rotation)
4. Posture of the knee (knee valgus or tremor)
5. Depth of squat (inability to contact heel to ground)

Table 4.4: Step-down test protocol

4.5 Discussion

This literature review identified evidence of reliability and validity for the SLST and SDT, with a large proportion of the literature determining these psychometric properties in the healthy population. While there was only one study that offered evidence of validity for the SLST in individuals with non-arthritic hip pain, there was evidence that both tests may be useful in evaluating for range of motion, strength, and proprioceptive deficiencies of the hip and surrounding muscular structures. These tests

assess for several deviations in trunk, pelvis, and hip performance that are considered important when assessing individuals with non-arthritic hip pain. From the identified articles, a standardized protocol and scoring criteria was created for administering the SLST and SDT based on the best available evidence.

The SLST demonstrated moderate to excellent reliability for evaluation of test performance. Visual assessment of overall quality of movement for the SLST showed a 73-87% agreement for inter-rater and intra-rater reliability (Kappa= 0.61 - 0.80) based on a five-point scoring criteria.[201] Moderate to excellent reliability was also present in the inter-tester evaluation of adolescent trunk, hip, and knee postural orientation utilizing a four-point scoring criteria (Kappa = 0.54 – 0.86).[217] Visual observation of dynamic knee valgus and frontal plane projection angle (FPPA) was also shown to be reliable in evaluation of asymptomatic patients during performance of the SLST.[14,207,218-221] While the SLST test has been shown effective in the pass/fail evaluation of an individual's trunk, hip, knee, and lower leg movement patterns, a more objective set of criteria is necessary for reliable identification of specific biomechanical deficiencies in multiple planes.[202] Kinematic evaluation of the trunk, pelvis, hip, and knee utilizing an electromagnetic tracking system demonstrated excellent intra-rater, intrasession reliability (ICC = 0.83 – 1.00) and intra-rater, intersession reliability (ICC = 0.82 – 0.96).[222]

In addition to evidence of reliability, the SLST was valid in the evaluation of dynamic lower extremity control and hip muscle function.[16,201,223] Individuals with documented hip chondropathy were shown to have an overall decrease in balance, as determined by the amplitude and velocity of center of pressure movement when

performing the SLST compared to healthy individuals.[16] Increased hip external rotation range of motion may also predict balance impairments for those with non-arthritic hip pathologies.[16] Moderate, negative correlations between test performance and muscle function of the hip abductors ($r = -0.37$, $p < 0.05$).[53] Hip abduction ($r = 0.466$, $p = 0.002$), hip external rotation ($r = 0.464$, $p = 0.003$), hip extension ($r = 0.396$, $p = 0.012$) and core musculature ($r = 0.426$, $p = 0.006$) were shown to have moderate, positive correlations to the frontal plane projection angle during performance of the SLST.[54] Individuals who were graded as having a "poor" SLST showed weakness and slower activation of the hip abductors specifically the gluteus medius as measured by electromyographic activity,[201] with an increase in hip adduction and flexion motions compared to those that were graded as "good" based on visual observation[224] Greater strength in the hip abductors and an increase in depth of knee flexion was shown to be related to a decrease in the valgus motion of the knee during the SLST.[225] The increase in coactivation of gluteal and hip adductor muscles was shown to also cause a decrease in valgus motion of the knee during the SLST as measured by electromyographic activity and an electromagnetic motion tracking system.[226,227] The SLST was shown to induce less hip adduction but more hip external rotation and knee abduction compared to the SDT.[17]

Although the evidence for reliability and validity of the SDT is less than that for the SLST, the SDT was shown to have moderate to excellent reliability for test performance. The SDT showed excellent interrater reliability for overall quality of movement (Kappa = 0.81, 0.68 – 0.94), as well as moderate to excellent interrater reliability for trunk alignment (Kappa = 0.72, 0.57 – 0.87), pelvic plane (Kappa = 0.71, 0.52 – 0.90), and knee positioning (Kappa = 0.87, 0.75 – 0.99) during performance in

individuals with patellofemoral pain.[228,229] Intra-rater reliability for SDT performance in individuals with patellofemoral pain syndrome and healthy subjects was also shown to be excellent (ICC = 0.94, SEM = 0.53).[128] The overall movement quality of the SDT has been shown to have moderate (Kappa = 0.67, 80% agreement)[215] to excellent inter-tester reliability (Kappa = 0.80, 85% agreement)[203] based on a five point scoring criteria in healthy individuals.[215] Moderate inter-rater reliability for the SDT was even shown amongst 142 physical therapists who evaluated 15 healthy subjects on a three level rating criteria (ICC = 0.61, 74% agreement).[230] Kinematic evaluation of the trunk, pelvis, hip, and knee utilizing an electromagnetic tracking system demonstrated excellent intra-rater, intrasession reliability (ICC = 0.83 – 1.00) and intra-rater, intersession reliability (ICC = 0.82 – 0.97).[222]

The available studies demonstrated evidence of validity for evaluation of hip and trunk muscle function. Hip abduction ($r = 0.446$, $p<0.001$) and external rotation ($r = 0.448$, $p<0.001$) strength were positively correlated with performance of the SDT.[214] Those evaluated as having "good" movement quality had significantly stronger hip abductors, increased knee active range of motion, and increased hip adduction range of motion than those with "moderate" movement quality.[203] "Moderate" quality of movement patterns also had an increased contralateral pelvic drop ($p= 0.01$) and increased knee external rotation ($p = 0.04$) compared to those that were evaluated as "good."[231] The SDT was found to be more biomechanically demanding when compared to the SLST, however, the differences between the two were not statistically significant (p range = 0.36 – 1.00).[191] Although similar in performance, when compared to the SLST the SDT demonstrated significantly greater knee flexion ($p<0.001$), as well as hip

flexion and adduction ($p \leq 0.013$) during test performance.[17,191] The frontal plane projection angle of the hip was also significantly higher during the SDT than in the SLST ($p < .001$) as observed with 3-D imaging, surface electromyographic activity, and ground reaction forces.[191] Examination of test performance for both functional tests have shown an increase in hip abductor strength and degree of knee flexion to have a significant effect on decreasing hip adduction and valgus motion at the knee. [17,232] The SLST and SDT are beneficial in evaluating patients through visual observation of pelvic tilt and rotation as well as trunk stability.[214,222,233]

This literature review was used to assimilate current evidence to construct standardized protocols for administering the SLST and SDT for use during the evaluation of individuals with non-arthritic hip pain. The proposed protocols for both the SLST and SDT reflect the authors' interpretations of best available evidence of reliability and validity extracted from the current peer-reviewed literature. Evaluation was based on an overall impression of each repetition (including balance and evaluation of the arm strategy), posture or movement of the trunk, positioning of the pelvic plane, hip joint movement and positioning, and knee joint movement and posture.[201-204]

The accumulation of procedures utilized for both the SLST and SDT were extracted and analyzed by the authors from the current peer-reviewed literature in order to assess for reliability and validity. These results were summarized and combined to create a recommended protocol and evaluation procedure for clinical utilization of the SLST and SDT in individuals with non-arthritic hip pain. The standardized protocol and scoring criteria for both the SLST and SDT can be found in Table 3 and Table 4, respectively.

There are limitations present in the current study that need to be considered when interpreting the results. The proposed protocols for administration of the SLST and SDT are based on the authors interpretation of the current peer-reviewed literature. These recommendations may not be the only viable options for administration of the SLST and SDT during assessment of individuals with non-arthritic hip pain. Different techniques for test performance as well as differing landmarks for the visual evaluation criteria could be utilized with effectiveness. Other functional performance tests may be beneficial in the evaluation of individuals with intra-articular conditions of the hip. Caution should also be exercised when generalizing the results of the current study to other populations. Future studies are needed to demonstrate the diagnostic accuracy of the SLST and SDT in evaluation of individuals with non-arthritic hip pain. The use of three-dimensional motion analysis technology and electromyographic activity could also add quantitative analysis to validate the use of the SLST and SDT in this population.

4.6 Conclusions

Evidence was available to support the reliable and valid use of the SLST and SDT. Both tests have been utilized to assess quality of movement in the hip and surrounding structures. These tests are indicative of the weight-bearing demands and dynamic muscular control needed for sports related movements. The best procedures used during research to assess reliability and validity of the tests were extracted, analyzed, summarized, and combined in order to create suggestions for practical, clinical procedures for utilization during administration of the SLST and SDT in individuals with non-arthritic hip pain.

Chapter 5

Evidence for Reliability and Validity of Functional Performance Testing in the Evaluation of Nonarthritic Hip Pain

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5.1 Abstract

Context: The single leg-squat test (SLST) and step-down test (SDT) are 2 functional performance tests commonly used to evaluate active people with nonarthritic hip pain and dysfunction. However, there is a lack of evidence to support the use of the SLST and SDT in this population.

Objective: To offer evidence of reliability and validity for the SLST and SDT in evaluating people with nonarthritic hip pain.

Study Design: Cross-sectional study.

Setting: Orthopaedic surgeon's clinical office.

Patients: Forty-five people (27 female and 18 male participants) diagnosed with nonarthritic hip pain and a mean age of 28.5 ± 10 years, height of 171.6 ± 10.1 cm, weight of 73.9 ± 15.2 kg, and body mass index of 25 ± 4.1, participated in this study.

Interventions: Evaluation of the SLST and SDT.

Main Outcome Measures: Inter-rater reliability and validity with passive internal rotation of the hip (IR), visual analog scale (VAS), and hip outcome score (HOS) for limitations in activities of daily living (ADLs) and sports-related activities (SRAs) were collected.

Results: There was moderate to excellent inter-rater reliability for both the SLST (0.603-0.939) and SDT (0.745-0.943). There was a statistically significant difference between the individuals that passed and failed the SLST and SDT on the following measures: VAS for the SLST [$F(1,43) = 16.21$, $P<.001$]; VAS for the SDT [$F(1,43) = 13.41$, $P=.001$]; HOS-ADL for the SLST [$F(1,40) = 5.15$, $P=.029$]; HOS-SRA for the SLST [$F(1,40) = 7.48$, $P=.009$]; and HOS-SRA for the SDT [$F(1,40) = 6.42$, $P=.015$].

Conclusions: Our study offers evidence for the use of the SLST and SDT as reliable and valid functional performance tests in the evaluation of physical function for people with nonarthritic hip pain.

Keywords: single-leg squat test, step-down test, visual analog scale, hip outcome score

5.2 Introduction

Functional performance tests are often used to evaluate dynamic movement patterns that combine range of motion, strength, and proprioception. These tests are indicative of the physical demands and neuromuscular control needed for sport-related movements. The single-leg squat test (SLST) and step-down test (SDT) are 2 functional performance tests commonly used in the clinical setting. While the SLST and SDT are commonly performed to evaluate basic dynamic movement patterns of the trunk and

lower extremity,[17] their use as functional performance tests for people with nonarthritic hip pain and dysfunction has not yet been defined in the literature.

The SLST and SDT account for several deviations in the hip, pelvis, and trunk that are considered important when assessing people for hip pain and dysfunction.[16,17] The overall normal, movement pattern during descent for both the SLST and SDT include hip and knee flexion with anterior pelvic tilt, flexion at the trunk, and hip adduction with knee internal rotation and abduction.[17,190,191] Visual observation of the SLST and SDT has been shown to be reliable in evaluating kinematic and biomechanical deficiencies of the hip, pelvis, and trunk in healthy people.[214,222] They have also been established as valid for assessing dynamic lower extremity control and hip muscle function in healthy people and those with diagnosed hip chondropathy.[16,201,203,214] While these 2 tests are similar in performance, they have been shown to produce different movement patterns, muscular recruitment patterns, and stresses on the intra-articular structures of the hip.[17,192,193] Specifically, the SLST is performed with more abduction of the knee while the SDT is performed with greater hip adduction.[17] An increase in hip abduction kinematics needed during the SDT can cause greater activation of the medial and lateral hamstrings compared with the SLST.[191]

Pathologies associated with the hip joint in the absence of severe degenerative joint disease that cause pain are defined as nonarthritic hip pain and include femoroacetabular impingement (FAI), acetabular labral tears, dysplasia, structural instability (ie. acetabular retroversion, femoral anteversion), and ligamentum teres tears.[7,8] These conditions are believed to occur from repetitive microtrauma developed during dynamic movement between the proximal femur and the acetabulum.[7,140]

Excessive femoral head motion and joint instability can also cause deficiencies and overactivation in the surrounding hip musculature leading to increased intra-articular symptoms over time.[23,32,64] With the increased attention attributed to nonarthritic hip pathologies,[20,65] identifying and diagnosing these conditions have become more common, especially in the young, athletic population. While functional performance tests are commonly used to evaluate active people with hip pain and dysfunction,[2,17,191] studies establishing the reliability and validity of their use in people with nonarthritic hip pain are limited.

Both the SLST and SDT could be useful for evaluating of people with nonarthritic hip pain and dysfunction as they assess for deficiencies relating to the hip and surrounding musculoskeletal structures. However, there is a lack of evidence to support the use of the SLST and SDT in this population. The purpose of our study is to offer evidence of reliability and validity for SLST and SDT in evaluating people with nonarthritic hip pain. Our first hypothesis is that there will be moderate to excellent interrater reliability between differentially trained musculoskeletal experts evaluating both the SLST and SDT. Our second hypothesis will establish validity by demonstrating that people who pass the SLST and SDT will have greater passive internal rotation of the hip (IR), lower reported pain levels, and greater self-reported levels of function, than those who fail.

5.3 Methods

Our cross-sectional study compared evaluations between a certified athletic trainer (R.P.M) and a board certified orthopaedic surgeon and sports medicine specialist

with greater than 10 years' experience performing arthroscopic hip preservation surgery (J.J.C.). The independent variables were evaluation of test performance (passing or failing) of the SLST and SDT. The main outcome variables were passive IR, visual analog scale (VAS) score, and hip outcome score (HOS) for limitations in activities of daily living (ADLs) and sports-related activities (SRAs).

5.3.1 Participants

Forty-five people consecutively diagnosed with nonarthritic hip pain who met the inclusion/exclusion criteria participated in our study. This included 27 female and 18 male participants with a mean age of 28.5 years (range,14-48 years; SD = 10), height of 171.6 cm (range, 155-190.5 cm; SD = 10.1), weight of 73.9 kg (range, 41.7-108.9 kg; SD = 15.2), and body mass index (BMI) of 25 (range, 16.3-35.4; SD = 4.1). These physically active participants reported an average of 24.2 months (range, 1-144 months; SD = 24.2) for duration of symptoms relating to their nonarthritic hip pain. They were evaluated by the secondary investigator (J.J.C.) and diagnosed with the following pathologies: 40 with labral tears (89%), 20 with FAI (44%), 9 with dysplasia (20%), 5 with structural instability (11%), and 3 with ligamentum teres partial tears (7%). All participants and parents/guardians (when applicable) approved and signed the written informed consent and authorization to disclose protected health information for a research study established under the Allegheny Singer Research Institute – Institutional Review Board.

Inclusion criteria included people between 14 and 49 years old, BMI <40, clinical diagnosis of intra-articular pathology (confirmed by magnetic resonance imaging or magnetic resonance arthrogram evaluated by a radiologist and the secondary

investigator), ambulation without mobility aids or assistance, physical ability to perform the SLST and SDT on the unaffected leg, and ability to read and understand English.

Exclusion criteria were age >49 years, BMI ≥40, moderate to severe (Tönnis 2 or 3) osteoarthritic change of the hip[79], any previous surgical intervention on the affected hip; documented current injuries to the lumbar spine, knee, and/or ankle of the affected side (within the previous 6 months), and concurrent extra-articular, musculoskeletal conditions confirmed by magnetic resonance imaging or magnetic resonance arthrogram (ie. gluteus tendinopathies, trochanteric bursitis, hamstring tendinopathies).

5.3.2 Data Collection

The secondary investigator evaluated and recorded IR with the participant in a supine position with the hip and knee positioned at a 90° angle during the initial physical exam. The VAS scores for current pain level, HOS-ADLs, and HOS-SRAs, were completed by the participants before functional test performance. The VAS was quantified on a scale of 0 to 10, while both the HOS-ADLs and HOS-SRAs were quantified on a scale of 0 to 100. The VAS has been shown to be a reliable and valid psychometric response scale for pain in participants with spine fractures and dislocations.[118] Both the HOS-ADLs and HOS-SRAs have been shown to have high reliability and responsiveness of testing as well as a high correlation to measures of physical function in people with nonarthritic hip pain.[121-123]

5.3.3 Functional Test Performance

A standardized protocol for administering both the SLST (Figure 5.1) and SDT (Figure 5.2) was determined from a prior literature review and incorporated into the routine clinical practice of the secondary investigator.[234] Participants were required to wear shorts or tight-fitting pants that enabled the evaluators to observe their lower extremity position throughout the performance of both functional tests. The primary investigator (R.P.M) demonstrated test performance for both the SLST and SDT. Participants were then instructed to perform both tests on the unaffected leg in the presence of the primary investigator. Three repetitions of each test were then completed to evaluate the participant's ability to perform as well as understanding of the proper technique before proceeding to performance on the affected side.

5.3.4 Single-Leg Squat Test

A "T" (6" horizontal and 10" vertical) was marked with 1 ½" white athletic tape on the floor. Participants were instructed to stand barefoot with both legs shoulder width apart and parallel, with arms positioned at their side. They were instructed to place their unaffected foot on the long axis of the T-shape with the second metatarsal aligned perpendicular to the stem but not touching the line. The participants then transitioned to a single leg-stance on the unaffected leg with the non-stance knee flexed to 90° and the thigh vertically aligned with the stance leg. While maintaining a straight trunk the participants were then instructed to squat down until they could no longer see the line in front of their toes (~45°-60° of flexion), while maintaining a balanced and controlled motion at a rate of 1 squat per 2 seconds.

Figure 5.1: The single-leg squat test. A – initial test position. B – squat position.

5.3.5 Step-Down Test

Participants were instructed to stand barefoot with both legs shoulder width apart and parallel, with arms positioned at their side on a standardized step that is 20 to 25 cm high. They were then asked to transition to a single-leg stance on the unaffected leg with the non-stance knee extended out from the step with the foot in dorsiflexion. The stance leg was positioned so that the toes were even with the front edge of the step. While maintaining a straight trunk, participants were then instructed to bend their knee on the stance leg until the heel of the contralateral leg touched the floor. Without putting weight on the heel, they returned to the starting position at a rate of 1 squat per 2 seconds.

Figure 5.2: The step-down test. A – initial test position. B – step-down position.

5.3.6 Functional Test Evaluation

An assessment of 3 trials of the SLST and SDT for the affected extremity was then performed in front of the primary and secondary investigator. The order of testing for the SLST and SDT was randomized for all participants. Both investigators completed forms evaluating the participants' test performance for the SLST and SDT. Each repetition for both SLST and SDT on the affected extremity was evaluated for (1) overall impression of the trials (including balance and evaluation of the arm strategy), (2) posture or movement of the trunk, (3) posture or movement of the pelvis, (4) hip joint movement and posture, (5) knee joint movement and posture, and (6) depth of squat.[201-204] Along with an overall impression, each repetition was graded as *positive for deviation* or *negative for deviation* for the other 5 criteria. The evaluated deviations are shown in

Table 5.1. For the participant to pass, the evaluator must first grade the overall impression of test performance as passing. Second, a total of 4 out of the 5 specific criteria must be *negative for deviation*. A passing grade of at least 1 out of the 3 repetitions was needed for the overall evaluation to be graded as passing. Therefore, failing 2 out of 3 tests still elicited a passing assessment.

	SLST	**SDT**
Trunk	Forward lean Lateral flexion Lateral rotation Thoracic rotation	Forward lean Lateral flexion Lateral rotation Thoracic rotation
Pelvis	Compensated Trendelenburg Rotation	Compensated Trendelenburg Rotation
Hip	Adduction Internal rotation	Adduction Internal rotation
Knee	Valgus Knee tremor	Valgus Knee tremor
Depth of squat	Orientation to tape "T" Bilateral comparison	Ability to touch heel to ground Return to starting position
Overall impression	Balance Gross arm deviation Ability to perform test	Balance Gross arm deviation Ability to perform test

Table 5.1: Evaluated deviations for the SLST and SDT.

5.3.7 Sample Size

To determine the sample size needed for our study, a power analysis (G*Power 3.1.9.1, Universität Dusseldorf, Dusseldorf, Germany) was performed for validity based on a 1-way (apriori), analysis of variance (ANOVA) with omnibus, fixed effects. Our power analysis was derived from a pilot study of 9 people with nonarthritic hip pain evaluated by the primary and secondary investigators. This demonstrated 2 people

passing the SLST with a mean HOS-SRAs of 61.05 (SD = 3.92), while 7 people failed the SLST with a mean HOS-SRAs of 45.72 (SD = 16.31). From this sample a calculated effect size of 0.6373290, alpha error probability of 0.05, and power value of 0.80 produced a total sample size of 22. This total sample size was derived for 2 groups with 11 people each. Due to the sample population demonstrating that roughly 25% of participants with nonarthritic hip pain would pass the SLST, the current study called for 44 participants.

5.3.8 Statistical Analysis

5.3.8.1 Reliability

Statistical analysis for reliability was evaluated as the interrater reliability between the primary and secondary investigators. Interrater reliability was first assessed as an interclass correlation coefficient (ICC) with a 2-way mixed model ($_{3,1}$) to compare the total number of deviations (out of 6) assessed by both investigators for each repetition of the SLST and SDT. Interrater reliability using the Cohen's Kappa statistic was assessed for the overall evaluation of passing or failing for each repetition of the SLST and SDT. Reliability was also assessed using the Kappa statistic for a dichotomous assessment of positive for deviation versus negative for deviation for each repetition of the SLST and SDT in the evaluation of the trunk, pelvis, hip, knee, and depth of squat. Both the $ICC_{3,1}$ and Kappa coefficient were valued on a scale of 0.0 to 1.0, with values closer to 1 showing higher reliability.[199] A value for either the ICC or Kappa that was ≥0.75 was considered excellent, between 0.74 and 0.40 was considered moderate, and <0.40 was considered poor.[196]

5.3.8.2 Validity

Statistical analysis for evidence of validity was measured as the assessment of IR, VAS, HOS-ADLs, and HOS-SRAs between participants with passing and failing evaluations of the SLST and SDT. A 1-way ANOVA calculation was performed for each value to assess for any statistically significant differences between the means of those that were graded as passing and those graded as failing for both the SLST and SDT. All data were analyzed using a common statistical software program (IBM SPSS Statistics, Version 23, Armonk, NY).

5.4 Results

5.4.1 Reliability

The $ICC_{3,1}$ and Kappa values for analysis of interrater reliability are presented in Table 5.2. The $ICC_{3,1}$ values of 0.939 for the SLST and 0.942 for the SDT demonstrated excellent interrater reliability between the primary and secondary investigator in evaluating participants for total number of deviations for each repetition. The Kappa values for the overall evaluation of passing or failing for each repetition of the SLST (0.933) and SDT (0.841) demonstrated excellent reliability. Kappa values for evaluation of the trunk, pelvis, hip, knee, and depth of squat demonstrated moderate to excellent interrater reliability for both the SLST (0.603-0.831) and SDT (0.745-0.943).

	SLST	SDT
$ICC_{3,1}$	.939	.942
Kappa: test pass/fail	.933	.841
Kappa: trunk	.831	.933
Kappa: pelvis	.799	.745
Kappa: hip	.603	.943
Kappa: knee	.707	.899
Kappa: depth of squat	.604	.755

Table 5.2: Interrater reliability statistics for the SLST and SDT.

5.4.2 Validity

Of the 45 people who participated in this study, 11 were evaluated as passing the SLST and 6 were evaluated as passing the SDT. The mean and SD values of IR, VAS, HOS-ADLs, and HOS-SRAs for participants passing and failing the SLST and SDT are presented in Table 5.3. One-way ANOVAs were conducted to examine the relationship between those participants who passed and those who failed the SLST and SDT. The results of these analyses for IR, VAS, HOS-ADLs, and HOS-SRAs are presented in Table 5.4. There was a statistically significant difference between the participants who passed and failed for the following measures: VAS for the SLST [$F(1,43) = 16.21$, $P<.001$]; VAS for the SDT [$F(1,43) = 13.41$, $P=.001$]; HOS-ADLs for the SLST [$F(1,40) = 5.15$, $P=.029$]; HOS-SRAs for the SLST [$F(1,40) = 7.48$, $P=.009$]; and HOS-SRAs for the SDT [$F(1,40) = 6.42$, $P=.015$]. There was not a statistically significant difference for the following measures: IR for the SLST [$F(1,43) = 0.63$, $P=.431$]; IR for the SDT [$F(1,43) = 0.14$, $P=.710$]; and HOS-ADLs for the SDT [$F(1,40) = 2.83$, $P=.101$].

	SLST (mean ± SD)		SDT (mean ± SD)	
	Pass	Fail	Pass	Fail
IR (degrees)	28.6 ± 15.2	23.8 ± 18.1	22.5 ± 13.3	25.4 ± 18.1
VAS (out of 10)	3.6 ± 1.6	5.8 ± 1.6	3.0 ± 0.9	5.6 ± 1.7
HOS-ADL (out of 100)	78.8 ± 7.4	68.7 ± 14.1	79.7 ± 7.5	70.0 ± 13.7
HOS-SRA (out of 100)	65.8 ± 7.1	48.9 ± 19.9	70.4 ± 6.3	50.5 ± 18.9

Table 5.3: Means and SD for participants who passed and participants who failed the SLST and SDT.

	SLST F-value (significance)	SDT F-value (significance)
IR	0.63 (.431)	0.14 (0.710)
VAS	16.21 (.000)*	13.41 (.001)*
HOS-ADL	5.15 (.029)*	2.83 (.101)
HOS-SRA	7.48 (.009)*	6.42 (.015)*

* - Significant at $P<.05$

Table 5.4: One-way ANOVA results between participants who passed and participants who failed the SLST and SDT.

5.5 Discussion

Our study offers evidence of reliability and validity for the use of the SLST and SDT as measures of functional performance for people with nonarthritic hip pain and dysfunction. Our results confirm the first hypothesis, that there was moderate to excellent interrater reliability between a certified athletic trainer and orthopaedic surgeon in evaluating the SLST and SDT. While both the SLST and SDT were shown as reliable, a greater agreement was noted in the evaluation of the SDT. The SDT was also shown to be more difficult to pass than the SLST for people with nonarthritic hip pain. Self-reported pain and physical function during sports SRAs were shown to be significantly different between participants who passed and failed the SLST and SDT. However, self-

reported physical function in ADLs was only shown to be significantly different between those who passed and failed the SLST. Due to the difficulty of test performance and the insignificant relationship with physical function in ADLs, the SDT could be suggestive of higher-level functional performance compared with the SLST. Therefore, the inclusion of both the SLST and SDT in a comprehensive clinical exam could effectively evaluate for limitations in the daily and sports-related function of people with nonarthritic hip pain.[17,191]

Diagnosis of nonarthritic hip pain is commonly evaluated through a combination of diagnostic imaging and a comprehensive clinical exam.[7] Internal rotation is a common physical measurement assessed during an exam for people with intra-articular hip pathologies. Limitation in IR could possibly affect the functional test performance of the SLST and SDT. However, the results of our study demonstrated that there was not a statistically significant difference in IR between those who passed and those who failed the SLST and SDT. Our results did not support the hypothesis that participants who passed the SLST and SDT would have greater passive IR than those who failed. The diverse representation of pathologies presented in our study could explain why the amount of IR did not influence test performance for both the SLST and SDT. The presence of participants with dysplasia and structural instability as well as only 20 of the 45 participants being diagnosed with FAI demonstrates that not all intra-articular conditions may cause a functional limitation of IR.

Together with a thorough physical exam, a comprehensive clinical exam should include the use of outcome measures that have been shown to be reliable and valid in constructing a satisfactory representation of a person's self-reported pain and physical

function. All participants were administered the VAS and HOS before performing the SLST and SDT. By administering these measures, our study could determine the relationship of outcomes to a participant's success in passing the SLST and SDT. There was a statistically significant difference between the participants who passed and participants who failed the SLST for the VAS, HOS-ADLs, and HOS-SRAs. Participants who passed the SLST demonstrated less pain, greater functional ability in their ADLs, and greater functional ability in their SRAs than those who failed. Overall, there was a significant difference in self-reported pain and physical function during ADLs and SRAs between participants who passed and participants who failed the SLST. This confirms our hypothesis that participants who passed the SLST would report less pain and greater levels of physical function in their ADLs and SRAs.

There was a statistically significant difference between the participants who passed and the participants who failed the SDT for the VAS and HOS-SRAs. However, there was not a statistically significant difference for HOS-ADLs. Participants who passed the SDT demonstrated less pain and greater functional ability in their SRAs than those who failed. Those who passed the SDT did not demonstrate statistically more functional ability in their ADLs than those that failed. However, there was still a mean score difference of 9.7 points between the 2 groups. There was a significant difference in self-reported pain and physical function during SRAs between participants who passed and participants who failed the SDT. While participants who passed the SDT reported less pain and greater function during their SRAs, they did not demonstrate greater function in ADLs. Due to the difficulty most participants had with test performance, the SDT could be indicative of higher-level function in participants with nonarthritic hip

pain, therefore not having a significant impact on the lower-level function associated with ADLs.

There are limitations present in our study that need to be considered when interpreting the results. Internal rotation was evaluated visually by the secondary investigator during the comprehensive physical exam. A previous study demonstrated that there was no significant difference between an experienced orthopaedic surgeon visually assessing hip IR compared with goniometric measurements performed by 2 experienced physiotherapists.[235] The secondary investigator had 11 years' experience as an orthopaedic surgeon at the time of our study and was able to accurately assess for IR during the initial physical exam. Other passive range of motion measurements could also have been evaluated in our study including hip flexion, extension, abduction, and external rotation for relationships to the functional performance tests and the participants assessed. Caution should also be exercised when generalizing the results of our study to other populations. Further studies are needed to confirm results with multiple testers of differing backgrounds (ie. physical therapist, primary care physician) and participants with other lower extremity and hip-specific disorders. The use of 3-dimensional motion analysis technology could add quantitative analysis to validate the use of the SLST and SDT in future studies.

Deficiencies in neuromuscular control during dynamic weight-bearing activities have been shown to drastically change functional movement patterns and increase the risk for musculoskeletal injuries.[33,36] The loss of strength, functional motion, and proprioception during weight-bearing activities combine to cause neuromuscular deficiencies that decrease the dynamic stability of the hip, pelvis, and trunk.[32]

Deficiencies in people with nonarthritic hip pain during dynamic movements should be evaluated before a rehabilitation intervention or conservative treatment is prescribed.[37] The use of both the SLST and SDT could be beneficial for evaluating and screening people reporting nonarthritic hip pain, however, these functional performance tests should not be used to indicate specific impairments.

5.6 Conclusions

The results of our study demonstrate the ability of the SLST and SDT to assess people with differing diagnoses of intra-articular hip pathologies. There was moderate to excellent interrater reliability for evaluating both the SLST and SDT. There was a significant difference in self-reported pain and physical function during ADLs and SRAs between participants who passed and participants who failed the SLST. There was a significant difference in self-reported pain and physical function during SRAs between participants who passed and participants who failed the SDT. We offer evidence for the use of the SLST and SDT as reliable and valid functional performance tests in evaluating physical functional for people with nonarthritic hip pain.

Chapter 6

Methods

6.1 Experimental Design

A retrospective, cross-sectional study evaluating prospectively collected information to assess whether individuals with non-arthritic hip pain that improved functional movement control during the SLST and SDT had better PRO's than those that did not improve, following the implementation of a rehabilitation protocol and home-exercise program. The clinical staff working under and including John J. Christoforetti, MD prospectively collected all information included in this study. The research staff for Dr. Christoforetti accessed the patient data and de-identified the information into a cloud-based software system. The primary investigator (RPM) was supplied the de-identified information and completed data analysis and interpretation of the results. The dependent variables of interest were the evaluated PRO's including: 1) current pain level (VAS), 2) hip outcome score (HOS) for limitations in activities of daily living (HOS-ADL), 3) sports-related activities (HOS-SRA), 4) percent global rating for activities of daily living (% - ADL), 5) percent global rating for sports-related activities (% - SRA), 6) categorical assessment of function; 7) patient satisfaction; and 8) the individual's choice to proceed with surgical intervention or not. The independent variable of interest was the evaluation of functional movement control by performance of the SLST and SDT from the initial evaluation to follow-up evaluation, following a rehabilitation intervention and a standardized home-exercise program.

6.2 Orthopaedic Treatment Clinical Outcomes Registry

The current study will retrospectively evaluate information that was prospectively collected for the Orthopaedic Treatment Clinical Outcomes Registry (OTCOR) established by John J. Christoforetti, MD under the Allegheny Springer Research Institute – West Penn Allegheny Health Systems Internal Review Board (ASRI – WPAHS IRB). This outcomes registry operates under the Allegheny Health Network Research Policies and Procedures and all applicable federal and state laws and regulations including 45 CFR 46 and the HIPAA Privacy Rule. The information included in this registry was recorded by the research staff in such a manner that subjects cannot be identified, directly or through identifiers linked to the subjects. All data and records generated from this registry are kept confidential in accordance with the institutional polices and HIPAA on subject privacy.

The primary objective of the OTCOR registry is to produce a de-identified set of prospectively collected data from orthopaedic care delivered in the outpatient setting for analysis and reporting of patient-derived value. This prospective data registry operates as a single center initiative for creation of a secure, electronic de-identified data repository. Research utilizing this registry is conducted on the de-identified data, which is not considered human subjects research. The use of the de-identified data set includes exportation for multicenter outcomes study participation and retrospective review for comparison of treatment outcomes. The individuals in this registry are prospectively recruited from the treating patient population of Dr. Christoforetti. All subjects and parents/guardians (when applicable) approved and signed the written informed consent

and authorization to disclose protected health information for a research study established under the ASRI – WPAHS IRB.

The protocol for this registry requires entry of data points collected as part of standard orthopaedic care from Dr. Christoforetti's sub-specialty practice in outpatient orthopaedic care. Only researchers who have completed CITI training have access to the patient data prior to de-identification and are necessary members of the clinical care team. The OTCOR study is conducted at the West Penn Hospital and outpatient orthopaedic offices of Allegheny Orthopaedic Associates. The data collection is sourced from three primary locations: the outpatient medical record, the hospital radiology technology access software, and the practice management software for scheduling at the Allegheny Orthopaedic Associates. Data is queried by the research staff who are trained in handling of the protected health information and de-identification of such data for research. Once stripped of the pertinent health information, the de-identified data will be stored in a secure cloud-based software storage program approved by the Allegheny Springer Research Institute – West Penn Allegheny Health Systems Internal Review Board (ASRI – WPAHS IRB).

The collected data points, including physical examination, PRO's, radiographic findings, and all elements used in determining clinical care delivery, are entered into the de-identified database concurrent with routine medical record documentation. The data collected from the outpatient medical record include: age, gender, sports or recreational activities of choice, mechanism of injury, diagnosis, procedures or treatments recommended, key physical exam findings supporting diagnosis and used in directing treatment, radiographic findings documented on routine radiographs or other outpatient

imaging studies, participation status in physical therapy or other non-surgical care pathway, and an office interaction record. Patient-reported outcomes are collected for pre- and post-treatment time points per the routine practice of Dr. Christoforetti. The data points collected are all considered portions of routine and follow-up care within the practice of Dr. Christoforetti.

Inclusion criteria for the OTCOR study includes: 1) males and females aged 1-100, 2) completed office medical record and operative note (for operative patients), 3) past, present, and future treatment within the office of John J Christoforetti, MD for an ambulatory orthopaedic diagnosis and completion of informed consent document (for prospective portion), 4) parental/guardian permission (informed consent) and if appropriate, child assent, and 5) must be able to read and understand English and consent for themselves. Exclusion criteria for this study includes any patient failing to sign the informed consent.

6.3 Subjects

Subjects included in the current study were patients of Dr. Christoforetti who were clinically diagnosed and conservatively treated for non-arthritic hip pain from chondrolabral lesions caused by FAI, dysplasia and/or structural abnormalities. Participants must have had evaluations for both the initial (pre-) test performance of the SLST and SDT as well as follow-up (post-) test performance, following the completion of a rehabilitation intervention and a standardized home-exercise program. Individuals who did not have a follow-up evaluation of the SLST and SDT were not included in the current study. All subjects and parents/guardians (when applicable) approved and signed

the written informed consent and authorization to disclose protected health information for the OTCOR study established under the ASRI-WPAHS IRB. The sample size estimate of 42 was projected from a power analysis established in Section 6.7.

All data in the current study was retrospectively collected from a secure cloud-based software storage program and was previously prospectively collected as part of the routine clinical care for patients with non-arthritic hip pain that are treated in the office of Dr. Christoforetti. Demographic information included age, gender, height, weight, body mass index (BMI), side of involved hip, duration of symptoms, and intra-articular diagnosis. The following PRO's were collected for each participant from the initial and follow-up clinical evaluations: VAS; HOS-ADL, HOS-SRA, % - ADL, % - SRA, and the categorical assessment of function. Patient satisfaction and the individual's decision to proceed with surgical intervention or not, were also collected from the follow-up clinical evaluation.

6.4 Instrumentation

6.4.1 Patient-Reported Outcomes

Patient-reported outcomes administered by the clinical staff and included in this study are the visual analog scale (VAS); hip outcome score (HOS) for limitations in activities of daily living (HOS-ADL), sports-related activities (HOS-SRA), percent global rating for activities of daily living (% - ADL) and sports-related activities (% - SRA), and the categorical assessment of function; patient satisfaction; and the individual's decision to proceed with surgery or not. The PRO's collected evaluated

perception of symptoms, functional limitations, health-related quality of life, and satisfaction ratings for quality of care. Evidence for the diagnostic accuracy of these measures can be found in Chapter 2, section 2.3.2.2.3.1.

6.4.2 The Single Leg Squat and Step-Down Tests

The protocols for administration of both the SLST and SDT for individuals with non-arthritic hip pain were derived from a recently performed systematic review (Chapter 4) and incorporated into the routine practice by the clinical staff in the office of Dr. Christoforetti. A detailed demonstration of these protocols in Chapter 5 provides evidence of reliability and validity for the use of the SLST and SDT as measures of functional performance for individuals with non-arthritic hip pain and dysfunction.

All individuals wore shorts or tight-fitting pants that enabled the evaluators to observe their lower extremity position throughout the performance of both functional tests. The clinical staff demonstrated test performance for both the SLST and SDT. Individuals were then instructed to perform both tests on the unaffected leg. Three repetitions of each test were then completed for evaluation of ability to perform as well as understanding of the proper technique.

6.4.2.1 Single Leg Squat Test

A “T” (6” horizontal and 10” vertical) was marked with 1 ½” white athletic tape on the floor. Patients were instructed to stand barefoot with both legs shoulder width

apart and parallel, with arms positioned at their side. They were instructed to place their unaffected foot on the long axis of the "T" shape with the second metatarsal aligned perpendicular to the stem but not touching the line. The individuals then transitioned to a single leg-stance on the unaffected leg with the non-stance knee flexed to 90° and thigh vertically aligned with the stance leg. While maintaining a straight trunk the participants were then instructed to squat down until they could no longer see the line in front of their toes (~45-60 degrees of flexion), while maintaining a balanced and controlled motion at a rate of 1 squat per 2 seconds (Figure 6.1).

Figure 6.1: The single leg squat test. A – initial test position. B – squat position.

6.4.2.2 Step-Down Test

Patients were instructed to stand barefoot with both legs shoulder width apart and parallel, with arms positioned at their side on a standardized step that is 20-25 cm high. They were then asked to transition to a single leg-stance on the unaffected leg with the non-stance knee extended out from the step with the foot in dorsiflexion. The stance leg is positioned so that the toes are even with the front edge of the step. While maintaining a straight trunk, individuals were then instructed to bend their knee on the stance leg until the heel of the contralateral leg touches the floor. Without putting weight on the heel, they returned to the starting position at a rate of 1 squat per 2 seconds (Figure 6.2).

Figure 6.2: The step-down test. A – initial test position. B – step-down position.

6.4.2.3 Functional Performance Test Evaluation

An assessment of 3 trials of the SLST and SDT for the affected extremity were then performed in front of the clinical staff. The order of testing for the SLST and SDT was randomized for all individuals. Forms were completed by the clinical staff evaluating the individuals test performance for the SLST (Figure 6.3) and SDT (Figure 6.4). Each repetition for both the SLST and SDT on the affected extremity was evaluated for six criteria including: 1) overall impression of the trials (including balance and evaluation of the arm strategy), 2) posture or movement of the trunk, 3) posture or movement of the pelvis, 4) hip joint movement and posture, 5) knee joint movement and posture, and 6) depth of squat.[201-204] Each repetition was graded as "positive for deviation" with a 1 or "negative for deviation" with a 0, for all six criteria. Each repetition was given a total score of 0 to 6, with 0 being "negative for any deviation" and 6 being "positive for all deviations." The lowest score of the three repetitions was taken for both the initial (pre-test) and follow-up (post-test) evaluation of both the SLST and SDT.

		Repetition 1	Repetition 2	Repetition 3
Trunk Movement	Forward lean Lateral flexion Lateral rotation Thoracic rotation			
Posture of Pelvis	Compensated Trendelenburg Rotation			
Posture of Hip	Adduction Internal rotation			
Posture of knee	Valgus Tremor			
Depth of squat	Orientation to "T" Bilateral comparison			
Overall impression	Balance Gross arm deviation Ability to perform test			
Grade (X/6):		_____	_____	_____

Figure 6.3: Single leg squat evaluation form.

		Repetition 1	Repetition 2	Repetition 3
Trunk Movement	Forward lean Lateral flexion Lateral rotation Thoracic rotation			
Posture of Pelvis	Compensated Trendelenburg Rotation			
Posture of Hip	Adduction Internal rotation			
Posture of knee	Valgus Tremor			
Depth of squat	Ability to touch heel to ground with return			
Overall impression	Balance Gross arm deviation Ability to perform test			
Grade (X/6):		_____	_____	_____

Figure 6.4: Step-down test evaluation form.

6.4.3 Rehabilitation Intervention

All individuals performed a rehabilitation intervention focused on patient education, activity modification, limitation of aggravating factors, an individualized physical therapy protocol, and home-exercise program. Supervised physical therapy was

provided by the Athletic Trainer and/or Physical Therapist of the patient's choosing. The individualized physical therapy protocol focused on addressing biomechanical deficiencies with neuromuscular training of the hip and lumbopelvic regions. The home-exercise program distributed to the patients reflected the best available evidence from a recently performed systematic review, which is presented in Chapter 3 and was incorporated into the routine practice by the clinical staff in the office of Dr. Christoforetti. Participants completed 4 exercises (~15 minutes) of the provided home-exercise program (Appendix B) on the week-days when they were not participating in a supervised physical therapy intervention. The patient was instructed to cycle through the 12 total exercises during the week, while not repeating an individual exercise on back-to-back days. This rehabilitation intervention was established to imitate a normal referral for conservative management for individuals seen in an orthopaedic surgeon's office.

The follow-up evaluation took place after a minimum 4-weeks of participation in the rehabilitation intervention. Each participant was instructed to schedule a follow-up appointment before leaving the office of the secondary investigator during their initial evaluation.

6.5 Procedures

The following information was retrospectively collected from the OTCOR registry by the research staff in the office of John J. Christoforetti, MD: age, gender, height, weight, body mass index (BMI), side of involved hip, duration of symptoms, intra-articular diagnosis, VAS, HOS-ADL, HOS-SRA, % - ADL, % - SRA, the

categorical assessment of function, patient satisfaction, the individual's decision to proceed with surgical intervention or not, and evaluations for test performance of the SLST and SDT from both the initial and follow-up clinical evaluations. The research data for the current study was de-identified so that subjects could not be identified, directly or through identifiers linked to the subjects. The information attained from this retrospective analysis was recorded in a deidentified, Microsoft® Excel spreadsheet (Version 1708, Redmond, WA) by the research staff in Dr. Christoforetti's office. Data analysis and interpretation of the results were then performed by the primary investigator from this de-identified spreadsheet.

6.6 Statistical Analysis

A one-tail, independent t-test with a pre-determined alpha set of 0.05 was performed for each continuous PRO (VAS, HOS-ADL, HOS-SRA, % - ADL, % - SRA). These analyses determined whether the mean change in PRO scores were significantly different between individuals that improved and those that did not improve their functional movement control during performance of the SLST and SDT (for pre- and post- rehabilitation intervention evaluations). The dependent variable for each independent t-test was the mean change from an initial (pre-) to follow-up (post-) PRO score following rehabilitation intervention. The independent variable was the evaluation of change (improved or did not improve) for functional movement control during performance of the SLST and SDT between an initial (pre-) and follow-up (post-) evaluation.

A one-way analysis of covariance (ANCOVA) with a pre-determined alpha set of 0.05 was performed for each continuous PRO (VAS, HOS-ADL, HOS-SRA, % - ADL, % - SRA). These analyses determined whether the post-rehabilitation intervention PRO scores were significantly different between individuals that improved and those that did not improve their functional movement control during performance of the SLST and SDT (for pre- and post- rehabilitation intervention evaluations). The dependent variable for each ANCOVA was the post-rehabilitation intervention PRO score; the independent variable was the evaluation of change (improved or did not improve) for functional movement control during performance of the SLST and SDT between an initial (pre-) and follow-up (post-) evaluation; and the covariate was the pre-rehabilitation intervention PRO score.

A Fisher's exact test with a pre-determined alpha set of 0.05 was performed for each categorical PRO (categorical rating of function, patient satisfaction, and choice for surgical intervention or not). These analyses determined whether a significant relationship was present between the PRO's and individuals that improved and those that did not improve their functional movement control during performance of the SLST and SDT. The dependent variables for the three Fisher exact tests were the categorical rating of function (improved or did not improve), patient satisfaction (yes or no), and choice for surgical intervention or not (yes or no). The independent variable for each analysis was the evaluation of change (improved or did not improve) in an individual's functional movement control during performance of the SLST and SDT between an initial (pre-) and follow-up (post-) evaluation. All data was analyzed using a common statistical software program (IBM SPSS Statistics, Version 23, Armonk, NY).

6.7 Power Analysis

To determine the sample size needed for this study, a power analysis (G*Power 3.1.9.2, Universität Dusseldorf, Dusseldorf, Germany) was performed based on a one-tail (a-priori), t-test with the difference between two independent means (two groups). The one-tail power analysis was derived from the expected difference in HOS-SRA scores between individuals who improved and those that did not improve from their initial (pre-test) to follow-up (post-test) evaluation for performance of the SLST and SDT, following the implementation of a rehabilitation protocol and home-exercise program. For the current study we utilized the estimated effect size (Cohen's d) of 0.80 based on Cohen's[126] reporting of a large effect size for an independent t-test calculation. The determination to estimate a large effect size was founded from Martin & Philippon's[122] evaluation of responsiveness for the HOS-SRA. Their study reported a large effect size (Cohen's d = 1.5) for the difference between a "change" group and "stable" group, 7-months after hip arthroscopy for individuals with non-arthritic hip pain.[122] A large effect size was also shown for differences in the HOS-SRA score between individuals that were graded as "passing" and "failing" in functional performance of both the SLST and SDT in the study presented in Chapter 5. The difference in HOS-SRA scores of individuals that "passed" and "failed" for the SLST (mean=65.8, SD=7.1 vs. mean=48.9, SD=19.9) and SDT (mean=70.4, SD=6.3 vs. mean=50.5, SD=18.9) demonstrated large effect sizes of Cohen's d = 1.13 and Cohen's d = 1.41, respectively. Also included in this power analysis calculation was an alpha error probability = 0.05, power value = 0.80, and an allocation ratio (N2/N1) = 1, to produce a sample size of 42.

Chapter 7

Results

7.1 Subjects

Forty-six individuals consecutively diagnosed and referred for a rehabilitation intervention were retrospectively included in this study. This population included 31 females and 15 males with a mean age of 30 years (range = 14-61; SD = 12), height of 170.7 cm (range = 154.9-193; SD = 9.2), weight of 74.3 kg (range = 51.7-119.7; SD = 14.7), and body mass index (BMI) of 25.5 (range = 16.6-37.3; SD = 4.2). These physically active individuals reported an average of 10 months (range = 1-36; SD = 10) for duration of symptoms (DOS) relating to their non-arthritic hip pain prior to the initial clinical evaluation. They were evaluated by Dr. Christoforetti and diagnosed with one or more of the following pathologies: 46 with acetabular labral tears (100%), 21 with FAI (46%, 18 cam and 3 pincer deformities), 13 with structural instability (28%), 9 with chondral deformities (20%), and 8 with dysplasia (17%). Following the completion of an individualized physical therapy intervention and home-exercise program, individuals were evaluated at an average of 8 weeks (range = 4-19; SD = 3) from their initial consultation. A total of 30 individuals improved and 16 did not improve their functional movement control during performance of the SLST, while 31 improved and 15 did not improve their functional movement control during performance of the SDT. Twenty-six individuals improved their functional movement control during both the SLST and SDT, 4 improved their functional movement control for only the SLST, 5 improved their

functional movement control for only the SDT, and 11 did not improve their functional movement control for either the SLST and SDT. The average age, height, weight, BMI, and DOS for those that improved and did not improve their functional movement control for both the SLST and SDT are reported in Table 7.1. The ratios for gender and the involved extremity for each group are also reported in Table 7.1.

	SLST		SDT		Total
	mean ± SD		mean ± SD		mean ± SD
	Improved	Did Not Improve	Improved	Did Not Improve	
Age	30 ± 12.2	29 ± 12.0	29 ± 11.9	32 ± 12.3	30 ± 12
Height (cm)	171.4 ± 8.5	169.3 ± 10.4	171.6 ± 9.1	168.7 ± 9.3	170.7 ± 9.2
Weight (kg)	75.9 ± 15.7	71.4 ± 12.4	74.3 ± 15.5	74.6 ± 13.4	74.3 ± 14.7
BMI	25.8 ± 4.7	24.9 ± 3.2	25.1 ± 4.2	26.3 ± 4.5	25.5 ± 4.2
DOS (months)	7.5 ± 8.3	13.2 ± 12.0	7.9 ± 8.8	12.7 ± 11.8	10 ± 10
Gender (females:males)	20:10	11:5	20:11	11:4	31:15
Extremity (right:left)	16:14	8:8	14:17	10:5	24:22

Table 7.1: Mean and standard deviations for age, height, weight, BMI, DOS, and the ratios of gender and the involved extremity.

Results of independent t-tests demonstrated no statistical difference between individuals that improved and those that did not improve their functional movement control during performance of the SLST and SDT for age (SLST p=.676; SDT p=.419), height (SLST p=.472; SDT p=.313), weight (SLST p=.336; SDT p=.942), BMI (SLST p=.485; SDT p=.390), and DOS (SLST p=.064; SDT p=.124).

The mean and standard deviation values for the continuous PRO's collected at the initial and follow-up evaluations are organized into those that improved and those that

did not improve their functional movement control during performance of the SLST and SDT and are provided in Table 7.2 and Table 7.3, respectively.

	Improved		Did Not Improve	
	mean ± SD		mean ± SD	
	Initial Evaluation	Follow-up Evaluation	Initial Evaluation	Follow-up Evaluation
VAS (out of 10)	3.9 ± 1.9	2.0 ± 2.2	4.6 ± 1.9	4.4 ± 2.1
HOS-ADL (out of 100)	72.6 ± 14.7	82.4 ± 16.6	63.3 ± 17.1	61.9 ± 20.4
HOS-SRA (out of 100)	56.1 ± 22.0	72.1 ± 26.0	45.1 ± 21.6	42.6 ± 26.5
% - ADL (out of 100)	63.4 ± 23.3	77.6 ± 22.1	53.2 ± 19.6	43.7 ± 24.8
% - SRA (out of 100)	43.4 ± 28.5	65.3 ± 31.0	26.1 ± 25.1	28.3 ± 25.9

Table 7.2: Initial and follow-up mean and standard deviation values for continuous patient-reported outcomes of individual that improved and did not improve their functional movement control during performance of the SLST.

	Improved		Did Not Improve	
	mean ± SD		mean ± SD	
	Initial Evaluation	Follow-up Evaluation	Initial Evaluation	Follow-up Evaluation
VAS (out of 10)	4.0 ± 1.9	2.1 ± 2.1	4.5 ± 1.9	4.3 ± 2.4
HOS-ADL (out of 100)	71.7 ± 15.7	80.9 ± 17.5	64.6 ± 16.1	63.6 ± 21.4
HOS-SRA (out of 100)	54.6 ± 22.2	69.5 ± 26.3	47.5 ± 22.2	45.9 ± 30.3
% - ADL (out of 100)	62.4 ± 23.3	75.6 ± 21.9	54.5 ± 20.0	45.5 ± 29.1
% - SRA (out of 100)	44.0 ± 27.9	63.5 ± 29.5	22.6 ± 24.2	29.5 ± 32.1

Table 7.3: Initial and follow-up mean and standard deviation values for continuous patient-reported outcomes of individual that improved and did not improve their functional movement control during performance of the SDT.

The 2 X 2 contingency table for the categorical rating of function for individuals that improved and those that did not improve their functional movement control during performance of the SLST and SDT is provided in Table 7.4. The 2 X 2 contingency tables for patient satisfaction with the rehabilitation intervention and the individual's

decision to proceed with surgical intervention or not are provided in Table 7.5 and Table 7.6, respectively.

Categorical Function	SLST		SDT	
	Improved	Did Not Improve	Improved	Did Not Improve
Improved	16	4	15	5
Did Not Improve	14	12	16	10

Table 7.4: Change in categorical rating of function following rehabilitation and home exercise program.

Patient Satisfaction	SLST		SDT	
	Improved	Did Not Improve	Improved	Did Not Improve
Yes	28	3	27	4
No	2	13	4	11

Table 7.5: Patient satisfaction with the rehabilitation intervention and home exercise program.

Surgery	SLST		SDT	
	Improved	Did Not Improve	Improved	Did Not Improve
Yes	7	12	8	11
No	23	4	23	4

Table 7.6: Surgical decision following the rehabilitation intervention and home exercise program.

7.2 Statistical Results

A one-tail, independent t-test was performed to explore the effect of the rehabilitation intervention and home exercise program on the mean change for each continuous PRO score (VAS, HOS-ADL, HOS-SRA, % - ADL, % - SRA) for those individuals that improved and did not improve their functional movement control during performance of the SLST and SDT. The results of these analyses are presented in Table 7.7. There was a statistically significant difference between individuals that improved and those that did not improve their functional performance for the following measures: VAS for SLST, VAS for the SDT, HOS-ADL for the SLST, HOS-ADL for the SDT, HOS-SRA for the SLST, HOS-SRA for the SDT, % - ADL for the SLST, % - ADL for the SDT, and % - SRA for the SLST. There was not a statistically significant difference for % - SRA for the SDT.

	SLST	SDT
	t-value (p-value)	t-value (p-value)
VAS	-2.587 (.007)*	-2.583 (.007)*
HOS-ADL	2.780 (.004)*	2.459 (.009)*
HOS-SRA	2.955 (.003)*	2.553 (.007)*
% - ADL	3.100 (.002)*	2.811 (.004)*
% - SRA	2.088 (.022)*	1.338 (.094)

*Significant at $p<0.05$

Table 7.7: Summary table for the one-tail independent t-tests for mean change in continuous PRO scores.

A one-way analysis of covariance was performed to explore the effect of the rehabilitation intervention and home exercise program on the post-rehabilitation continuous PRO score (VAS, HOS-ADL, HOS-SRA, % - ADL, % - SRA) for those

individuals that improved and did not improve their functional movement control during performance of the SLST and SDT. The results of these analyses are presented in Table 7.8. There was a statistically significant difference between individuals that improved and those that did not improve their functional performance for the following measures: VAS for SLST, VAS for the SDT, HOS-ADL for the SLST, HOS-ADL for the SDT, HOS-SRA for the SLST, HOS-SRA for the SDT, % - ADL for the SLST, % - ADL for the SDT, % - SRA for the SLST, and % - SRA for the SDT.

	SLST	SDT
	F-value (p-value)	F-value (p-value)
VAS	11.879 (.001)*	9.997 (.003)*
HOS-ADL	9.558 (.003)*	6.966 (.012)*
HOS-SRA	10.668 (.002)*	7.273 (.010)*
% - ADL	19.158 (.000)*	13.741 (.001)*
% - SRA	10.643 (.002)*	6.206 (.017)*

*Significant at $p<0.05$

Table 7.8: Summary table for one-way analyses of covariance for post-rehabilitation continuous PRO scores.

A Fisher's exact test was performed to explore the effect of the rehabilitation intervention and home exercise program on the relationship between each categorical PRO (categorical rating of function, patient satisfaction, and choice for surgical intervention or not) and the individuals that improved and did not improve their functional movement control during performance of the SLST and SDT. The results of these analyses are presented in Table 7.9. There was a statistically significant relationship between those individuals that improved and those that did not improve their functional performance for both the SLST and SDT with patient satisfaction and surgery.

There was not a statistically significant relationship between those individuals that improved and those that did not improve their functional performance for both the SLST and SDT with their categorical rating of function.

	SLST	SDT
	p-value	p-value
Categorical Rating of Function (Improved or Did Not Improve)	.117	.365
Patient Satisfaction (Yes or No)	.000*	.000*
Surgery (Yes or No)	.001*	.004*

*Significant at $p<0.05$

Table 7.9: Summary table for Fisher's exact test for categorical PRO scores.

Chapter 8

Discussion

8.1 Introduction

The purpose of this study was to determine if individuals with non-arthritic hip pain that improved their functional movement control during the SLST and SDT would have better PRO's than those that did not improve, following the implementation of a rehabilitation intervention and a standardized home-exercise program. It was hypothesized that individuals who improved their functional movement control during performance of the SLST and SDT would have better PRO's than those that did not improve. Specifically, the individuals with improved functional movement control would have the following: 1) lower reported pain levels; 2) higher scores on the HOS-ADL, HOS-SRA, % - ADL, % - SRA; 2) better categorical rating of function; 3) higher level of satisfaction and 4) lower rate of choosing surgery than those that did not improve. The results of the current study supported the hypothesis. Individuals who improved their functional movement control for the SLST and SDT reported less pain (VAS), higher scores for functional ability in their daily and sports-related activities (HOS-ADL and HOS-SRA), higher scores for their global rating of functional ability in their daily and sport-related activities (% - ADL and % - SRA), higher patient satisfaction, and lower rates of surgery than those that did not improve after an average 8-week rehabilitation intervention and standardized home-exercise program.

The following discussion will focus on the different PRO's for those individuals that improved and those that did not improve their functional movement control during performance of the SLST and SDT. The clinical implications will be discussed with consideration for the limitations of the current study that may affect the interpretation of these results. This discussion will conclude with recommendations for future investigations that could build upon the results of the current study.

8.2 Functional Movement Control

The main finding from the current study was that individuals who improved their functional movement control during performance of the SLST and SDT over an average 8-week timeframe reported significantly better PRO scores in comparison to those that did not improve. A total of 65% (30/46) and 67% (31/46) of individuals in the current study improved their functional movement control during performance of the SLST and SDT, respectively, following the implementation of a rehabilitation intervention and a standardized home-exercise program. Individuals that improved their functional movement control during performance of the SLST and SDT started with a mean of 4.5 ± 0.82 (mean ± SD) and 5.4 ± 0.79 positive deviations, respectively. At their follow-up evaluation those that improved demonstrated a mean of 3.0 ± 1.03 and 3.6 ± 1.29 positive deviations during performance of the SLST and SDT, respectively. Conversely, individuals that did not improve their functional movement control during performance of the SLST an SDT started with a mean of 4.4 ± 1.02 and 5.1 ± 1.10 positive deviations, respectively. At their follow-up evaluation those that did not improve demonstrated a

mean of 4.6 ± 0.96 and 5.3 ± 1.29 positive deviations during performance of the SLST and SDT, respectively. Those individuals that improved their functional movement control demonstrated an average improvement of nearly 2 deviations for both the SLST and SDT, while those that did not improve demonstrated the same number of deviations and in some cases an increase in positive deviations.

The effect size is a standardized measure of change that identifies the size or magnitude of the differences between the two groups.[126,236] The effect size (Cohen's d) was calculated for each independent t-test comparing the continuous variables (VAS, HOS-ADL, HOS-SRA, % - ADL, % - SRA) for those that improved and did not improve their functional movement control during performance of the SLST and SDT. These values are provided in Table 8.1. A Cohen's d value for an independent t-test is classified as having a " large effect size" if greater than 0.80, a "medium effect size" if greater than 0.50, and having a "small effect size" if greater than 0.20.[126]

	SLST	SDT
	Cohen's d	Cohen's d
VAS	0.82*	0.91*
HOS-ADL	0.94*	0.84*
HOS-SRA	0.95*	0.83*
% - ADL	1.02*	0.88*
% - SRA	0.71ǂ	0.46^

* - large effect size; ǂ - medium effect size; ^ - small effect size

Table 8.1: Effect size for the continuous PRO's.

Therefore, mean values for the VAS, HOS-ADL, HOS-SRA, and % - ADL were found to be largely different between those individuals that improved and did not improve their functional movement control for both the SLST and SDT. The mean values for % - SRA

were found to have a "medium effect size" (Cohen's d = 0.71) for the SLST and a "small effect size" (Cohen's d = 0.46) for the SDT. All Cohen's d values were above 0.20, which would classify improving functional movement control during the SLST and SDT as having an "observable" or "plainly evident" effect on all continuous dependent variables.[126] According to Cohen,[126] there is still a observable difference for % - SRA between those that improved and did not improve their functional movement control during performance of the SLST and SDT despite these "medium" and "small" effect sizes.

8.3 Patient-Reported Outcomes

Along with the evaluation of functional movement control, outcomes measures are used by healthcare providers to collect an individual's perception of symptoms, their self-reported functional limitations, health-related quality of life, and satisfaction levels relating to quality of care.[113] The use of PRO's in the evaluation of non-arthritic hip pain should incorporate both hip specific outcome measures as well as generic outcome measures that assess for pain and quality of life.[115] Patient-reported outcomes should be included in the initial assessment as well as all follow-up evaluations to monitor any change in functional deficiencies and/or limitations.[13] The PRO's included in the current study were used to evaluate each individual's perceived levels of dysfunction before and after the implementation of a rehabilitation intervention and a standardized home-exercise program. The mean change for the continuous PRO's of those that improved and did not improve their functional movement control during performance of the SLST and SDT is presented in Table 8.2.

	SLST		SDT	
	mean ± SD		mean ± SD	
	Improved	Did Not Improve	Improved	Did Not Improve
VAS	-1.9 ± 2.4	-0.2 ± 1.7	-1.9 ± 2.3	-0.1 ± 1.6
HOS-ADL	9.7 ± 14.8	-1.4 ± 7.7	9.2 ± 14.4	-1.0 ± 9.5
HOS-SRA	15.9 ± 21.7	-2.4 ± 16.5	14.9 ± 21.6	-1.6 ± 18.0
% - ADL	14.2 ± 27.8	-9.5 ± 17.4	13.2 ± 24.7	-9.0 ± 26.0
% - SRA	22.0 ± 34.4	3.1 ± 14.7	19.6 ± 33.8	6.9 ± 20.0

Table 8.2: Mean change of continuous PRO's from initial to follow-up evaluation.

8.3.1 Visual Analog Scale

Most PRO's utilized in the assessment of non-arthritic hip pain do not assess for an individuals reported pain level.[116] The VAS is commonly used to assess pain in the orthopaedic settings, including hip arthroscopy. Despite its common use, there is limited evidence to support interpreting change in VAS scores. The VAS has been shown to be a reliable and valid psychometric response scale for pain in patients with spine fractures and dislocations.[118] The responsiveness of testing for the VAS score has been shown with a minimal clinically important differences (MCID) value of 1.4 for individuals treated for rotator cuff disease of the shoulder after 6 weeks of non-operative care.[119] The current study demonstrated a mean decrease in reported pain levels of 1.9 ± 2.4 and 1.9 ± 2.3 for individuals that improved their functional movement control during performance of the SLST and SDT, respectively. This improvement was significantly greater than the 0.2 ± 1.7 and 0.1 ± 1.6 decrease in reported pain levels for those that did not improve their functional movement control during performance of the SLST and SDT, respectively. Individuals who improved their functional movement control not only reported statistically less pain (independent t-test and ANCOVA) but also demonstrated a

clinically meaningful decrease in pain than those that did not improve during performance of the SLST and SDT.

8.3.2 Hip Outcome Score

The HOS is a commonly used self-reported outcome measurement that accounts for limitations in activities of daily living and sports-related activities and has shown evidence of reliability, validity, and responsiveness for those with FAI and labral pathologies.[121-123,125] Studies have also demonstrated "large effect sizes" for the HOS-ADL and HOS-SRA as 1.2 and 1.5, respectively.[122,126] From the area under the ROC curves the HOS-ADL was determined to have an MCID value of 9 points, while HOS-SRA demonstrated an MCID value of 6 points.[122] The results from the current study demonstrated a clinically meaningful change of 9.7 ± 14.8 and 9.2 ± 14.4 on the HOS-ADL for those individuals that improved their functional movement control for the SLST and SDT, respectively. In comparison, those individuals that did not improve their functional movement control for the SLST and SDT reported a mean change of -1.4 ± 7.7 and -1.0 ± 9.5 on the HOS-ADL, respectively. A clinically meaningful change of 15.9 ± 21.7 and 14.9 ± 21.6 was also shown on the HOS-SRA for those individuals that improved their functional movement control for the SLST and SDT, respectively. In comparison, those individuals that did not improve their functional movement control for the SLST and SDT reported a mean change of -2.4 ± 16.5 and -1.6 ± 18.0 on the HOS-SRA, respectively. Individuals who improved their functional movement control during the SLST and SDT not only reported statistically significant improvements in their activities of daily living and sports-related activities (independent t-test and ANCOVA)

but also demonstrated a clinically meaningful increase in function compared to those that did not improve.

8.3.3 Generic Ratings of Function

Along with the HOS-ADL and HOS-SRA subscales, individuals completing the HOS were asked to generically rate their current level of function with a global percentage of function and categorical rating of function.[122,124] Although the quantification for global percentage of function and the categorical rating of function are commonly performed in the clinical setting, information regarding their psychometric properties have not previously been reported. The results from the current study demonstrated a mean change of 14.2 ± 27.8 and 13.2 ± 24.7 on the % - ADL for those individuals that improved their functional movement control for the SLST and SDT, respectively. In comparison, those individuals that did not improve their functional movement control for the SLST and SDT reported a mean change of -9.5 ± 17.4 and -9.0 ± 26.0 on the % - ADL, respectively. There was also a large mean change of 22.0 ± 34.4 and 19.6 ± 33.8 on the % - SRA for those individuals that improved their functional movement control for the SLST and SDT, respectively. In comparison, those individuals that did not improve their functional movement control for the SLST and SDT reported a mean change of 3.1 ± 14.7 and 6.9 ± 20.0 on the % - SRA, respectively. There was a statistically significant difference for the reported % - ADL (independent t-test and ANCOVA) and % - SRA (independent t-test and ANCOVA) between those that improved their functional movement control and those that did not during performance of the SLST. While there was a statistically significant difference for the reported % -

ADL (independent t-test and ANCOVA) and % - SRA (ANCOVA) between those that improved their functional movement control and those that did not during performance of the SDT, the independent t-test analysis for the reported % - SRA did not demonstrate a statistically significant difference. One possible explanation could be that individuals would not return to full sports participation without first consulting the treating orthopaedic surgeon at the follow-up evaluation. However, there was still a mean score difference of 12.7 percentage points between the two groups.

The generic rating of function was included as an overall categorical rating of function for each individual.[122,123] A reported change in function was noted if the individuals evaluation from the initial to follow-up was different for the following: "normal" = 0, "nearly normal" = 1, "abnormal" = 2, or "severely abnormal" = 3. The initial and follow-up categorical ratings of function for individuals that improved and did not improve their functional movement control during performance of the SLST and SDT are presented in Table 8.3 and 8.4, respectively.

	Improved		**Did Not Improve**	
	(out of 30)		(out of 16)	
	Initial Evaluation	Follow-up Evaluation	Initial Evaluation	Follow-up Evaluation
Normal	0	8	0	1
Nearly normal	14	14	2	1
Abnormal	15	8	11	12
Severely abnormal	1	0	3	2

Table 8.3: Initial and follow-up categorical ratings of function for individuals that improved and did not improve their functional movement control during performance of the SLST.

	Improved (out of 31)		Did Not Improve (out of 15)	
	Initial Evaluation	Follow-up Evaluation	Initial Evaluation	Follow-up Evaluation
Normal	0	7	0	2
Nearly normal	13	14	3	1
Abnormal	17	10	9	10
Severely abnormal	1	0	3	2

Table 8.4: Initial and follow-up categorical ratings of function for individuals that improved and did not improve their functional movement control during performance of the SDT.

There was not a statistically significant difference between those individuals that improved and those that did not improve their functional performance for both the SLST and SDT with their categorical rating of function. One possible explanation for this could be that the categorical rating of function with 4 choices was not sensitive enough to identify changes. However, there is an observable increase in the reporting of function as "normal" or "nearly normal" for individuals that improved their functional movement control for both the SLST (Table 8.3) and SDT (Table 8.4).

8.3.4 Patient Satisfaction

Patient satisfaction should be included in all clinical evaluations, particularly with the recent emphasis on reporting patient's perspectives on improvements in their overall quality of life.[115,127] During the follow-up evaluation and prior to the assessment of performance for the SLST and SDT, each individual was asked, "Are you satisfied with the rehabilitation intervention and standardized home-exercise program that we have provided?" Each individual was asked to answer with a response of "yes" or "no." A

significant number of individuals that improved their functional movement control for the SLST (93%, 28/30) and SDT (87%, 27/31) responded that they were satisfied with the prescribed rehabilitation intervention and standardized home-exercise program, while a significant number of those that did not improve for the SLST (81%, 13/16) and SDT (73%, 11/15) reported that they were not satisfied. It should be noted that 19% (3/16) and 27% (4/15) of individuals who did not improve their functional performance during the SLST and SDT were still satisfied with the prescribed intervention, respectively. In these cases, it may be that the individuals were satisfied with their treatment, even though they did not improve their functional movement control. The overall satisfaction with treatment that was observed in the current study is encouraging for future research of the non-operative management of non-arthritic hip pain associated with intra-articular pathologies.

8.3.5 Surgical Intervention

Previous studies have demonstrated that individuals who underwent surgical interventions for chondrolabral pathologies relating to FAI and dysplasia reported a decrease in pain, improvements in function, and a high level of satisfaction with the surgical procedure.[39,57-59] Despite the frequency of surgery and the positive PRO's associated with these interventions, there are limitations in the examination procedure that will help to determine which individuals warrant surgical intervention.[20,60-62] In the current study a significant number of individuals that improved their functional movement control for the SLST (77%, 23/30) and SDT (74%, 23/31) chose to return to activities without surgical intervention, while a significant number of those that did not

improve for the SLST (75%, 12/16) and SDT (73%, 11/15) chose to proceed with hip arthroscopy. Therefore, those that did not improve their functional movement control were more likely to choose surgical intervention than those that did improve. The addition of the SLST and SDT to the comprehensive clinical evaluation of non-arthritic pain could be utilized, with the goal of identifying functional limitations present that might predispose an individual to choosing surgical intervention or a return to normal activities. It should be noted, there was no follow-up on these subjects who chose not to undergo surgery. Therefore, although subjects chose not to undergo surgery at the follow-up evaluation, they may have chosen surgical intervention later if their symptoms returned.

8.4 Clinical Implications

The results of the current study may have a clinical significance for healthcare providers evaluating and treating individuals with non-arthritic hip pain. Prior to the current study, it was unclear whether a patient with non-arthritic hip pain could improve their functional movement control, and if they did, would it improve their patient-reported outcomes. Furthermore, it was unknown if the implementation of functional performance testing would be a beneficial addition to the comprehensive clinical evaluation of the hip. The results demonstrate that there is a potential significance for the routine addition of the SLST and SDT into the clinical assessment of non-arthritic hip pain and dysfunction to assess for functional movement control deficiencies. If individuals improve their functional movement control, they are likely to report less pain and greater functional ability in their daily and sports-related activities following a

prescribed rehabilitation intervention and standardized home-exercise program. Also, a significant number of individuals who improved their functional movement control had greater satisfaction with the prescribed intervention as well as lower rates of surgical intervention, than those that did not improve. This study also supports the use of a rehabilitation intervention and a standardized home-exercise program to improve outcomes for those with non-arthritic hip pain.

The goal of a rehabilitation intervention should be to establish dynamic stabilization of the surrounding musculature and proper core and pelvic control to prevent accessory motion of the hip joint during complex activities.[156,169] Specifically the rehabilitation and home-exercise program should include the following: hip musculature strengthening (specifically the hip abductors and deep external rotators);[9,25,31,65,149,152-154,156,158,160-171] pelvic positioning and stability in terms of posture;[25,31,65,102,152,153,155,156,158,164,165,167-170,172] core muscle strengthening;[19,31,102,152,153,155,156,159,161,164,166,167,173,174] neuromuscular training focused on hip and lumbopelvic stability;[9,31,156,157,159,163,166-172] stretching and flexibility for the surrounding hip musculature;[9,153-155,158,160,165-167,170,173,175] inclusion of manual therapy interventions focusing on soft-tissue mobilization of surrounding structures of the hip;[25,154,156,162,163,166,167,169,170,172,175,176] dynamic biomechanical control including proprioception, balance, and coordination training;[9,25,31,159,162,163,166-168,171] and gait training to address pathological adaptations with use of orthotics if necessary.[25,168,169,171] A rehabilitation intervention focused on patient education, activity modification, limitation of aggravating factors, an individualized physical therapy protocol, and a home

exercise program, was shown in the current study to decrease pain and improve function in individuals with non-arthritic hip pain.

Deficiencies in neuromuscular control during dynamic weight-bearing activities have been shown to change functional movement patterns and increase the risk for musculoskeletal injuries.[33,36] The loss of strength, functional motion, and proprioception during weight-bearing activities combine to cause neuromuscular deficiencies that decrease the dynamic stability of the hip, pelvis, and trunk.[32] The assessment of deficiencies in individuals with non-arthritic hip pain during dynamic movements should be evaluated before a rehabilitation intervention or conservative treatment is prescribed.[37] The use of both the SLST and SDT could be a beneficial addition for the evaluation and screening of individuals reporting non-arthritic hip pain. While the implementation of the prescribed intervention significantly improved the functional movement control of individuals in the current study, the long-term effects of this intervention on pain and overall function are unknown.

8.5 Limitations

There are limitations to the current study that need to be considered when interpreting the results. Limitations attributed to this study will be stratified into internal and external validity. Internal validity refers to limitations that challenge the cause-and-effect relationship between the independent variable (improvement in functional movement control during the SLST and SDT) and the dependent variables (PRO's). External validity refers to the generalizability of the results to other populations. This section will address how the limitations of the current study posed potential single group

threats to the internal validity and how they were controlled,[237] as well as potential threats to external validity.

8.5.1 Threats to Internal Validity

The pre-test/post-test design attributed to the current retrospective study lends to several threats of internal validity including: history and maturation effects, testing effects, instrumentation effects, and statistical regression.[237,238] All of these threats can affect the ability of the current study to establish a relationship between the improvement of functional movement control during performance of the SLST and SDT and the included PRO's.

8.5.1.1 History and Maturation Effects

A history effect occurs when an unplanned threat happens between the pre-test and post-test measurements that can affect the outcome.[238] In the current study, an individual experiencing a separate treatment that was not included in the methodology could influence the post-test evaluation. Due to the relatively short time frame of 8 weeks (range = 4-19; SD = 3) between the pre-test/post-test measurement in comparison to the average 10 months (range = 1-36; SD = 10) for duration of symptoms prior to the pre-test clinical evaluation, it is not likely that an outside treatment caused a significant improvement in the functional movement control. Furthermore, the individualized physical therapy protocol and the standardized home-exercise program were the only treatments that each individual participated in during the duration of the current study. No individuals were included in this retrospective analysis if they reported other

treatments that occurred during the pre-test/post-test measurements. All individuals included in the current study reported that they were compliant in completing 4 exercises, four times-a-week from the standardized home-exercise program, along with a supervised physical therapy intervention by the healthcare provider of their choosing, one time-a-week during an average 8-week rehabilitation intervention. It should be noted that each individual received a different rehabilitation intervention and therefore some individuals could have received a better rehabilitation protocol than others, depending on the specific physical therapist and/or athletic trainer.

Similarly, a maturation effect is a natural occurrence that takes place between the pre-test/post-test measurement, such as ageing related changes to the internal structures of the hip.[237,238] Due to the short time frame of 8 weeks (range = 4-19; SD = 3) between the pre-test/post-test measurement, significant changes to the structure of the hip does not seem to be a justifiable threat to the internal validity of the current study.

8.5.1.2 Testing Effects

A testing effect is a threat that only occurs when a pre-test/post-test design is utilized in the methodology of a study. The testing effect occurs when the pre-test influences the outcomes associated with the post-test.[237,238] In the current study, performing both the SLST and SDT during an initial appointment could cause a learning effect that would influence the performance of the individual on the post-test performance. The average time between testing was 8-weeks (range = 4-19; SD = 3), which was believed to be an adequate amount of time to adjust for the learning effect of the specific technique needed for performance of both the SLST and SDT. The difficulty

of individuals to "pass" the SLST and SDT in the study presented in Chapter 5 demonstrated that a learning effect may not influence how an individual would perform on the tests. These functional performance tests are difficult measures of function that cannot be easily performed without proper ROM, strength, and proprioceptive control of the affected extremity.

Performance of three repetitions for both the SLST and SDT could also cause a fatigue effect in the individual and influence their performance, especially during the second functional performance test that was administered. To account for the fatigue effect, the order of testing for the SLST and SDT was randomized with the individual instructed to perform each repetition when they were ready to proceed. This allowed for a consistent testing procedure for everyone included in the current study and directly imitates the normal assessment utilized in the clinical setting of an orthopaedic surgeon's office.

8.5.1.3 Instrumentation Effects

Similar to the threat of testing effects, instrumentation threats only occur in the pre-test/post-test scenario. Instrumentation threats are changes in the instruments or evaluators that could cause a change in the outcomes of the study.[237,238] Issues with the consistency of testing and reliability of the SLST and SDT are two threats that need to be considered when interpreting the results of the current study. A comprehensive evidence-based protocol was established in Chapter 4 for the standardized performance and evaluation of both the SLST and SDT. Both the protocols for administration and evaluation of the SLST and SDT in the current study were based on this prior study to

control for any inconsistencies in testing. The study presented in Chapter 5 offers evidence of reliability for the use of the SLST and SDT as measures of functional performance for individuals with non-arthritic hip pain and dysfunction. There was moderate to excellent inter-rater reliability for both the SLST (.603-.939) and SDT (.745-.943) between a certified athletic trainer and an orthopaedic surgeon. The consistency of testing and reliability that was established for both the SLST and SDT prior to the current study allowed for a consistent experience to account for any threats to instrumentation.

8.5.1.4 Statistical Regression

Statistical regression or regression to the mean is a threat that occurs when two non-random measures in a study are not perfectly correlated.[237,238] In a pre-test/post-test study design, statistical regression is caused by the selection of subjects based on their extreme scores.[238] This would occur if individuals scored extremely high or extremely low on their pre-test PRO's. Since individuals were being seen for functional limitations associated with non-arthritic hip pain, there could be concern that those low scores would improve, and the high scores would not improve regardless of the rehabilitation intervention and standardized home-exercise program. In the current study, there was not a statistically significant difference in PRO scores during the pre-test administration between those that improved and did not improve their functional movement control during performance of the SLST and SDT. Furthermore, inclusion of the ANCOVA calculation adjusted for the pre-test PRO scores to demonstrate the significant difference in post-test PRO scores that was achieved for those individuals that improved their functional movement control during performance of the SLST and SDT. These

calculations demonstrated that the difference between post-test PRO scores for those that improved and those that did not improve their functional movement control, regardless of where they started with their pre-test PRO scores. Given the significant difference between the two groups on the continuous PRO's, a statistical regression does not seem to account for the observed enhancement of functional performance in those individuals that improved their functional movement control.

8.5.2 Threats to External Validity

External validity refers to the extent that the results of the current study can be generalized to other populations.[237,238] Caution should be exercised when generalizing the results of the current study to subjects with other lower extremity and hip specific disorders, including those with osteoarthritic changes. The conclusions of this study should only be applied to individuals with diagnosed non-arthritic hip pain from chondrolabral lesions caused by FAI, dysplasia, and/or structural abnormalities. These individuals were diagnosed and conservatively treated for these pathologies by a board certified orthopaedic surgeon with as specialty in arthroscopic hip preservation surgery. While several individuals in this study demonstrated extra-articular conditions associated with the lower extremity and surrounding hip structures, their primary diagnosis was attributed to intra-articular conditions of the hip. Therefore, the results should not be generalized to all painful conditions of the hip and lower extremity.

The methodology utilized in the current study may not be the only viable options for administration of the SLST and SDT during assessment of individuals with non-arthritic hip pain. Different techniques for test performance as well as differing

landmarks for the visual evaluation criteria could be utilized with effectiveness. Other functional performance tests may also be beneficial in the evaluation of individuals diagnosed with non-arthritic hip pain associated with intra-articular conditions of the hip. Similarly, the prescribed rehabilitation intervention and standardized home-exercise program may not be the only option for non-operative management of individuals with non-arthritic hip pain. Further research into effective conservative treatments for individuals with non-arthritic hip pain is necessary.

8.6 Recommendations for Future Research

The effect of improving functional movement control during functional performance testing is relatively new and there is limited evidence for its use in evaluating individuals with non-arthritic hip pain. The use of functional performance testing in the clinical setting can provide healthcare professionals with objective feedback for a patient's functional movement control.[37] Both the SLST and SDT account for several deviations in hip, pelvis, and trunk performance that could be useful in the evaluation of functional movement control for individuals with intra-articular pathologies of the hip.[16,17] The current study demonstrated that individuals with non-arthritic hip pain that improved their functional movement control during performance of the SLST and SDT had better PRO's than those that did not improve, following the implementation of a rehabilitation intervention and a standardized home-exercise program. The results of this study produce several additional areas of inquiry that are needed for the comprehensive clinical evaluation and non-operative management of individuals with non-arthritic hip pain.

While the SLST and SDT were shown to be effective in the evaluation of functional movement control, additional measures of functional performance could be beneficial in the evaluation of individuals with non-arthritic hip pain. Functional performance testing is commonly utilized to evaluate the basic dynamic movement patterns of the lower extremity with a combination of ROM, flexibility, balance, proprioception, motor control, as well as muscle strength, power, and/or endurance.[2,37,38] Adaptations in the pathomechanics of the lower extremity can lead to functional limitations during daily and sports-related activities, diminished strength in the musculature of the hip, and impaired kinematic and kinetic movements during weight-bearing activities.[19,31,32] A comprehensive clinical evaluation should examine all aspects of the individual's capabilities to provide a thorough presentation of function as well as assess and treat all individuals within their own setting of function regardless of injury.[2,111] In order to do so, clinicians need to integrate an evaluation process that incorporates several measures of function to accurately assess for neuromuscular limitations and dysfunction.[38,99] As this is the first known study, there is a need for additional research into the effectiveness of different functional performance measures in evaluating the functional movement control of individuals with non-arthritic hip pain. Additionally, the use of three-dimensional motion analysis technology could add quantitative analysis to not only validate the use of the SLST and SDT, but other functional performance measures in future studies.

Not only is there a need to investigate additional functional performance measures, but the effectiveness of these tests in evaluating an individual's neuromuscular and functional movement control needs to be explored. Deficiencies in neuromuscular

control during dynamic weight-bearing activities have been shown to notably change movement patterns and increase the risk for musculoskeletal injuries.[33,36] The combined loss of motion, strength, balance, and proprioception may cause neuromuscular deficits that result in impaired functional movement control of the hip, pelvis, and lumbosacral spine.[16,32,33,35] A decrease in hip and pelvis ROM in the frontal and sagittal planes as well as altered balance and proprioceptive control has been shown in individuals with non-arthritic hip pain during dynamic movements.[16,33,34] Significant muscle weakness with hip flexion, abduction, adduction, and external rotation has been shown in individuals with non-arthritic hip pain compared to healthy controls.[16,33,35] Additional studies examining changes in strength, flexibility, and endurance during functional performance testing is necessary to effectively evaluate the neuromuscular limitations that are attributed to non-arthritic hip pain and intra-articular pathologies of the hip.

The current study demonstrated that it may be possible to decrease intra-articular stresses in the presence of structural abnormalities through improving the functional movement control of the surrounding structures. Identification of deficiencies in functional movement control during functional performance testing could also improve the individualized rehabilitation intervention utilized to increase muscular strength around the hip, increase joint stability, and improve proprioceptive control during dynamic activities. The assessment of deficiencies in individuals with non-arthritic hip pain during dynamic movements should be evaluated before a rehabilitation intervention or conservative treatment is initiated.[37] The prescribed rehabilitation intervention and standardized home-exercise program in the current study may not be the only option for non-operative management of non-arthritic hip pain. The intervention was effective for

this group of individuals but considerations for the conservative management of non-arthritic hip pain should also be made on an individual basis by the treating healthcare professional. Additional studies into the effects of other non-operative management plans on different populations of individuals with non-arthritic hip pain is needed.

While the results of the current study demonstrate a significant difference in PRO's between individuals that improved their functional movement control during the SLST and SDT and those that did not improve, there is a need to perform additional "higher quality" studies.[147] These "high quality" studies should be performed utilizing aspects of the current methodology but in a blinded RCT format in order to verify the results.[147] These studies would help contribute to the current evidence on the effectiveness of improving an individual's functional movement control during functional performance testing on their reported outcomes. Additionally, future studies should focus on classifying predictors that identify individuals that are more likely to improve their functional movement control following non-operative management for non-arthritic hip pain.

While the current standard of care for treatment of individuals with non-arthritic hip pain include conservative care, rehabilitation, and/or surgical intervention, there is limited "high quality" research comparing operative to non-operative management.[20,60-62] Only two RCT's have been completed comparing the effects of operative and non-operative management of individual's with FAI.[239,240] Mansell et al.[239] randomized 80 patients from a military hospital that were diagnosed with FAI syndrome into a rehabilitation group or a surgical group. The rehabilitation group participated in a 12-session supervised clinic program within 3 weeks of diagnosis and patients in the surgical

group received surgery at a mean of 4 months after enrollment.[239] While there are several limitations present in this study,[241] the authors reported that there were no significant differences between the groups at a 2-year follow-up.[239] Griffin et al.[240] randomized 348 participants from hospitals in the United Kingdom that were diagnosed with FAI syndrome into 171 receiving hip arthroscopy and 177 receiving a personalized hip therapy program. While both hip arthroscopy and the personalized hip therapy program were shown to improve hip related quality of life, hip arthroscopy led to a clinically significant improvement when compared to conservative care.[240] While surgical interventions have been successful in treating non-arthritic hip pain,[39,57-59] the non-operative management of individuals with FAI syndrome improved the hip related quality of life for individuals in these two RCT's.[239,240] Further "high quality" studies evaluating the effects of non-operative management of FAI and other intra-articular pathologies in comparison to surgical interventions are needed.

The current study was successful in reporting the short-term effects of a rehabilitation intervention and standardized home-exercise program on the functional movement control of individuals with non-arthritic hip pain. The individuals included in this study still have structural pathologies that are untreated at the tissue level, and it is unknown whether the successful non-operative management presented in this study will progress to re-injury or the eventual degradation of the joint over time. Further studies are needed to confirm the long-term effects (ie. 1-year, 2-year, 5-year, 10-year follow-up) of this conservative rehabilitation intervention on individuals with non-arthritic hip pain.

8.7 Conclusions

1. Individuals who improved their functional movement control during performance of the SLST and SDT reported less pain, higher scores for functional ability in their daily and sports-related activities, higher scores for their global rating of functional ability in their daily and sport-related activities, higher patient satisfaction with the prescribed rehabilitation intervention and standardized home-exercise program, and lower rates of surgical intervention, than those that did not improve.
2. There is potential significance for the routine addition of the SLST and SDT into the clinical assessment of non-arthritic hip pain and dysfunction as measures of function.
3. Future research is needed to understand the long-term effects of improving functional movement control on pain and function during daily and sports-related activities for individuals diagnosed with non-arthritic hip pain.

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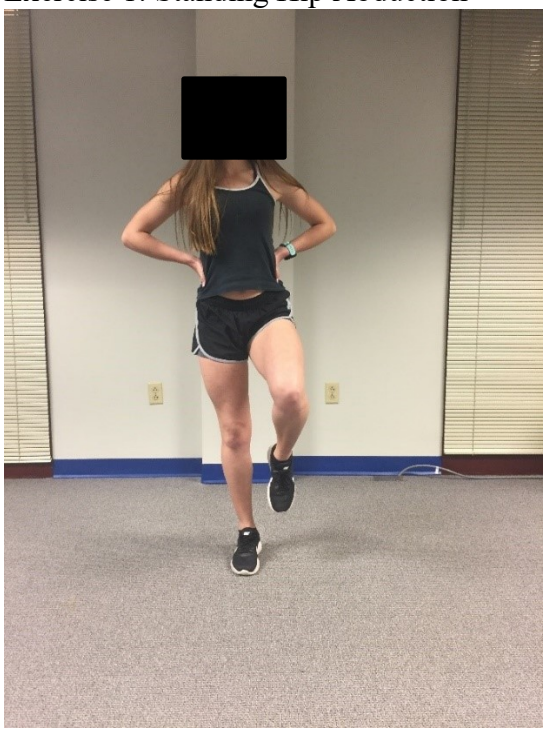
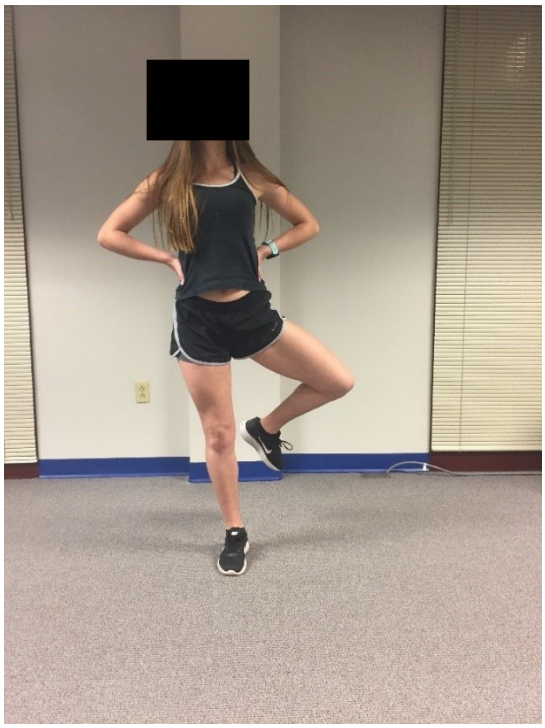
APPENDIX A

Non-Arthritic Hip Pain Home Exercise Program

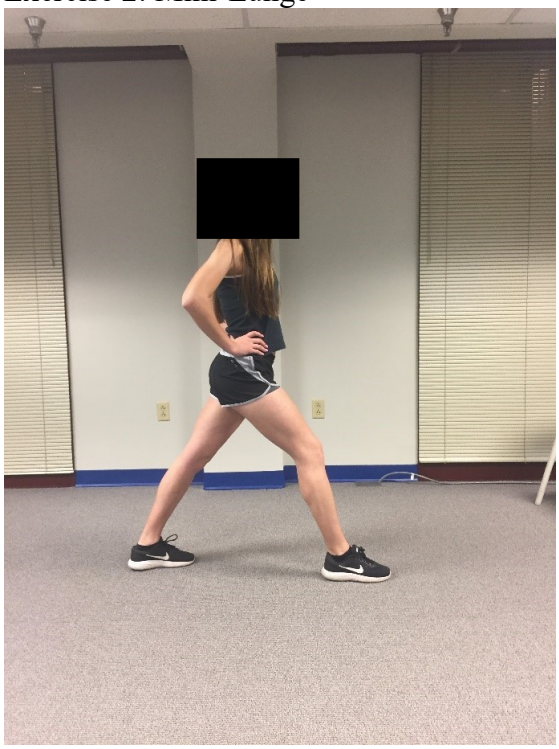
Exercise 1: Standing Hip Abduction

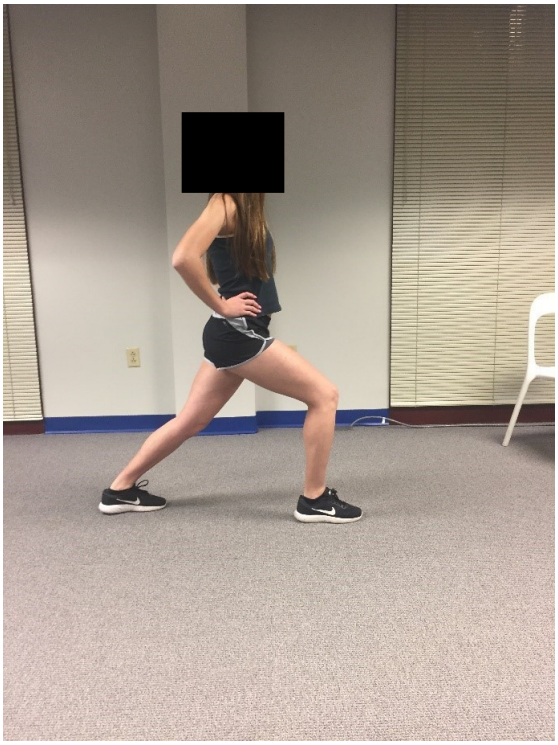




- Stand with feet together.
- Squeeze both gluteus muscles and lift leg with knee bent at a 45° angle.
- Maintain core, pelvis, and shoulder alignment without allowing any movement of your pelvis.
- Move the lifted leg away from midline, by rotating outward.
- Maintain a contracted gluteus muscle and the standing knee over the second toe.
- Hold for 3 seconds.
- Perform on both sides.

Exercise 2: Mini-Lunge





- Start with a wide stance.
- Lunge forward keeping the lunging knee over the second toe.
- Do not bend the knee past the front of the toes.
- Hold for 5 seconds.
- Perform on both sides.

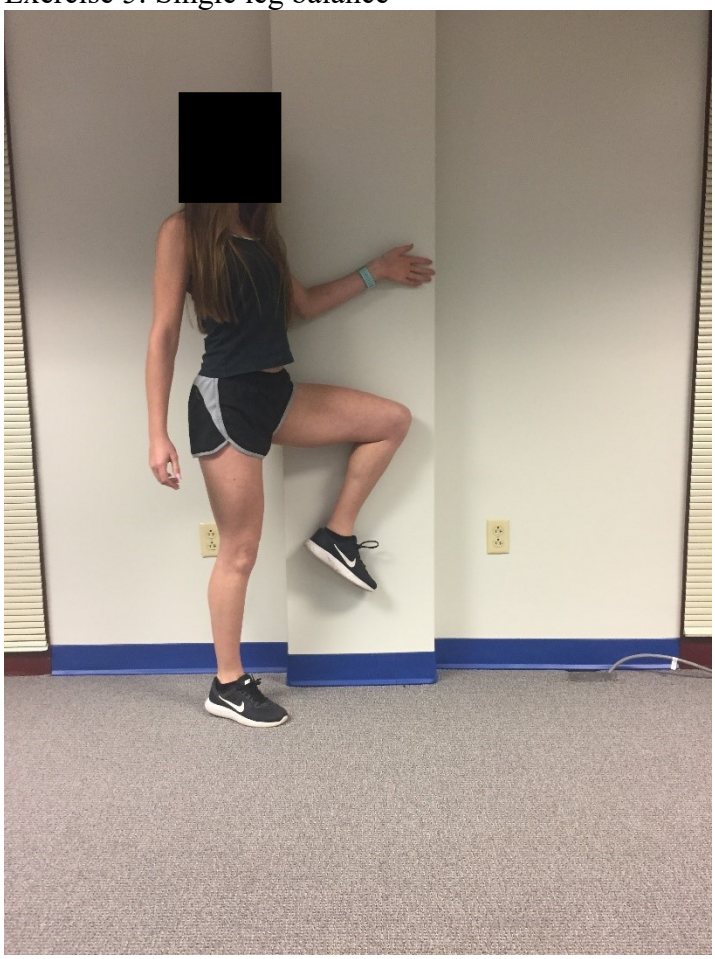
Exercise 3: Side Lunge

- Start with the feet shoulders width apart.
- Lunge to the side without shifting the hip or trunk.
- Maintain an upright core with a straight back position.
- Perform on both sides.

Exercise 4: Wall Slides

- Standing with the back against a wall and feet 18 inches from the wall.
- Slide down so that knees are slightly bent (~45°-60°).
- DO not go past 90°of knee flexion and keep the knees over the second toes.
- Hold for 15 seconds.

Exercise 5: Single leg balance

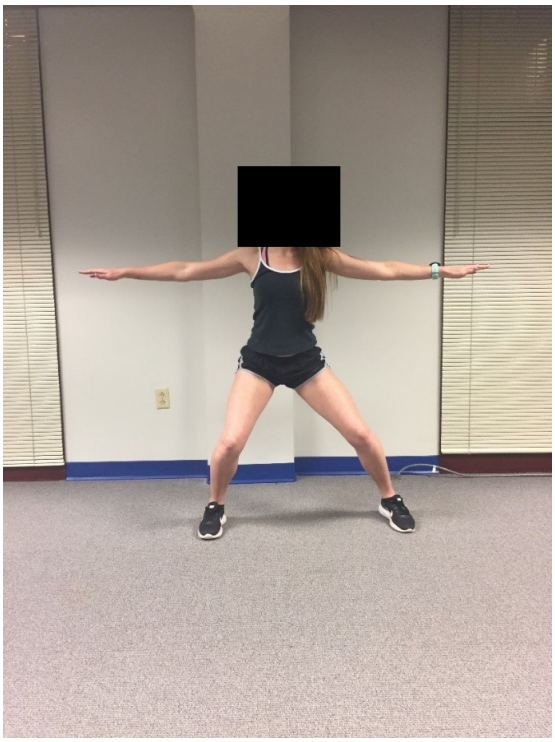


- Stand with the non-affected leg towards and touching the wall, with feet shoulders width apart.
- Lean against a wall with the non-affected leg lifted to 90°.
- Isometrically press the non-affected leg against the wall.
- Balance on the affected leg with knee slightly bent and knee over second toe.
- Hold for 5 seconds.

Exercise 6: Eccentric Hamstring Stretch

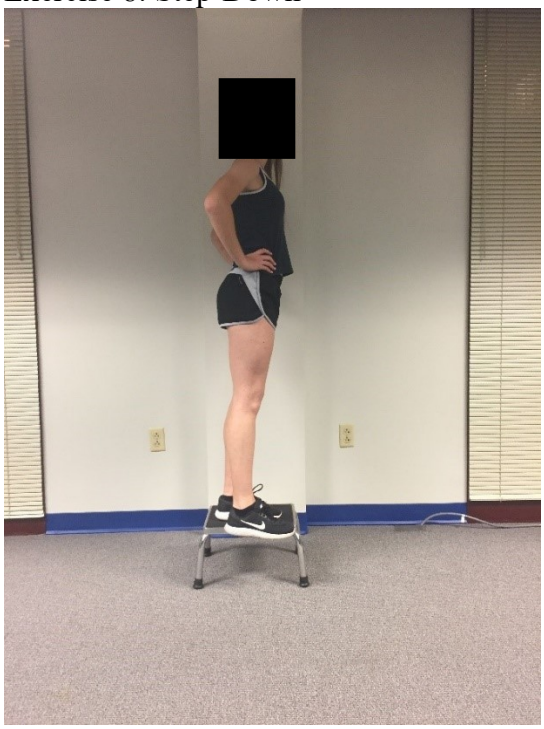
- Stand on the affected leg with knee slightly bent and arms out to side.
- Maintain a straight back and lean forward
- Extend the hip and knee trying to keep body parallel with the floor.
- Hold for 3 seconds.
- Slowly return to starting position.
- Perform on both sides.

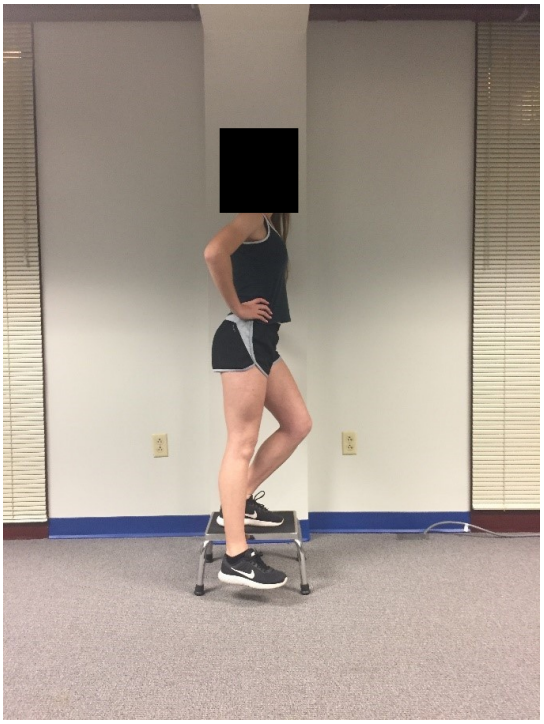
Exercise 7: Side-to-Side Walk



- Side-to-side walk with comfortable stance.
- Step width should maintain a balanced trunk and upper extremities.
- Do not overextend laterally.
- Maintain slightly bent knees (~45°-60°).
- Perform in both lateral directions for 15 feet.

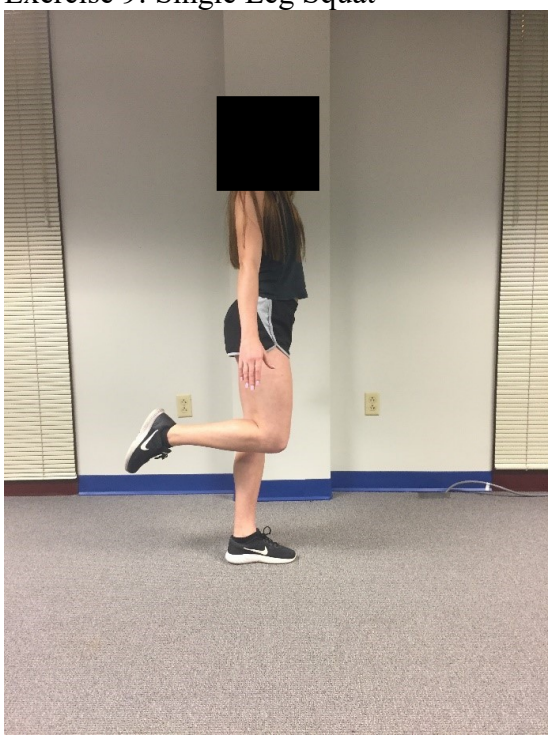
Exercise 8: Step-Down

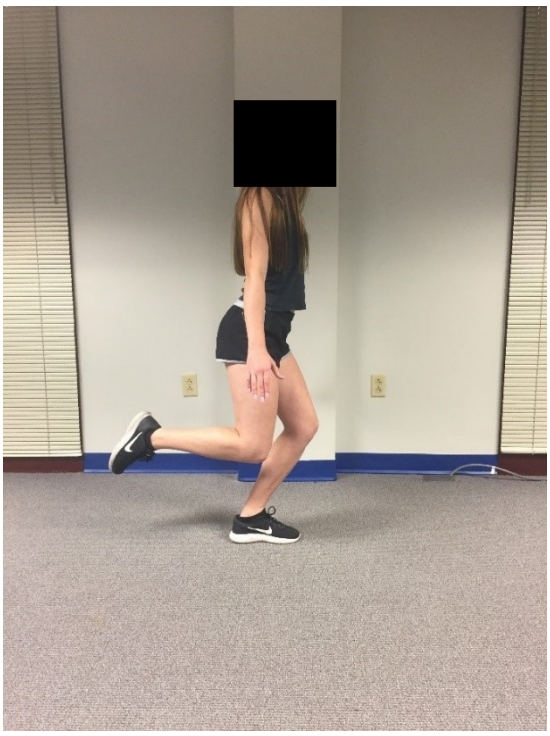




- Stand on stool or raised surface.
- Maintain a straight back with unaffected leg off the stool or raised surface.
- Allow unaffected leg to drop until the heel touches the ground by bending the hip and knee.
- Keep the knee over the second toe.
- Return to starting position.

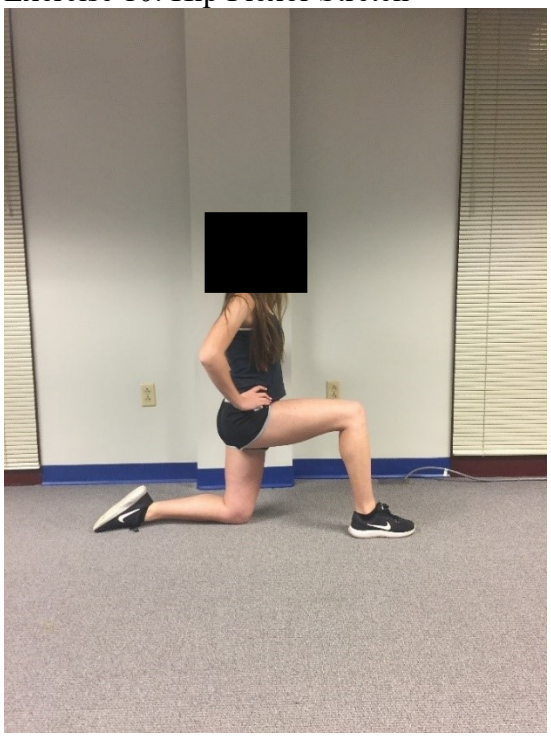
Exercise 9: Single Leg Squat

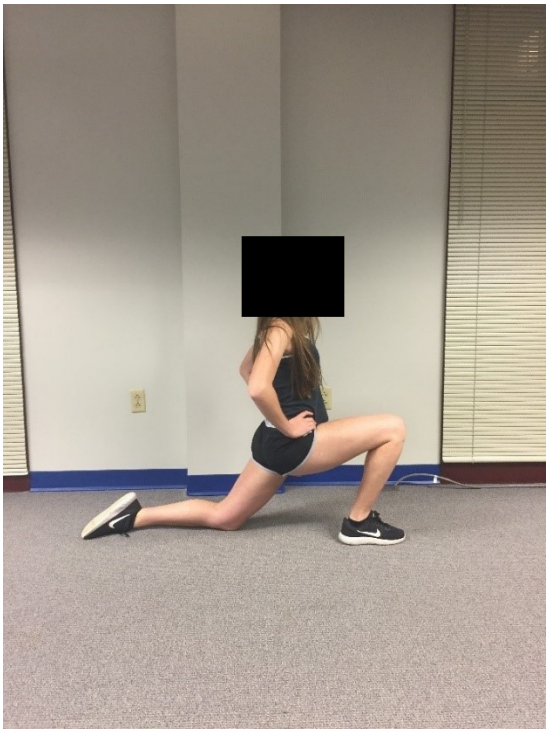




- Stand on the involved leg with back straight and opposite knee bent to 90°.
- Slightly bend the involved knee (~45°-60°) while keeping the knee over the second toe.
- Return to starting position.

Exercise 10: Hip Flexor Stretch



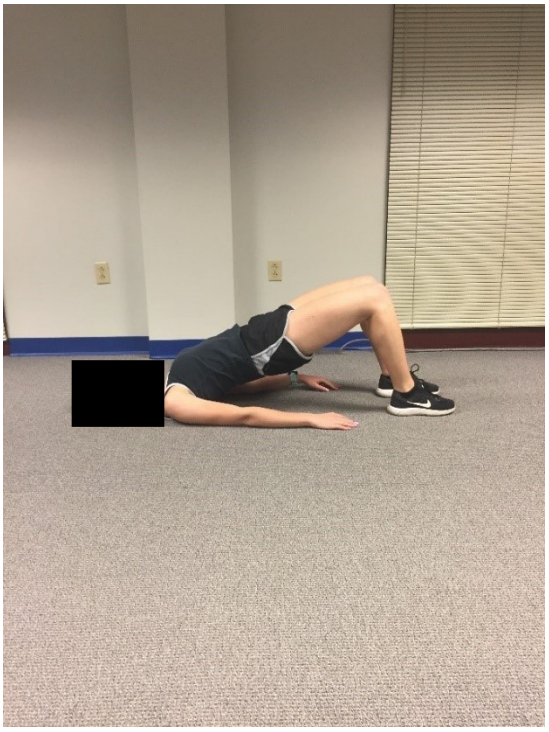


- Kneel on floor with a straight back.
- Lean forward until a stretch is felt in the back leg/hip.
- Do not let knee go in front of the toes.
- Hold for 5 seconds.
- Perform on both sides.

Exercise 11: Hip Extensions

- Begin on hands and knees.
- Maintain a straight back and contracted core.
- Extend leg while contracting gluteus muscles.
- Do not extend back or lift pelvis.
- Hold for 5 seconds.
- Perform on both sides.

Exercise 12: Bridge



- Lay on the ground with knees flexed.
- Lift hips as high as possible while maintaining a contracted core and gluteus muscles.
- Hold for 5 seconds.
- Lower to starting position.

Appendix B

Non-Arthritic Hip Home Exercise Program

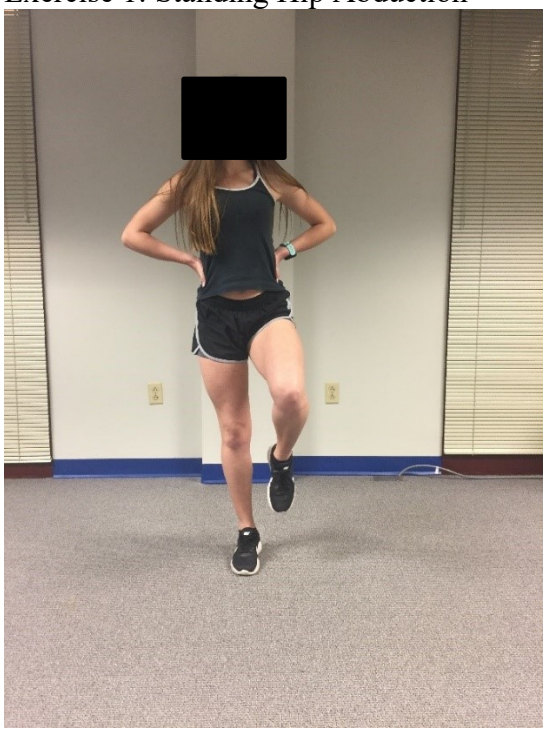
Established from an evidence-based, literature review currently in the peer-review process:

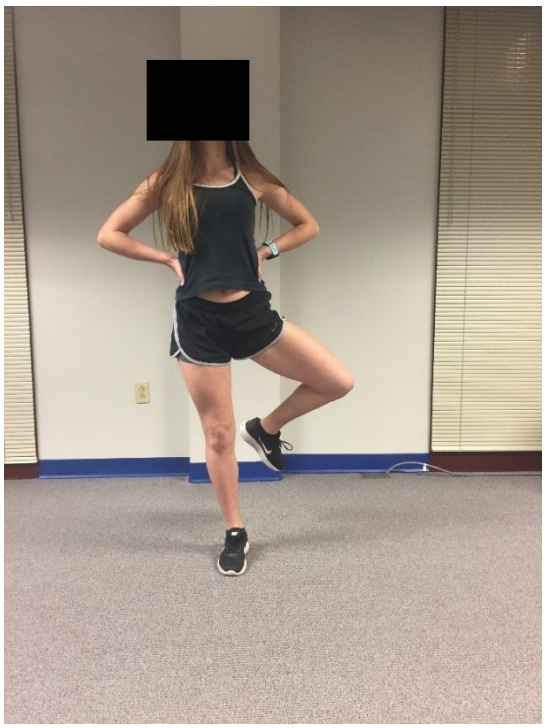
Non-Operative Management of Individuals with Non-Arthritic Hip Pain: A Literature Review.

Ryan P. McGovern, MS, LAT, ATC
RobRoy L. Martin, PhD, PT, CSCS
Benjamin R. Kivlan, PhD, PT, OCS, SCS
John J. Christoforetti, MD
Allegheny Health Network
&
Duquesne University

Participants should complete 4 exercises (~15 minutes) of the provided home-exercise program on the week-days when they were not participating in a supervised physical therapy intervention. Please rotate through the 12 total exercises during the week, while not repeating an individual exercise on back-to-back days.

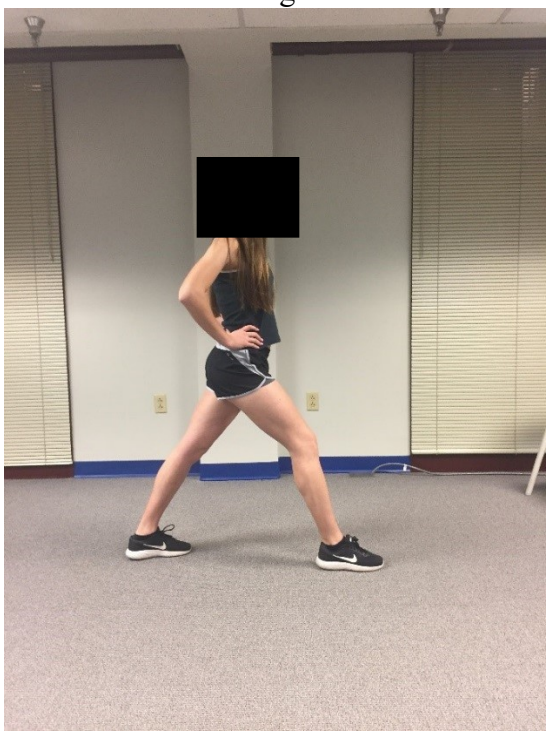
Exercise 1: Standing Hip Abduction

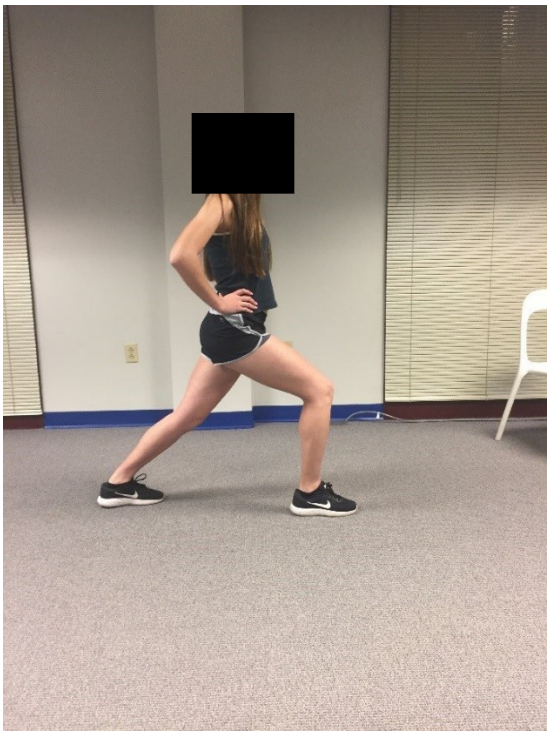




- Stand with feet together.
- Squeeze both gluteus muscles and lift leg with knee bent at a 45° angle.
- Maintain core, pelvis, and shoulder alignment without allowing any movement of your pelvis.
- Move your leg away from midline.
- Maintain a contracted gluteus muscle and keep your knee over your second toe.
- Hold for 3 seconds.
- Perform on both sides.

Exercise 2: Mini-Lunge





- Start with a wide stance.
- Lunge forward keeping your knee over your second toe.
- Do not bend the knee past the front of your toes.
- Hold for 5 seconds.
- Perform on both sides.

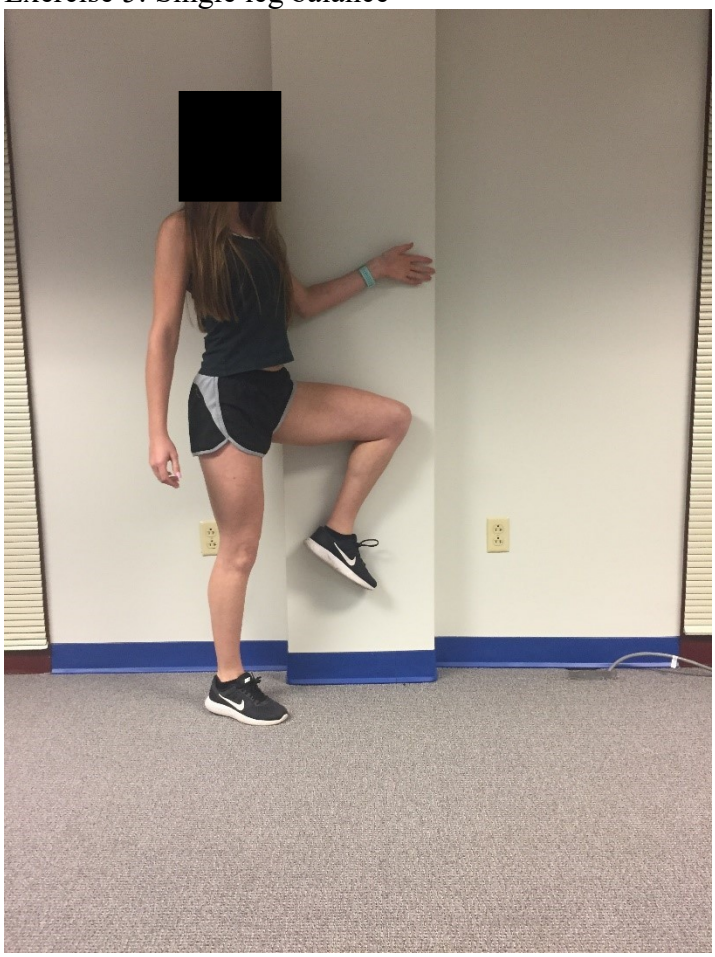
Exercise 3: Side Lunge

- Start with your feet shoulders width apart.
- Lunge to the side without shifting your hip or trunk.
- Maintain core with a straight back position.
- Perform on both sides.

Exercise 4: Wall Slides

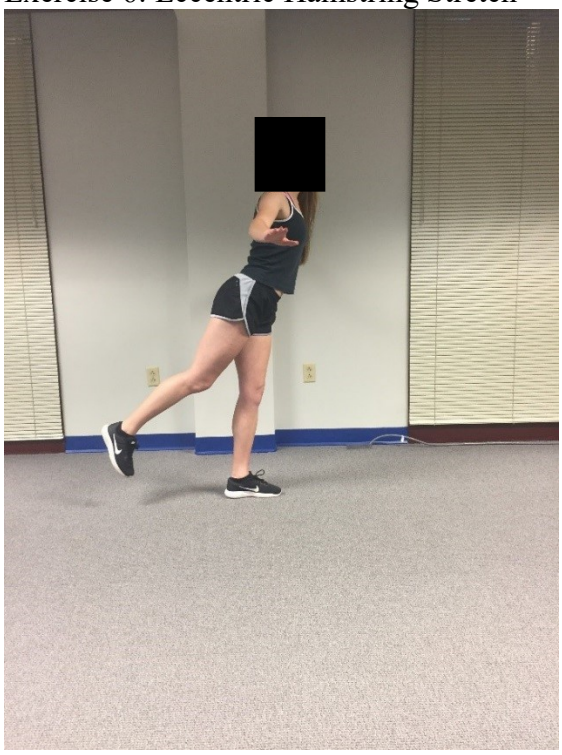
- Standing with your back against a wall and feet 18 inches from the wall.
- Slide down so that knees are slightly bent (~45°-60°).
- DO not go past 90°of knee flexion and keep your knees over your second toes.
- Hold for 15 seconds.

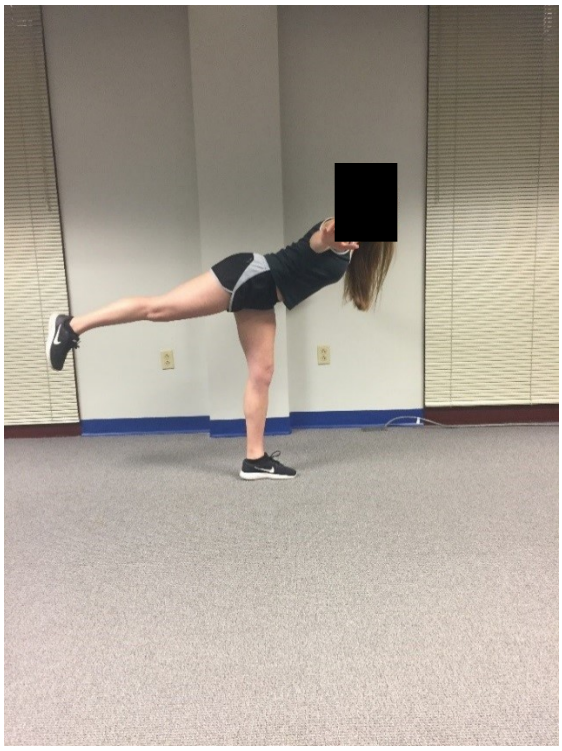
Exercise 5: Single leg balance



- Stand with your non-affected leg towards and touching the wall with feet shoulders width apart.
- Lean against a wall with your non-affected leg lifted to 90°.
- Isometrically press the non-affected leg against the wall.
- Balance on the affected leg with knee slightly bent and knee over second toe.
- Hold for 5 seconds.

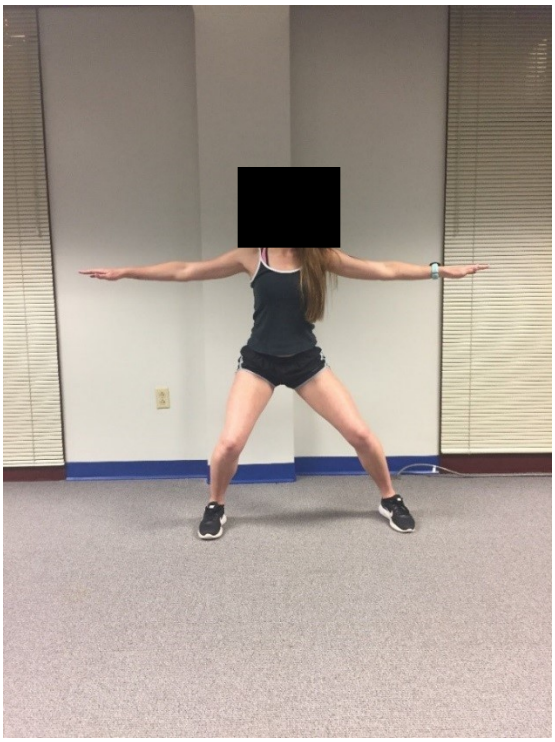
Exercise 6: Eccentric Hamstring Stretch





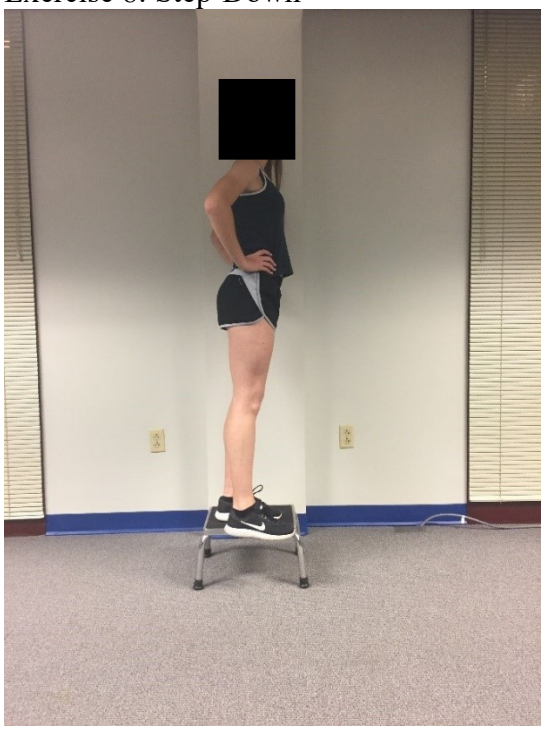
- Stand on the affected leg with knee slightly bent and arms out to side.
- Maintain a straight back and lean forward
- Extend the hip and knee trying to keep body parallel with the floor.
- Hold for 3 seconds.
- Slowly return to starting position.
- Perform on both sides.

Exercise 7: Side-to-Side Walk



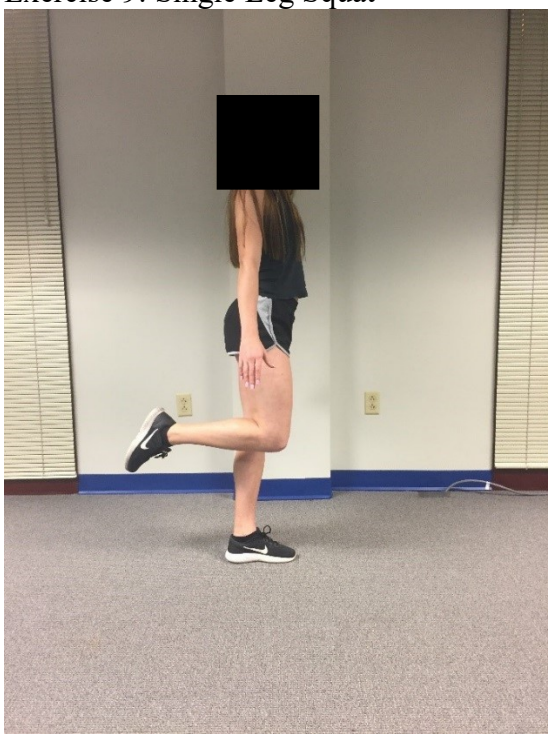
- Side-to-side walk with comfortable stance.
- Step width should maintain a balanced trunk and upper extremities.
- Do not overextend laterally.
- Maintain slightly bent knees (~45°-60°).
- Perform in both lateral directions for 15 feet.

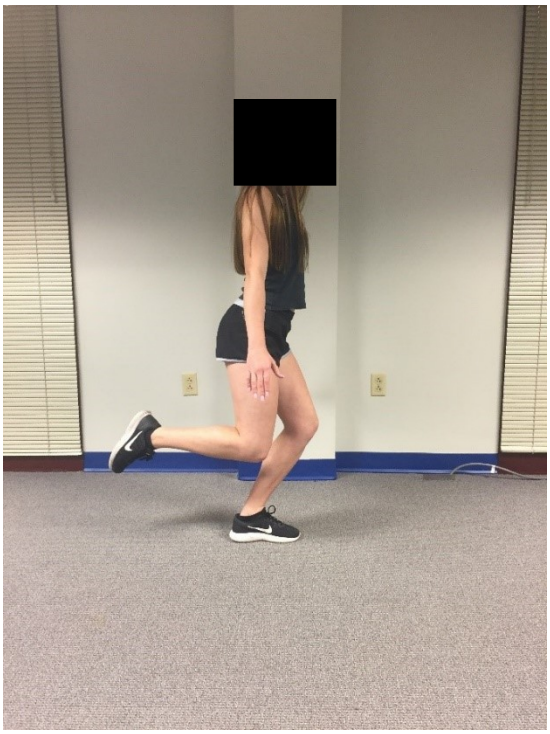
Exercise 8: Step-Down



- Stand on stool or raised surface.
- Maintain a straight back with unaffected leg off the stool or raised surface.
- Allow unaffected leg to drop until the heel touches the ground by bending the hip and knee.
- Keep your knee over your second toe.
- Return to starting position.

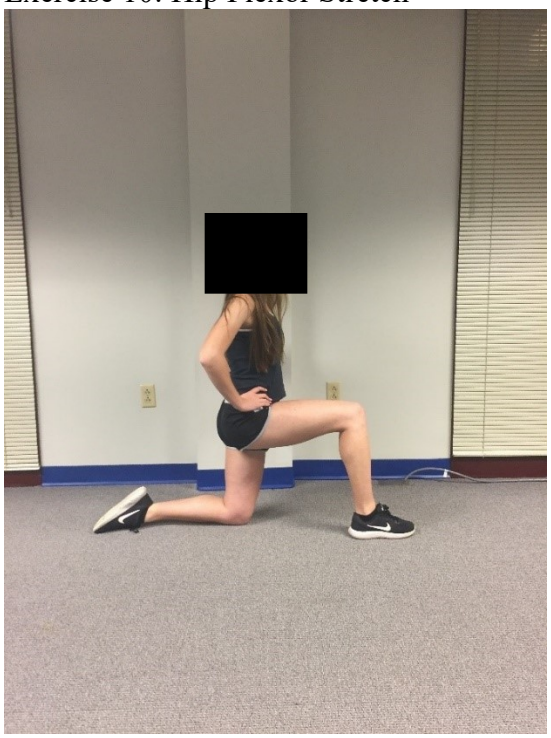
Exercise 9: Single Leg Squat

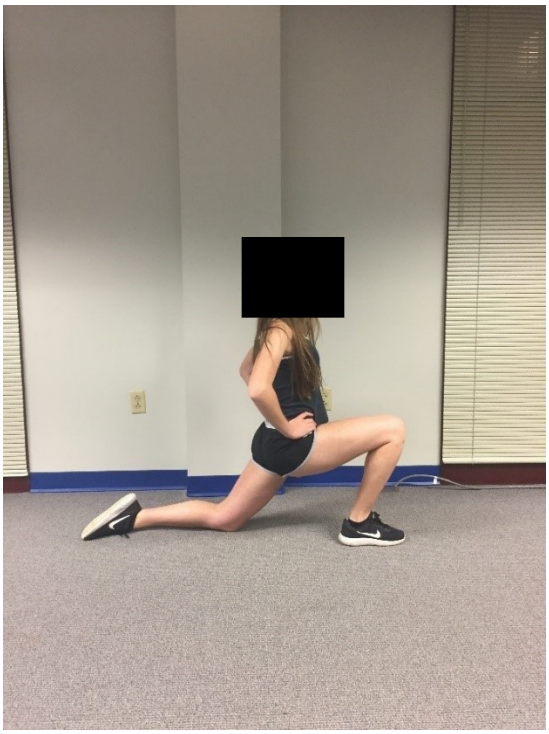




- Stand on the involved leg with back straight and opposite knee bent to 90°.
- Slightly bend your involved knee (~45°-60°) while keeping your knee over your second toe.
- Return to starting position.

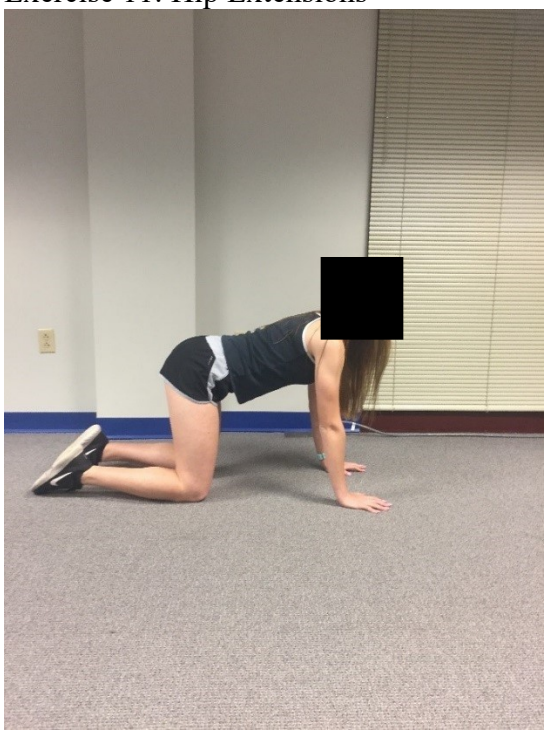
Exercise 10: Hip Flexor Stretch





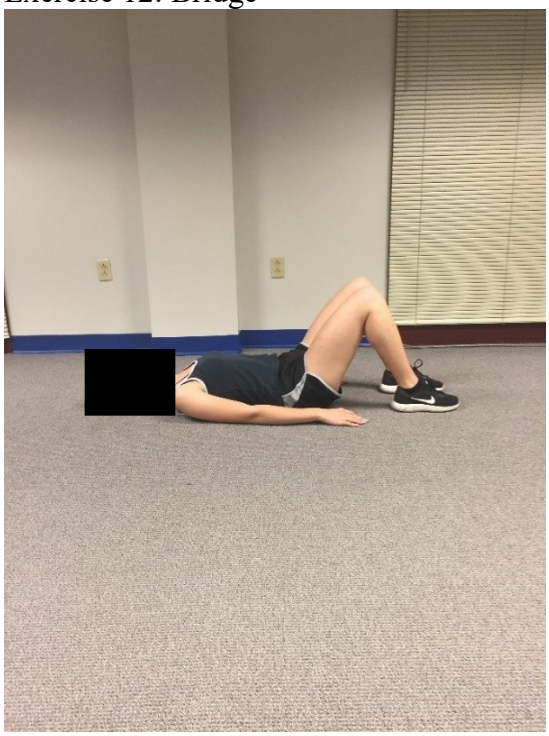
- Kneel on floor with a straight back.
- Lean forward until a stretch is felt.
- Do not let knee go in front of the toes.
- Hold for 5 seconds.
- Perform on both sides.

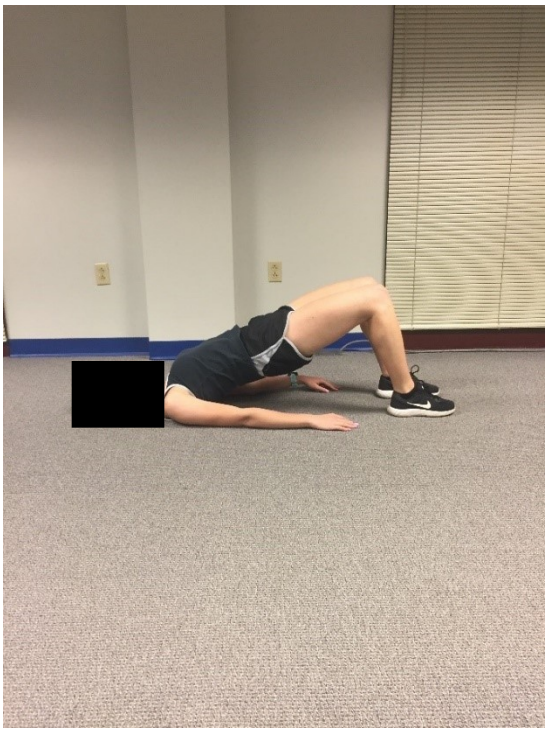
Exercise 11: Hip Extensions



- Begin on hands and knees.
- Maintain a straight back and contracted core.
- Extend leg while contracting gluteus muscles.
- Do not extend back or lift pelvis.
- Hold for 5 seconds.
- Perform on both sides.

Exercise 12: Bridge





- Lay on the ground with knees flexed.
- Lift hips as high as possible while maintaining a contracted core and gluteus muscles.
- Hold for 5 seconds.
- Lower to starting position.