THE EFFECT OF PRI PELVIC REPOSITIONING TECHNIQUE ON INNOMINATE ROTATION AND HIP RANGE OF MOTION

Carl A. White

A thesis submitted to the faculty of the University of North Carolina at Chapel Hill in partial fulfillment of the requirements for the degree of Masters of Arts in the Department of Exercise & Sport Science in the College of Arts and Sciences (Athletic Training).

Chapel Hill
2018

Approved By:

Meredith Petschauer

Erik Wikstrom

Kyeongtak Song

ABSTRACT

Carl A. White: Effect of PRI Repositioning Exercises on Innominate Rotation and Hip Range of Motion
(Under the direction of Meredith Petschauer)

Positional malalignment of the sacroiliac joint is a proposed mechanism of non-specific low back pain and a risk factor for lower extremity injury due to theoretical effects on hip range of motion. The Postural Restoration Institute™ (PRI) has introduced novel techniques for assessment and correction of these positional malalignments. Twenty-four subjects displaying a left anterior innominate rotation, as defined by the PRI, participated in two data collection sessions: a control session and an intervention session, where each subject completed a three-exercise pelvic repositioning series. Sagittal and transverse innominate rotation, measured by palpation-digitization, and hip range of motion were collected at three time-points in each session: before intervention, after intervention, and after walking one half-mile. Two-way repeated measures ANOVAs were used to examine interaction of session and time-point. A significant interaction ($p = .000$) between session and time-point was seen in left adduction range of motion and left total arc frontal plane range of motion. No interaction was observed in the sagittal or transverse innominate rotation angles. This finding supports the PRI's claim that left adduction range of motion can be increased through use of their repositioning series and provides support for clinical use of this technique in the treatment of hip and low back pain.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

3D	Three-dimensional
ACL	Anterior cruciate ligament
ADT	Adduction drop test
AIC	Anterior inferior chain
ASIS	Anterior superior iliac spine
BMI	Body-mass index
CAT	Computed axial tomography
ICC	Inter-class coefficient
LBP	Low back pain
LPHC	Lumbo-pelvic-hip complex
MDC	Minimal detectable change
MRI	Magnetic resonance imagery
PEC	Posterior exterior chain
PRI	Postural Restoration Institute
PSIS	Posterior superior iliac spine
ROM	Range of motion
RSA	Roentgen sterophotogrammetric analysis
SEM	Standard error of measurement
SIJ	Sacroiliac joint

CHAPTER 1: INTRODUCTION

Sacroiliac joint dysfunction is defined as degenerative change, positional malalignment, or kinematic fault of the sacroiliac joint (SIJ). SIJ dysfunction has been correlated with low back pain and limitation in hip range of motion, which has been identified as a risk factor for lower extremity injury. Low back pain and lower extremity injury are two common and costly medical conditions; low back pain is estimated to have a lifetime prevalence of 80% in the United States, and more than 50% of all injuries sustained in collegiate sports are lower extremity injuries.[16,26] Sacroiliac joint dysfunction has been hypothesized to be involved in as many as 55%-61.5% of cases of non-specific low back pain.[34] Deficit in hip range of motion has been associated with anterior cruciate ligament, hip, groin, and hamstring injuries, and is hypothesized to be involved in injury at the knee and ankle.[7,33,48]

Despite the relationship between SIJ dysfunction and these conditions, little research has been conducted examining the effects of positional malalignment or kinematic fault of the innominate. This is due in part to difficulty in measuring the small magnitude of sacroiliac motion, which has been measured to range between 0 and 8 degrees about three axes.[22] Valid and reliable techniques to assess sacroiliac joint motion include computed axial tomography (CAT) scans, Kirschner wires, or roentgen sterophotogrammetric analysis (RSA).[11-13] However, these techniques are all expensive, invasive, and clinically inapplicable. Clinically, assessments of SIJ malalignment involve palpation of bony landmarks of the pelvis. These techniques have been shown to be invalid and unreliable due to the difficulty of accurately palpating and comparing these landmarks bilaterally.[11-13,22] Recently, palpation-digitization analysis using an electromagnetic tracking device has been introduced as a reliable and accurate assessment of innominate position and motion.[1-5,11-13]

Despite the lack of support for palpation-based assessment, these techniques are widely used clinically alongside a variety of techniques designed to correct observed malalignments. These techniques include muscle energy techniques and mobilization or manipulation of the SIJ and lumbar spine. Recently, the Postural Restoration Institute™ (PRI) has popularized a novel approach for assessing positional malalignment of the SIJ. PRI hypothesizes that anterior rotation of the left innominate is a natural resting position of the body, due to asymmetry of the diaphragm and viscera in the abdominal cavity. The PRI approach involves assessing innominate positioning through examination of concomitant changes in hip adduction range of motion. PRI also proposes a novel series of isometric exercises to correct for this common malalignment, focused on recruitment of abdominal, hamstring, gluteal, and adductor muscles to correct innominate position, which allows for greater hip range of motion. However, research is needed to support this theoretical basis of this approach. Namely, the ability of these repositioning exercises to correct innominate positioning, and the ability of these repositioning exercises to alter hip range of motion must be supported to validate the widespread clinical use of the technique.[27-28]

Through the use of the palpation-digitization technique, this study aims to accurately measure changes in innominate rotation at the sacroiliac joint after completion of PRI repositioning series in patients displaying an anteriorly rotated left innominate. This study also aims to correlate innominate positioning to the arc of hip range of motion in the sagittal, transverse, and frontal planes by measuring changes in these joint motions after completion of the repositioning technique.

Clinical Significance

This study will build the base of evidence for a popular technique with varied and important clinical uses. If supported, this technique provides a method to assess and correct positional malalignments that can be a causative factor of low back pain as well as a number of other hip and pelvic pathologies. This technique is clinician-friendly, as it does not require specialized equipment and can be adapted to a varied patient population. If supported, assessment of pelvic alignment through its effect on range of motion could be a welcome alternative to the inaccurate and unreliable palpation assessment. This technique could also provide a method of correcting asymmetries in hip range of motion, which may decrease the risk of lower extremity injury.

Research Questions and Hypotheses:

RQ1: Is palpation-digitization using an electromagnetic tracking system a reliable method for assessing transverse and sagittal innominate rotation?

RH1: We hypothesize that palpation-digitization using an electromagnetic tracking system will be a reliable method for assessing transverse and sagittal innominate rotation.

RQ2: Does completion of PRI pelvic repositioning technique affect hip range of motion in individuals displaying a left anterior innominate rotation more than rest?

RQ2a: Does completion of PRI pelvic repositioning technique change hip frontal plane range of motion in individuals displaying a left anterior innominate rotation more than rest?

RH2a: We hypothesize that completion of PRI pelvic repositioning technique will increase the angle of left hip adduction range of motion and decrease the angle of left hip abduction range of motion, but will not alter total arc frontal plane range of motion in individuals displaying a left anterior innominate rotation more than rest.

RQ2b: Does completion PRI pelvic repositioning change hip transverse plane range of motion in individuals displaying a left anterior innominate rotation more than rest?

RH2b: We hypothesize that completion of PRI pelvic repositioning technique will increase the angle of left hip internal rotation range of motion and decrease the angle of left hip external rotation range of motion, but will not alter total arc transverse plane range of motion in individuals displaying a left anterior innominate rotation more than rest.

RQ2c: Does PRI pelvic repositioning change hip sagittal plane range of motion in individuals displaying a left anterior innominate rotation more than rest?

RH2c: We hypothesize that completion of PRI pelvic repositioning technique will increase the angle of left hip extension range of motion and decrease the angle of left hip flexion range of motion, but will not alter total arc sagittal plane range of motion in individuals displaying a left anterior innominate rotation more than rest.

RQ3: Does completion of PRI pelvic repositioning technique change the angles of sagittal and transverse innominate rotation in individuals displaying a left anterior innominate rotation more than rest?

$RQ3_a$: Does completion of PRI pelvic repositioning technique change the angles of sagittal and transverse left innominate rotation in individuals displaying a left anterior innominate rotation more than rest?

$RH3_a$: We hypothesize that completion of PRI pelvic repositioning technique will decrease the angles of sagittal and transverse left innominate rotation in individuals displaying a left anterior innominate rotation more than rest.

RQ3$_b$: Does completion of PRI pelvic repositioning technique change the angles of sagittal and transverse right innominate rotation in individuals displaying a left anterior innominate rotation more than rest?

RH3$_b$: We hypothesize that completion of PRI pelvic repositioning technique will not change the angles of sagittal and transverse right innominate rotation in individuals displaying a left anterior innominate rotation more than rest.

RQ3$_c$: Does completion of PRI pelvic repositioning technique change the difference between left and right sagittal and transverse innominate rotation angles in individuals displaying a left anterior innominate rotation more than rest?

RH3$_c$: We hypothesize that completion of PRI pelvic repositioning technique will decrease the difference between left and right sagittal and transverse innominate rotation angles in individuals displaying a left anterior innominate rotation more than rest.

RQ4: Does walking one half mile immediately change left hip range of motion in individuals displaying a left anterior innominate rotation after completion of PRI repositioning technique?

RQ4$_a$: Does walking one half mile change hip frontal plane range of motion in individuals displaying a left anterior innominate rotation after completion of PRI repositioning technique?

RH4$_a$: We hypothesize that walking one half mile will not change right or left hip adduction, adduction, or total arc abduction and adduction range of motion in individuals displaying a left anterior innominate rotation after completion of PRI repositioning technique.

RQ4$_b$: Does walking one half mile change hip transverse plane range of motion in individuals displaying a left anterior innominate rotation after completion of PRI repositioning technique?

RH4$_b$: We hypothesize that walking one half mile will not change right or left hip internal rotation, external rotation, or total arc internal and external rotation range of motion in individuals displaying a left anterior innominate rotation after completion of PRI repositioning technique.

RQ4$_c$: Does walking one half mile change hip frontal plane range of motion in individuals displaying a left anterior innominate rotation after completion of PRI repositioning technique?

RH4$_c$: We hypothesize that walking one half mile will not change right or left hip flexion, extension, or total arc flexion and extension range of motion in individuals displaying a left anterior innominate rotation after completion of PRI repositioning technique.

RQ5: Does walking one half mile immediately change the angle of left or right sagittal and transverse innominate rotation in individuals displaying a left anterior innominate rotation after completion of PRI repositioning technique?

RH5: We hypothesize that walking one half mile will not change the angles of left or right sagittal and transverse innominate rotation in individuals displaying a left anterior innominate rotation after completion of PRI repositioning technique.

RQ6: Does completion of PRI repositioning technique result in an increase the adduction range of motion of the left hip, as examined by a change in outcome of the left Adduction Drop Test?

RH6: We hypothesize that completion of PRI repositioning technique will result in an increase in the adduction range of motion of the left hip, as examined by a change in outcome of the left Adduction Drop Test.

RQ7: Does walking one half-mile result in a change in left hip adduction range of motion, as examined by a change in outcome of the left Adduction Drop Test, after completion of PRI repositioning technique?

RH7: We hypothesize that walking one half-mile will not result in a change in left hip adduction range of motion, as examined by a change in outcome of the left Adduction Drop test, after completion of PRI repositioning technique.

CHAPTER 2: REVIEW OF LITERATURE

The sacroiliac joint (SIJ) is a complex joint with great impact on the kinematics of the lumbo-pelvic-hip complex due to its influence on the positioning of the innominates. Proper mobility at the SIJ is integral for both femoro-acetabular and lumbo-pelvic motion. Low back pain and lower extremity injury are two common and costly medical conditions associated with positional faults of the SIJ. Positional malalignments of the SIJ have historically been diagnosed clinically through palpation techniques, but these tests have been shown to be unreliable, insensitive, and unspecific due to the difficulty in assessing the small magnitude of motion present at the SIJ. There are also many proposed interventions to correct for positional faults, but there is a paucity of research supporting the ability of these techniques to alter the bony positioning of the innominates. Recently, the Postural Restoration Institute™ has popularized a technique to assess and correct positional malalignments at the SIJ. In order to fully understand the mechanics of SIJ movement, this review will explore the functional anatomy of the pelvis, sacrum, and SIJ. This review will then discuss the theoretical and empirical links between the SIJ, low back pain and lower extremity injury, as well as the epidemiology and societal costs of both of these conditions. This review will also discuss the effectiveness of various techniques currently used to diagnose positional malalignment of the SIJ. Finally, the theoretical basis of the PRI techniques will be explored to make a case for examination of these techniques.

Functional Anatomy of the SIJ

The classification of the SIJ has been a point of contention in literature. Once believed to be synarthroses, SIJ were later classified as diarthroses between the sacrum and the ilia.[31]

However, more recent magnetic resonance imagery (MRI) and microscopic examination has prompted a reevaluation of this classification. Puhakka, et al., describe the SIJ to be a "symphysis with some characteristics of a synovial joint;" the proximal portion two-thirds of the joint are defined by the thick, intertwined fibrocartilage and ligaments of the ilium and the sacrum, while the distal one-third possesses an "inner capsule with synovial cells," on MR imagining and microscopy.[40] However, a wide variation in SIJ anatomy has been observed. In the same study, Puhakka, et al., noted that the transition between the proximal and distal portions of the sacroiliac joint was "microscopically rich in anatomical variants," including "osseus clefts, cartilage, and subchondral defects."[40] Differences in SIJ anatomy between sexes has also been observed. Articular surfaces in the female SIJ have been determined to be smoother, shorter, and more angled than in males. These adaptations decrease friction and allow for more motion at the SIJ, which is thought to allow for adaptions in bony geometry in pregnancy and childbirth.[13] Thus, significant differences in SIJ range of motion have been observed between males and females.[13] Similarly, significant differences in motion have been observed between self-reported "dominant" and contralateral leg, suggesting that some variability in SIJ motion may be due to patterns of use.[11-13]

Examination of joint motion has revealed that the joint moves about three different axes: the transverse (X-) axis, which courses through the right and left posterior superior iliac spine (PSIS), the sagittal (Z-) axis, which courses anterior-posterior midway between the anterior superior iliac spines (ASIS), and the longitudinal (Y-) axis, which courses superior-inferior through the midline of the sacrum. Translation and rotation of the sacrum exist upon each of these axes, giving the joint six degrees of freedom. In a review of in-vivo and in-vitro studies of SIJ motion, rotation along each axis ranged from -1.1 to 2.2 degrees along the X-axis, -0.8 to 4.0

degrees along the Y-axis, and -0.5 to 8.0 degrees along the Z-axis. Translation ranged from -0.3 to 8.0mm along the X-axis, -0.2 to 7.0mm along the Y-axis, and -0.3 to 6.0mm along the Z-axis.[22] Due to the complex shape, articular structure, and anatomy of the SIJ, and despite the small magnitude of movement in each plane, these planar motions work in coordination to produce difficult-to-measure three dimensional (3D) motions of the innominate on the sacrum. The small magnitude of these motions also suggests that any deviation of the sacrum beyond its narrow range of motion could be a painful and important event.

Four positional malalignments of the innominate associated with SIJ dysfunction have been described: 1.) unilateral anterior tilt of one innominate bone, 2.) unilateral posterior tilt of one innominate bone, 3.) bilateral, antagonistic tilt of both innominates (one posteriorly tilted, one anteriorly tilted), and 4.) bilateral anterior tilt of both innominates, which is referred to as pelvic torsion.[14-15] However, the biomechanical causes and effects of these positional faults have been underexamined. There is evidence that pelvic torsion is a common compensation for individuals with an anatomical leg length discrepancy.[15,29] In individuals with positional malalignment but without evidence of a leg length discrepancy, the prevailing theory of malalignment causation is that a muscular imbalance, coupled with hypermobility of the SIJ, can cause lasting abnormal rotation of one or both innominates.[14,47]

It is theorized that rotation of the innominate could have effects on femoro-acetabular kinematics by 1.) altering the length-tension relationship of muscles crossing the SIJ and femoro-acetabular joint and 2.) altering the positioning of the acetabulum. The piriformis, which originates on the anterior surface of the sacrum and inserts on the greater tubercle of the femur, is hypothesized to be a muscle with great influence on lumbo-pelvic-hip stability due to its line of force across both joints and role as a stabilizer of rotation in the transverse plane.[32] There is also some evidence connecting piriformis cross-sectional area, a measure associated with muscular strength and endurance, and low back pain, supporting the theory that the piriformis could play an undiscovered role in pelvic bony kinematics.[32] The gluteus maximus also crosses both the SIJ and the femoro-acetabular joint, and thus is hypothesized to be an additional influence on the positioning of the SIJ. The transverse abdominus, among other muscles involved in "local" stability of the lumbo-pelvic-hip complex, has also been theorized to influence and stabilize the sacroiliac joint, but Gnat, et al., were unable to find a change in innominate rotation with transverse abdominus contraction.[21] Likewise, change to the innominate position could influence the line of force and function of muscles crossing the femoro-acetabular joint. Specifically, alteration to the line of pull of the obdurator internus, an important muscle for stabilization of the femoro-acetabular joint, could significantly decrease its ability to provide dynamic stabilization of the femoral head.[25]

Femoro-acetabular Motion

The femoro-acetabular joint, or hip joint, is the articulation between the innominate and the femur. This joint is a ball-and-socket joint which allows for motion in the transverse, frontal, and sagittal planes. The innominate is comprised of three bones, the ilium, the ischium, and the pubis, which fuse together to form the acetabulum, the socket of the hip joint. Motion at the femoro-acetabular joint occurs in three planes: abduction and adduction in the frontal plane, internal and external rotation in the transverse plane, and flexion and extension in the sagittal plane. Measurement of the range of motion in these planes using a goniometer has shown high intra- and inter-rater reliability, but low validity as compared to measurement via electromagnetic tracking systems. However, this high reliability supports the use of goniometers in longitudinal analyses.[38]

Recently, the "total motion concept" has been popularized with regard to shoulder joint motion. This concept involves summing each motion to find the total arc range of motion for each plane. In the shoulder, differences in internal rotation range of motion between the dominant and non-dominant limb are common. However, the total arc internal and external range of motion remains equal between limbs.[50] This principle has been applied to rotational motion at the hip, as hip rotational motion has shown similar adaptations to limb dominance in baseball and tennis players.[33] Comparison of total arc range of motion offers another useful comparison between potentially asymmetric limbs.

The point of limitation in each range of motion may be due to soft tissue approximation, tension in the capsulo-ligamentous or muscular structures, or bony approximation. Recently, acetabular position has been found to be an important factor in range of motion limitations. Changes in acetabular position, due to unilateral or bilateral innominate tilt, may influence tension on capsulo-ligamentous structures or approximation of the femoral head-neck junction and the acetabulum. Ross, et al., concluded that dynamic changes in pelvic tilt "significantly influence the functional orientation of the acetabulum," causing decreases in internal rotation range of motion in subjects displaying an anterior pelvic tilt.[44] Similarly, Bagwell, et al., found a 1.2-1.6 degree increase of closed-kinetic-chain femoro-acetabular internal rotation for every 5-degree increase in anterior pelvic tilt as well as a converse relationship between posterior pelvic tilt and external rotation.[6] This suggests that altered pelvic control or positioning has the potential to influence transverse plane range of motion at the femoro-acetabular joint.[6]

Pathology and Epidemiology

It is theorized that sacroiliac dysfunction, defined as degenerative changes, positional malalignments or kinematic faults at the SIJ, is one of the leading causative factors of non-specific low back pain. Non-specific low back pain is defined as back pain with no known underlying pathology, which makes up 90%-95% of all diagnosed low back pain.[30] Low back pain is one of the most common and most costly musculoskeletal conditions, with point and lifetime prevalence estimated at 15% and 80%, respectively, and causes an estimated $12.2-$90.6 billion in direct costs and $7.4-$28.2 billion in indirect costs per year in the United States.[16] Through confirmation via intra-articular injections, SIJ dysfunction has shown to be involved in a minimum of 15%-30% of low back pain[44], but some estimates based on clinical provocation tests have found SIJ dysfunction to be involved to as high as 55%-61.5% of low back pain[34]. In a study of patients suffering from low back pain resulting from SIJ dysfunction, Adhia et al., found significant differences in innominate movement patterns between groups.[3-4] While it is difficult to separate cause and effect of low back pain of sacroiliac origin and innominate positional or kinematic abnormalities, there is a clear and strong correlation between the two conditions.

Likewise, there is evidence of a correlation between limited hip range of motion (ROM), especially hip rotation, and low back pain. It is theorized that this correlation could be due to dysfunction of the SIJ, which is the direct connection between the femoro-acetabular joint and the lumbar spine, or that low back pain could be a result of compensation for limitations in rotation at the hip.[23] Some have also postulated that muscular imbalances in the piriformis, which crosses both the SIJ and the femoro-acetabular joint, could cause movement deficiencies at both joints.[14,47] LaBan, et al., found a more direct correlation between SIJ dysfunction and hip rotational range of motion; patients with unilateral SIJ pain were found to have asymmetry of hip rotation ROM on the symptomatic side as compared to the contralateral limb.[23] Cibulka et al., also found asymmetries in hip rotation range of motion in patients with low back pain due to SIJ dysfunction and connected this asymmetry to a specific positional malalignment of sacroiliac joint. Specifically, patients identified to have a posteriorly rotated innominate via palpation techniques were found to have a greater asymmetry of internal and external rotation on the posteriorly rotated side as compared to the contralateral side.[14]

Hip rotation range of motion deficits have been identified as significant risk factors for lower extremity injury, so any contributing factors and proposed interventions should be thoroughly researched. These deficits may alter the kinematics of the lower extremity, predisposing athletes to lower extremity injuries. Lower extremity injuries are highly prevalent among athletes at the recreational, high school, collegiate, and professional levels and account for over 50% of all musculoskeletal injuries at the collegiate level.[26] A majority of these injuries are non-contact in nature, suggesting that these injuries may be caused by faulty movement patterns.[26] Any positional malalignment affecting the dynamic control of the hip joint could lead to injurious biomechanics.[19] Reduced hip total arc rotation range of motion and hip internal rotation range of motion have been found to be predictive measures for anterior cruciate ligament (ACL), hip, groin, and hamstring injuries.[7,33,48] ACL injuries, 70% of which are non-contact, pose a great cost to society, with the lifetime costs averaging $38,121 per injury with surgical reconstruction and $88,538 per injury with conservative management.[26,35] Hamstring strains are the most common muscle strains in athletes, with an injury rate of 3.05 per 10,000 athlete-exposures at the collegiate level.[17] Groin injuries are estimated to be 2%-5% of all athletic injuries, are especially common in soccer and hockey athletes, comprising an estimated 10%-11% of all injuries in these sports.[45]

Evaluation Techniques

Diagnosis of SIJ dysfunction can be divided into two categories: diagnosis via diagnostic tools and diagnosis via clinical evaluation. Current diagnostic tools used include computerized axial tomography (CAT) scans, roentgen sterophotogrammetric analysis (RSA), and Kirschner wires to assess positional and kinematic dysfunction, and intra-articular nerve blocks to diagnose painful conditions of unknown origin.[11-13] While each of these methods is accurate, these methods are all costly, invasive, and impractical in the clinical setting. The current clinical technique of assessing positional malalignments relies on clinician ability to locate bony structures like the ASIS, PSIS, and iliac crests through palpation and compare their position. Another common technique involves bilateral comparison of the medial malleoli, as functional leg length discrepancies are believed to be a compensation with unilateral rotation of the innominate, or that innominate malalignment presents as a compensation for a leg length discrepancy.[15] Movement faults are clinically assessed via palpation of the same structures while the patient flexes or extends at the hip. Comparison of these techniques and diagnostic imaging, such as RSA, has proven these techniques to be unreliable and inaccurate. Further attempts at objectifying the difference in bony landmark positioning, such as use of inclinometers or potentiometers, have proven similarly inadequate.[1-5,11-13,22]

Recently, palpation-digitization using an electromagnetic tracking device has been introduced as a reliable and accurate assessment of innominate position and motion.[11-13] This technique is not invasive, does not expose the subject to radiation, and can provide real-time feedback to researchers and clinicians. Studies have been conducted to establish the validity, intra-rater reliability, and inter-rater reliability of this assessment.[1-5,11-13] This technique has been shown to be valid and to possess a high level of intra-rater reliability.[1-3] However, there is not currently enough evidence to confirm inter-reliability of the technique.[1-3]

Clinical Interventions

Manipulations of the SIJ and lumbar spine and specific manual therapy techniques, such as muscle energy techniques, have been commonly used to correct positional malalignments clinically. Cibulka et al., found significant displacement in pelvic landmarks before and after manipulation of the SIJ, but the SIJ position in this study was assessed via palpation, not via the objective measures discussed above.[14] Muscle energy techniques utilize isometric contractions of the muscles acting on the pelvis to restore a neutral position. Commonly, these include the hip adductors and abductors, as well as the hamstrings and quadriceps. These techniques are highly variable across clinicians, making unbiased clinical trials difficult to conduct. While these techniques are popular in the clinical setting, there is no evidence to support use of these techniques to improve patient outcomes. To date, there is no examination on the effect of muscle energy technique on the SIJ positioning.[20]

Theoretical Basis of Postural Restoration

The Postural Restoration Institute™ (PRI), founded by Ron Hruska, DPT., has proposed a novel method for assessing and correcting innominate postural malalignment and expanded upon theories regarding the importance of SIJ position on mechanics of the lower extremity. PRI assessment and correctional techniques, which are taught in courses around the United States, present a potentially valuable approach to assessing and correcting innominate position and rotation. The proposed techniques are very clinician-friendly; they do not require specialized equipment, and they can be applied to a diverse patient population.

The theoretical basis of the PRI approach centers on the body's inherent asymmetry and resulting patterned neuromuscular imbalances. PRI postulates that the asymmetry of the diaphragm, lungs, heart, brain, and visual system creates a predictable pattern of muscular imbalances and dysfunctional movements throughout the body.[27-28,42] PRI identifies these imbalances as over-activity of certain poly-articular chains of muscle, which present in predictable and uniform ways across all populations without a congenital condition altering organ position, such as situs inversus.[27-28] Two of the proposed muscular imbalances, dominance of the left anterior inferior chain (Left AIC) or posterior exterior chain (PEC), present with unilateral or bilateral anterior rotation of the innominate, respectively.[27-28] The PRI postulates that muscle activity and range of motion in the sagittal, frontal, and transverse planes at the hip joint are altered by this malalignment, and restoration of proper alignment is the cornerstone to successful treatment of all patients presenting with issues in the lower extremity. Despite the exciting, global claims made and taught by the PRI, there is very little evidence to support these claims. The anatomical effects and patient outcomes must be researched before adoption of such techniques.

Postural Restoration Evaluation and Intervention

The PRI evaluation of innominate position depends on the assumption that innominate malalignment affects range of motion at the femoro-acetabular joint. Specifically, PRI proposes that innominate position can be extrapolated from the ability of the femur to adduct on the acetabulum. In this proposed mechanism, abnormal innominate positioning rotates the acetabulum, altering its bony congruity with the femoral head and producing a bony block in adduction.[27-28,42] The test, called the Adduction Drop Test (ADT), is a variation of Ober's test for iliotibial band tightness; the subject is side-lying, with hips and knee flexed to 90 degrees, and the top limb is extended to zero degrees and passively adducted towards the table. Inability to adduct is evidence of malalignment of the innominate, a predictable patterned response to the proposed muscle chain imbalances. A series of case reports has supported this claim, but no clinical testing comparing adduction range of motion in this testing position to innominate position has been conducted.[8,27-28,42]

The PRI also proposes novel techniques to correct for this malalignment. PRI repositioning techniques, the centerpiece of their approach, are presented for each of the common muscle imbalances proposed. Treatment of the left AIC pattern, which is said to be the most common, involves isometric contraction of the hamstrings and abdominals with diaphragmatic breathing, and activation exercises for the left adductor group and right gluteus maximus.[27-28] Successful implementation of these exercises is stated to correct innominate malalignment and restore proper range of motion at the hip joint.[27-28] This change should be immediate, and can quickly be assessed by recompletion of the Adduction Drop Test. Similarly, this effect has not been well-evidenced outside of case reports.[8,43] In one non-controlled study of the effect of the repositioning technique on patients with lumbopelvic pain, significant differences in adduction range of motion in the testing position were observed as well as significant decreases in patient-reported Numeric Pain Scale responses.[42] Again, no objective measurement of innominate rotation before or after these proposed repositioning exercises has been attempted.

CHAPTER 3: METHODOLOGY

Research Design

This study was conducted as a cross-sectional within-individuals comparison study. Each subject completed a control session and an interventional session. Passive hip range of motion and innominate rotation measurements were compared within individuals before and after completing an intervention of PRI repositioning exercises.

Participants

Twenty-four individuals, aged 18-35, who were in good general health, participated in this study. Participants were free of hip or low back injury at the time of data collection and for a minimum of six months prior to data collection and participated in a minimum of thirty minutes of exercise three times in one week. Participants were excluded if they reported a history of low-back or hip surgery, a current, symptomatic hip or low back injury or a history of such injury in the last sixmonths, a leg length discrepancy of greater than 2 cm, or reported a pregnancy or the possibility of pregnancy. All participants were screened for innominate rotation before recruitment; only participants who presented with left Anterior Interior Chain dominance, or left anterior innominate rotation, as defined by the Postural Restoration Institute were recruited for data collection. All participants read and signed an informed consent form approved by the Institutional Review Board of the University of North Carolina at Chapel Hill.

Instrumentation

The TrackStar electromagnetic motion-analysis system (Version 8.0; Ascension Technology Corporation, Burlington, VT, USA) was used to collect innominate rotation data.

Data was collected using Motion Monitor capture and analysis software via an A/D board. Lower extremity passive range of motion was measured using a digital inclinometer (Sanders Group, Inc., Chaska, MN, USA) and a standard 8-inch plastic goniometer.

Procedures

Participants reported to the Sports Medicine Research Laboratory for a screening session and returned within one week for two consecutive days of testing sessions wearing their own athletic shorts, shirt, and shoes suitable for walking one-half mile. Each participant completed the Control Session on the first day of data collection and returned for the Intervention Session on the following day. Data collection was scheduled as close to exactly twenty-four hours apart as schedules allowed; all data collection was conducted later than twenty-two hours after the start of the first session and earlier than twenty-six hours after the start of the first session. An outline of the data collection procedure can be visualized in figure 1.

Screening Protocol

The left Anterior Interior Chain dominance screening protocol consisted of three trials of the Adduction Drop Test, as defined in the Myokinematic Restoration course manual (Hruska), on each limb. The participant laid on his or her side with the hip and knee of the lower leg flexed to 90 degrees. The examiner passively flexed the knee to 90 degrees and passively flexed, abducted, and extended the hip to neutral while maintaining 90 degrees of knee flexion and pelvic stabilization. The examiner ensured the top innominate was positioned directly over the bottom innominate to limit femoral internal rotation. A positive test is indicated by the inability of the top femur to adduct on the acetabulum; the medial epicondyle of the top leg is unable to cross the plane of the femur of the bottom leg. A positive Adduction Drop Test on the left limb with a negative adduction drop test on the right indicates a left anteriorly rotated pelvis.

Participants with three consecutive positive tests on the left limb and three consecutive negative tests on the right limb were considered for data collection.

Experimental Protocol

Prior to the start of each session, participants were outfitted with electromagnetic sensors over the sacrum and the lateral aspect of each thigh. Sacral sensor position was determined by bisecting a line between the right and left PSIS; the sensor was fixed to a one-inch by one-inch square of Orthoplast and affixed to the sacrum one inch below this line. Bilateral PSIS and the superior and inferior borders of the Orthoplast were marked with dry-erase marker to ensure proper replacement of the sensor. Sensors were secured with athletic tape. The x-y-z global axes were established according to the right-hand three-dimensional Cartesian coordinate system. The positive x-axis was designated forward, the positive y-axis to the left, and the positive z-axis upward, relative to the participant. The ASIS and PSIS were palpated and digitized bilaterally using MotionMonitor software; three-dimensional coordinates of these bony landmarks were estimated using MotionMonitor software. A single examiner conducted all palpation and digitization of the ASIS and PSIS. All sensors were removed in between data collection time-points.

Innominate Rotation Angles

Innominate rotation was measured with the subject standing in a neutral position with feet facing forward and shoulder-width apart. World axes, stylus length, and sensor position were calibrated at the start of each day of data collection but were not re-calibrated if more than one data collection session was conducted consecutively on a given day. The subject was instructed to march in place for a period of five to ten seconds and come to a stop in a comfortable standing position. A single examiner then palpated and digitized the right and left ASIS and PSIS using the stylus, and a trial of these location data was recorded. Data was sampled at 140Hz for a five-second window; the Cartesian coordinates of each bony landmark were sampled at the midpoint of five seconds of neutral stance. From these coordinates, vectors were calculated between each ASIS and PSIS and both PSIS in the transverse and sagittal planes. After recording, the subject was re-digitized for three more measures, and vectors were recalculated; the average of four innominate rotation angles was used for each assessment.

The angle of sagittal innominate rotation was defined as the angle between the ASIS-PSIS vector and the x-axis in the sagittal plane. The angle of transverse innominate rotation was defined as the angle between the ASIS-PSIS vector and a line perpendicular to the PSIS-PSIS vector in the transverse plane. Visual representations of these angles are presented in Figures 2 and 3, respectively. Both angles were recorded for the right and left hips. The difference between right and left transverse and sagittal innominate rotation angles was calculated and recorded.

Passive Range of Motion and Adduction Drop Test

Passive ranges of motion were measured for hip internal rotation, hip external rotation, hip abduction, hip adduction, hip flexion, and hip extension. The testing procedures utilized for each range of motion measurement are described in Table 1. Each range of motion measurement was conducted three times; the mean of each measure was recorded. The Adduction Drop Test was conducted as described in the screening protocol. A single examiner, trained and experienced in analysis of lower extremity range of motion, measured all hip ranges of motion throughout the data collection protocol.

Experimental Protocol: Control Session

The control session for each participant began with measurement of each outcome measure: innominate rotation angles, passive hip range of motion, and the adduction drop test.

The participant then rested on the plinth for a period of twenty minutes, equal to the time of the intervention. The examiner then re-measured all outcome measures. The participant then walked on a treadmill at a self-selected speed for one half-mile. The participant returned to the plinth, and the examiner measured outcome measures for the final time. All sensors were removed from the subject between assessments. The subject was instructed to avoid high-intensity physical activity or physical activity that deviates from their normal exercise schedule in between data collection sessions.

Experimental Protocol: Intervention Session

The intervention session for each participant began with measurement of each outcome measure: innominate rotation angles, passive hip range of motion, and the adduction drop test. A single examiner led all intervention exercises. This examiner was certified as completing the Myokinematic Restoration and Pelvis Restoration courses through the Postural Restoration Institute and had three years of experience in prescribing and directing PRI intervention exercises. First, the examiner instructed the subject to take three deep breaths in a supine, hook-lying position. The examiner viewed the subject's breathing technique and provided cues to improve diaphragmatic breathing, such as "breathe in through your nose and out through your mouth," "have your chest and stomach rise and fall together," "exhale as if you were blowing up a balloon," and "think about rounding out your spine into the table." The subject then completed three more diaphragmatic breaths to ensure retention of cuing. The examiner then led the participant through an intervention of three exercises designed to correct left anterior innominate rotation.

The exercises completed were the 90-90 Hip Lift, Right Sidelying Adductor Pull Back, and Left Sidelying Right Glute Max, as listed in the Myokinematic Restoration course manual.[27]

The 90-90 Hip Lift was completed with the participants' heels resting on a wooden block; the participant then performed isometric bilateral hamstring contraction and posterior pelvic tilting while completing diaphragmatic breathing. The Right Sidelying Left Adductor Pull Back was completed in a hook-lying position on the subject's right side, with the participant completing isometric left adductor contraction with diaphragmatic breathing. The Left Sidelying Right Glute Max was completed in a hook-lying position on the patient's left side, with the participant completing isometric right gluteus maximus contraction into a resistance band (Theraband, Akron, OH, USA) with diaphragmatic breathing. Four sets of four breaths (repetitions) of each exercise were completed. The examiner instructed the subject directly from the Myokinematic Restoration Manual.[27] During each exercise, the examiner provided feedback, such as cuing to expel all air from lungs, round out the back, and maintain isometric contractions, during each exercise to ensure proper completion.

After the intervention, the examiner re-measured all outcome measures. The participant then walked on a treadmill at a self-selected speed for one half-mile, equal to the speed selected during the control session. The participant returned to the plinth, and the examiner measured outcome measures for a final time. All sensors were removed from the subject between assessments.

Statistical Analysis

An interclass correlation coefficient (ICC) was calculated for each measure within and between days of measurement. Coefficients of 0.75 or higher considered to be good-to-excellent, and coefficients of 0.75 or lower considered to be poor-to-moderate. The within-session ICC was calculated between the pre-control and post-control time-points. The between-sessions ICC was calculated between the pre-control and pre-intervention time-points. These ICC values were used in analysis of research question 1.

For research questions 2 through 5, two-way (time-point, session) repeated measures ANOVAs were used to analyze the variance between time-points of collection for both the hip range of motion measures and the innominate rotation angle measures. Bonferroni pairwise comparisons were used to further determine differences in the presence of a significant time x intervention interaction. The alpha level for inferential statistical tests was set at $p = 0.05$.

The standard error of measurement (SEM) and minimal detectable change (MDC) was also calculated to provide a measure of variability. SEM values were calculated as follows: $SEM = SD_{pooled} \times \sqrt{(1-ICC)}$, with SD_{pooled} representing the standard deviation of the measure. The MDC reflects the magnitude of change necessary to provide confidence that any change is not due to random variation or measurement error. MDC values were calculated as follows: $MDC = 1.96 \times SEM \times \sqrt{2}$.

For research questions 6 and 7, we ran Fisher's exact test of independence to determine the interaction between intervention and Adduction drop test to compare the expected and observed proportions of positive and negative tests.

Table 1. *Passive Range of Motion Measurement Procedures*

Range of Motion Measurement	Participant Body Position	Lower Extremity Position	Passive Range of Motion	Goniometer/ Inclinometer
Hip internal rotation	Prone	Knee flexed to 90° angle	Femur internally rotated	Digital inclinometer perpendicular to medial tibia
Hip external rotation	Prone	Knee flexed to 90° angle	Femur externally rotated	Digital inclinometer perpendicular to lateral tibia
Hip extension	Prone	Leg straight	Femur extended	Goniometer aligned across lateral midline of pelvis and femur
Hip flexion	Supine	Knee maximally flexed	Femur flexed	Goniometer aligned across lateral midline of pelvis and femur
Hip adduction	Supine	Leg straight; contralateral limb maximally abducted	Femur adducted	Goniometer aligned across ASIS and femur
Hip abduction	Supine	Leg straight	Femur abducted	Goniometer aligned across ASIS and femur

Figure 1. *Outline of Data Collection*

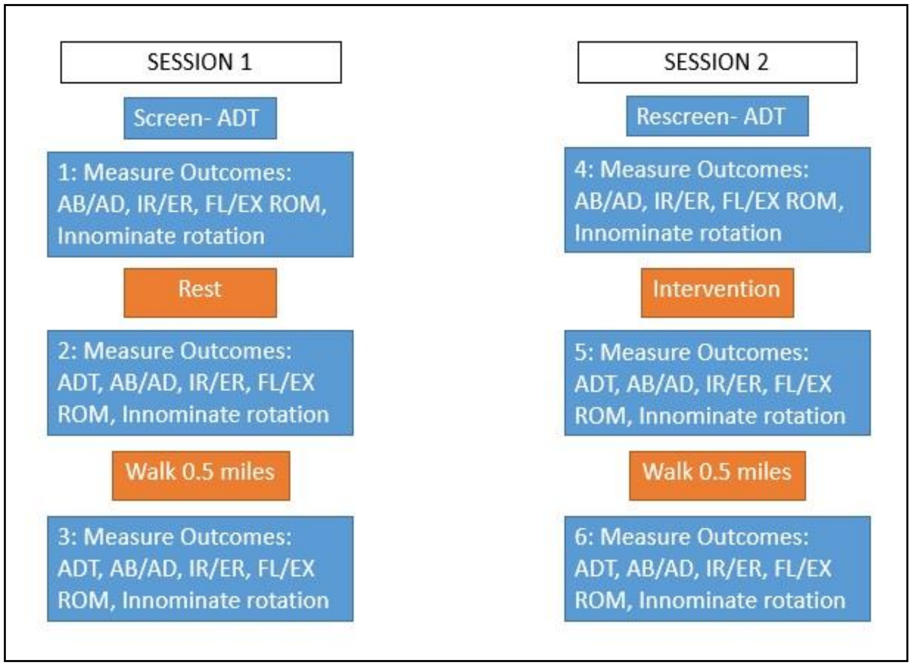


Figure 2. *Model of Sagittal Innominate Rotation Angle*

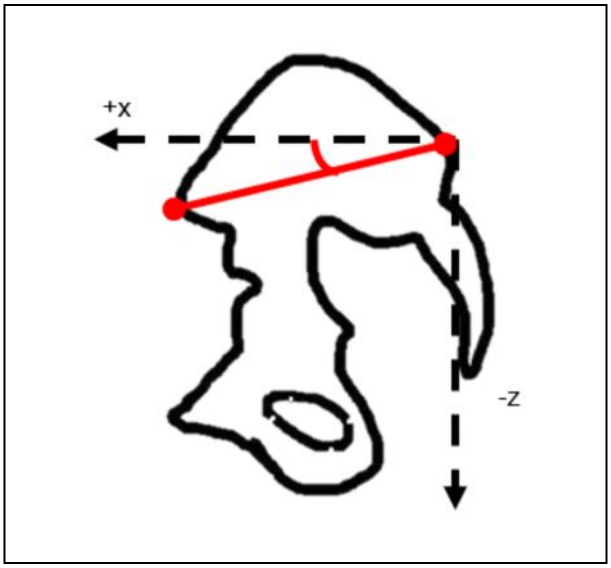
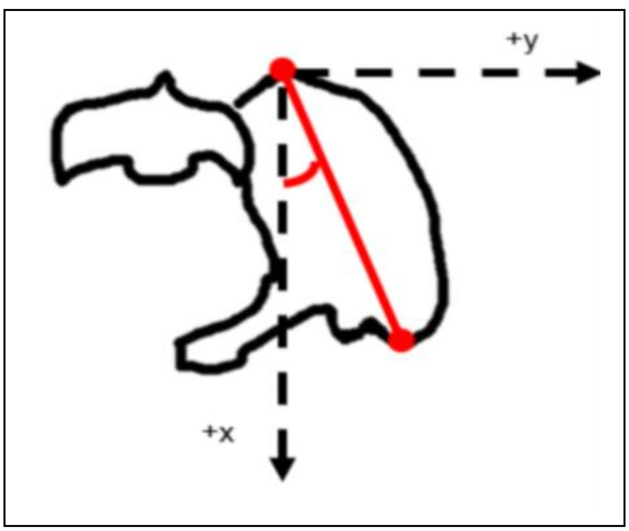


Figure 3. *Model of Transverse Innominate Rotation Angle*



CHAPTER 4: RESULTS

Data from all twenty-four participants (n=24) were used in the final analyses of hip range of motion and sagittal innominate rotation angles. Demographic data for the sample is listed in Table 2.

Data from four participants were not included in the final analyses of left and right transverse innominate rotation angles due to measurement error. Likely calibration error of the Flock of Birds system caused inaccurate recording of Cartesian coordinates of the ASIS and PSIS four individuals. Calculation of the transverse innominate rotation angle from these data revealed impossible angle measures, such as transverse innominate rotation angles of above 180º, and these data were excluded in further statistical analysis. The corresponding sagittal innominate rotation angles for these subjects fell within the realm of anatomic possibility and were not excluded.

Reliability (RQ1)

Within the control data collection session, ICC values for the right sagittal innominate rotation angle, left sagittal innominate rotation angle, right transverse innominate rotation angle, and left transverse innominate rotation angle were all considered good-to-excellent (ICC > 0.75). Between data collection sessions, ICC values for left and right sagittal innominate rotation angle were considered good-to-excellent (ICC > 0.75). Between sessions, ICC values for left and right transverse rotation angles were both considered poor-to-moderate (ICC < 0.75). ICC values are listed in Table 3.

Within- and between-session ICC values for all range of motion measures were considered good-to-excellent (ICC > 0.75). ICC values are listed in Table 3.

Range of Motion (RQ2 & RQ4)

Completion of the PRI pelvic repositioning technique affected hip range of motion of the left limb in the frontal plane more than the control condition. A significant interaction ($p < 0.001$) in left hip adduction range of motion was shown between the pre-intervention ($\mu = 13.85^\circ \pm 2.15^\circ$) and post-intervention ($\mu = 17.64^\circ \pm 2.84^\circ$) time-points, as compared to the difference between the pre-control ($\mu = 13.71^\circ \pm 1.82^\circ$) and post-control time points ($\mu = 13.64^\circ \pm 1.82^\circ$). This change ($\mu = 3.79^\circ \pm 2.45^\circ$) exceeded the minimal detectable change (MDC) of the measure (MDC = 2.41º). This finding was associated with a large effect size (1.85, 95% CI [1.17, 2.52]) as seen in figure 3. No difference in adduction range of motion was observed on the right limb after completion of the intervention.

Similarly, a significant ($p = 0.02$) difference in left total arc frontal plane range of motion was seen between the pre-intervention ($\mu = 59.72^\circ \pm 6.59^\circ$) and post-intervention ($\mu = 64.35^\circ \pm 6.47^\circ$) time-points, as compared to the change between the pre- ($\mu = 60.64^\circ \pm 7.21^\circ$) and post-control time-points ($\mu = 60.00^\circ \pm 6.83^\circ$). This finding was associated with a large effect size (1.30) but the intervention change ($\mu = 4.63^\circ \pm 3.61^\circ$) did not exceed the calculated MDC score (6.74º). This change is illustrated in Figure 4. No difference in total arc frontal plane range of motion was observed on the right limb after the completion of the intervention.

Completion of the PRI pelvic repositioning technique did not affect hip range of motion in the sagittal plane of the right or left limbs. Left hip external rotation range of motion revealed a significant time x session interaction ($p = 0.02$), with significant differences between sessions ($\mu_c = 54.60^\circ \pm 9.83^\circ$, $\mu_i = 56.66^\circ \pm 8.53^\circ$) and between the pre- ($\mu = 56.66^\circ \pm 8.53^\circ$) and post-intervention ($\mu = 55.59° \pm 8.95°$) time-points. However, this difference between pre- and post-intervention ($\mu = -1.063° \pm 3.07°$) was well below the MDC (MDC = 4.93) of this measure. Hip internal rotation, total arc transverse plane range of motion, hip flexion, hip extension, or total arc sagittal plane range of motion were not different between the control and intervention sessions at any time points. These data can be found in Tables 4, 5, and 6.

There was no change observed in any range of motion after completion of the walking task. Pairwise comparisons of the post-intervention time-point (Time 2) and the post-walking time-point (Time 3) in left hip adduction range of motion and left total arc frontal plane range of motion revealed no significant difference ($p > 0.05$).

Innominate Rotation Angles (RQ 3 & 5)

A paired samples t-test revealed a significant difference ($p = 0.002$) between the mean left sagittal innominate rotation angle ($\mu = -11.2° \pm 4.77°$) and right sagittal innominate rotation angle ($\mu = -8.56° \pm 8.70°$) at the beginning of the control session. Omnibus repeated measures ANOVA analyses did not show significant Session x Time interactions in the sagittal or transverse innominate rotation angles on the left or right limb, or in the difference between right and left sagittal and transverse angles. Further pairwise comparison between time-points 1, 2, and 3 showed no significant differences in either sagittal or transverse innominate rotation angles before and after completion of the intervention and walking task, respectively. These data can be found in Table 7.

Adduction Drop Test (RQ 6 & 7)

All twenty-four participants began both data collection sessions displaying positive ADTs on the left leg and negative ADTs on the right leg. There was no change in this status for any participant during the control session. During the intervention session, twenty of the twenty-four participants (83.5%) showed a change from a positive ADT to a negative ADT in the left leg. After completion of the walking task, one participant experienced a change of left ADT from negative to positive; nineteen of the twenty-four participants (79.2%) displayed a negative ADT on the left leg after completion of the walking task. All twenty-four participants presented with a negative ADT on the right leg after the intervention and after the walking task. Analysis via Fisher's Exact Test revealed this change to be statistically significant at both Time 2 and Time 3 ($p = 0.00$).

***Table 2**. Patient Demographic Information*

	n	Height (m)	Weight (kg)	Age (yrs)
Combined	24	1.69 ± .09	67.08 ± 12.38	21.46 ± 1.35
Males	11	1.76 ± .06	75.48 ± 12.32	21.82 ± 1.25
Females	13	1.62 ± .06	59.97 ± 6.91	21.15 ± 1.40

***Table 3**. Reliability of Range of Motion and Innominate Position Measures*

Variable	Side	Within Session ICC (Con. T1-T2)	Between Sessions ICC (Con. T1- Inv. T1)
Flexion	L	0.95	0.93
	R	0.99	0.93
Extension	L	0.96	0.92
	R	0.97	0.94
Internal Rotation	L	0.98	0.98
	R	0.97	0.97
External Rotation	L	0.97	0.96
	R	0.98	0.94
Abduction	L	0.92	0.82
	R	0.97	0.96
Adduction	L	0.79	0.87
	R	0.90	0.89
Sagittal Innominate Rotation	L	0.86	0.77
	R	0.96	0.75
Transverse Innominate Rotation	L	0.95	0.45
	R	0.86	0.17

Table 4. Changes in Range of Motion in the Sagittal Plane (deg)

Variable	Session	Time 1 (t1) Mean	Time 1 (t1) St. Dev.	Time 2 (t2) Mean	Time 2 (t2) St. Dev.	Time 3 (t3) Mean	Time 3 (t3) St. Dev.
Flexion - Left	Control	132.18	7.31	133.10	7.26	133.96	7.85
	Intervention	134.14	7.79	135.54	6.65	135.58	6.46
Extension - Left	Control	22.14	4.35	22.29	4.15	22.50	4.34
	Intervention	23.65	4.25	22.81	4.45	22.96	4.51
Total Arc - Left	Control	154.32	10.60	155.39	10.17	156.46	10.59
	Intervention	157.79	10.52	158.35	9.47	158.54	9.45
Flexion - Right	Control	133.17	7.90	133.25	7.29	133.16	7.32
	Intervention	133.47	7.48	134.40	7.16	134.56	7.42
Extension - Right	Control	22.58	4.50	22.60	4.57	22.46	4.93
	Intervention	23.26	4.37	23.46	4.63	23.06	4.69
Total Arc - Right	Control	155.75	10.33	155.85	9.76	156.74	9.19
	Intervention	156.74	9.19	157.86	9.15	157.61	10.13

Table 5. Changes in Range of Motion in the Frontal Plane (deg)

Variable	Session	Time 1 (t1) Mean	Time 1 (t1) St. Dev.	Time 2 (t2) Mean	Time 2 (t2) St. Dev.	Time 3 (t3) Mean	Time 3 (t3) St. Dev.
Abduction - Left	Control	46.93	6.97	46.36	6.35	46.64	5.84
	Intervention	45.88	6.06	46.71	5.65	45.72	6.37
Adduction - Left	Control	13.71	1.82	***13.64***	***1.82***	***13.75***	***3.01***
	Intervention	13.85	2.15	***17.64***	***2.84***	***17.43***	***2.72***
Total Arc - Left	Control	60.64	7.21	***60.00***	***6.83***	***60.39***	***6.40***
	Intervention	59.72	6.59	***64.35***	***6.47***	***63.15***	***6.92***
Abduction - Right	Control	44.24	7.20	44.33	6.46	44.31	6.77
	Intervention	44.83	7.27	45.57	6.33	45.44	6.27
Adduction - Right	Control	19.03	2.80	18.42	2.82	18.31	3.04
	Intervention	19.06	3.55	18.93	2.65	19.07	3.28
Total Arc - Right	Control	63.27	8.44	62.75	7.29	62.61	7.82
	Intervention	63.89	8.02	64.50	7.13	64.51	7.13

Bold, italicized values denote significant interaction ($p < 0.05$) between time-point and session. This interaction was observed at both time-point 2 and time-point 3.

Table 6. *Changes in Range of Motion in the Transverse Plane (deg)*							
		Time 1 (t1)		Time 2 (t2)		Time 3 (t3)	
Variable	Session	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.
Ext. Rot. - Left	Control	54.60	9.83	***55.79***	***9.37***	***55.52***	***9.83***
	Intervention	56.66	8.52	***55.59***	***8.95***	***55.97***	***8.92***
Int. Rot. - Left	Control	36.53	9.78	36.17	9.39	36.47	9.81
	Intervention	35.76	10.05	35.97	8.88	36.59	9.63
Total Arc - Left	Control	91.14	7.14	91.96	7.79	91.89	7.64
	Intervention	92.41	7.63	91.56	6.45	92.56	6.65
Ext. Rot. - Right	Control	55.76	7.44	55.04	7.33	54.89	6.96
	Intervention	55.14	8.12	55.43	8.19	55.62	7.60
Int. Rot - Right	Control	39.61	8.05	39.26	7.40	39.78	7.70
	Intervention	39.72	8.05	38.74	8.06	40.44	8.52
Total Arc - Right	Control	95.38	8.77	94.30	8.48	94.67	8.21
	Intervention	94.86	9.13	94.17	7.82	96.06	8.35

Bold, italicized values denote significant interaction ($p < 0.05$) between time-point and session. This interaction was observed at both time-point 2 and time-point 3.

Table 7. *Changes in Innominate Position Angles (deg)*							
		Time 1		Time 2		Time 3	
Variable	Session	Mean	St. Dev	Mean	St. Dev	Mean	St. Dev
Left Sagittal Inn. Angle	Control	-11.18	4.76	-10.94	5.57	-10.89	4.56
	Intervention	-10.07	3.66	-9.99	5.09	-10.26	4.66
Right Sagittal Inn. Angle	Control	-8.61	8.88	-8.12	9.45	-7.56	8.02
	Intervention	-9.31	5.47	-9.21	5.77	-8.74	6.03
Sagittal Plane Difference	Control	-2.57	7.12	-2.82	6.54	-3.33	7.50
	Intervention	-0.77	3.80	-0.77	4.14	-1.52	4.29
Left Trans. Inn. Angle	Control	22.55	5.38	22.08	6.65	21.76	7.75
	Intervention	21.50	5.55	21.96	4.79	22.46	5.06
Right Trans. Inn. Angle	Control	32.53	7.91	31.08	9.80	29.39	9.70
	Intervention	32.94	8.15	30.01	6.21	29.79	7.90
Trans. Plane Difference	Control	9.98	8.21	9.01	11.56	7.63	10.53
	Intervention	11.44	9.89	8.05	9.05	7.33	9.73

Figure 4. *Left Adduction Range of Motion (p < 0.001)*

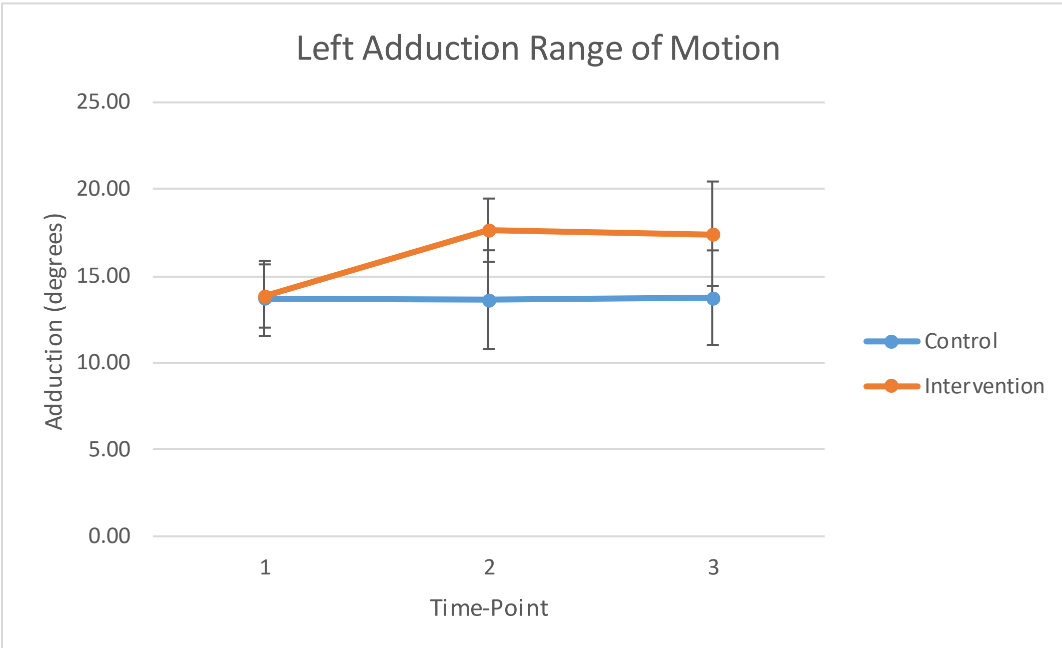
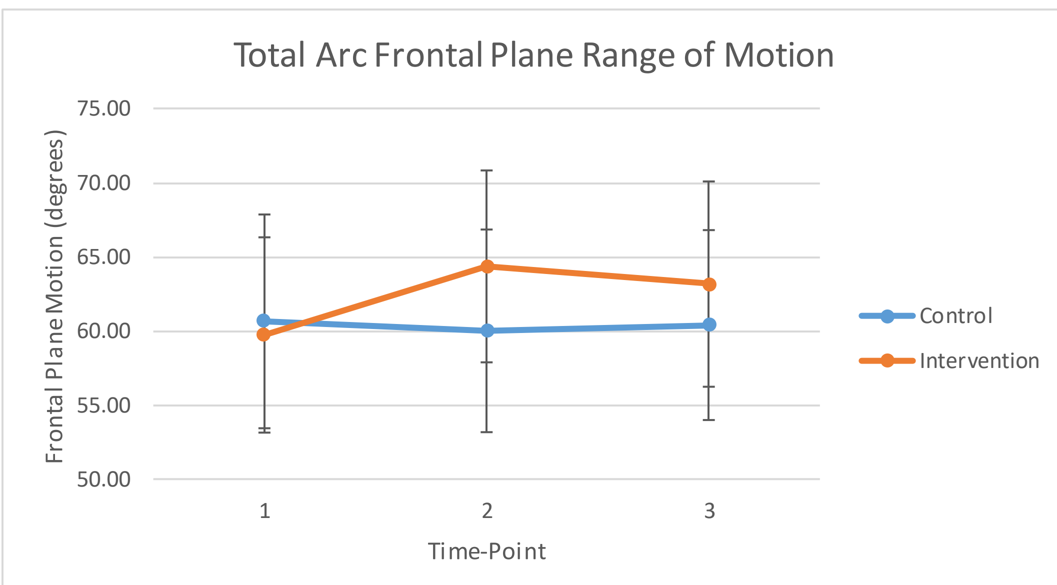


Figure 5. *Left Frontal Plane Range of Motion (p = 0.02)*



CHAPTER 5: DISCUSSION

The purpose of this investigation was to explore the effects of an intervention of rehabilitation exercises, designed by the Postural Restoration Institute, on hip range of motion and innominate rotation. We found that completion of this intervention was associated with an increase in adduction range of motion and total arc frontal plane range of motion on the left hip. We did not find any association between completion of the intervention and innominate rotation angle in either the sagittal or transverse plane.

Reliability (RQ1)

Before we could assess any change in sagittal and transverse innominate rotation angles due to the intervention, it was vital to establish the reliability of the palpation-digitization technique at measuring these angles. Within-session reliability measures for both left and right sagittal and transverse innominate rotation were assessed as good-to-excellent. This provides confidence that any changes observed in innominate rotation angles during a single session were not due to the measurement technique. Our strong reliability measures also support our hypothesis that palpation-digitization using an electromagnetic tracking system is a reliable technique for assessing innominate rotation in the sagittal and transverse planes, aligning with prior research that supports the strong reliability of a palpation-digitization technique to assess changes in innominate rotation within a single data collection session.[1-3,11-13]

While the between-session reliability of the right and left sagittal innominate rotation angles was assessed as good-to-excellent, the between-session reliability of the right and left transverse innominate rotation angles was assessed as poor-to-moderate. This poor between-session reliability did not affect the statistical analysis of this study, as our analysis explored changes within each data collection session. However, this does weaken support for the use of an electromagnetic palpation-digitization technique as an accurate, non-invasive method of assessing innominate position.

There are a number of possible reasons for this poor between-session reliability in the transverse plane. As discussed earlier, there is sparse research related to the assessment of innominate position over time, and it is possible that the transverse innominate rotation angle is inherently variable between days. While the examiner instructed the participants to abstain from unusual physical activity between data collection sessions, there was no attempt to control for normal physical activity before each session. It is possible that the transverse innominate rotation angle would be different between days if the subject spent one morning sleeping in and the next on his or her feet. It is also possibility that this poor reliability is due to the inconsistency of palpation in the examiner. The limitations of an examiner at accurately assessing innominate position through palpation of bony landmarks have been shown repeatedly in prior research.[1-5,11-13,22]

Range of Motion and Adduction Drop Test (RQ2, RQ4, RQ6, & RQ7)

The hypothesized effect of the repositioning exercise series on left hip adduction range of motion, as measured by both goniometry and the left Adduction Drop Test, was observed. This concurs with previous research and case series that have shown a change in left adduction range of motion,[8,42-43] and provides support for the theoretical claims of the Postural Restoration Institute.[27-28]

The PRI's proposed mechanism for the observed increase in left adduction range of motion is a repositioning of the innominate bone on the sacrum to a more symmetrical position with the contralateral limb. This repositioning of the innominate bone also changes the orientation of the acetabulum to the femoral head, allowing for an increase in adduction range of motion as an improved innominate position is achieved.

Despite the present effect of the PRI intervention on left adduction range of motion, we did not observe any concomitant changes in sagittal or transverse plane range of motion that were hypothesized to accompany a change in the position of the acetabulum. Changes in acetabular position via anterior pelvic tilt have previously been associated with changes in internal rotation range of motion,[44] but no changes in internal rotation measures were observed in this study. We hypothesized that we would observe changes in the flexion, extension, abduction, internal rotation, and external rotation ranges of motion due to the change in acetabular position. We also hypothesized that these changes of range of motion would not alter the total arc range of motion in any one plane; an increase in adduction range of motion would be concomitant with a decrease in abduction range of motion. We did not observe any evidence to support these hypotheses. The significant increase shown in left adduction range of motion was not accompanied by a decrease in left abduction range of motion.

The changes observed in adduction range of motion, as measured by goniometry and by the ADT, remained present after walking one-half mile. Despite the short duration and low intensity of this activity, this retention provides evidence that changes brought on by the PRI intervention last beyond the treatment table. Further research is required to assess how long these changes are retained, and if changes are retained after moderate- to high-intensity activity.

Innominate Position (RQ3 & RQ5)

At the baseline time-point of the control session, analysis of sagittal innominate rotation angle also revealed increased left innominate anterior rotation as compared to the right limb. To date, this is the first data connecting biometric analysis of innominate position with the Adduction Drop Test, the PRI's surrogate measure of innominate position. However, as participants were required to have a positive ADT indicating left anterior innominate rotation to participate in this study, no comparison of these values to a population displaying symmetric innominate rotation was conducted.

After intervention, no changes in innominate rotation angle in the sagittal or transverse planes were observed. Prior exploration of innominate position using the palpation-digitization technique has only examined change in innominate position between varying femoro-acetabular positions. This is the first study using this technique to quantify innominate position in a neutral stance. As there has also been no prior research quantifying the effect of any intervention to correct for pelvic position, it is unclear how large a magnitude of a change in innominate position is to be expected. The MDC of our sample was 4.53º in the sagittal plane and 6.58º in the transverse plane; it is possible that the hypothesized change in innominate position occurred, but we were unable to detect it using the palpation-digitization technique.

Alternate Mechanisms

It is also possible that the observed increase in adduction range of motion is achieved by another mechanism entirely. Diaphragmatic breathing is a widely-used relaxation technique that has been shown to increase parasympathetic nervous system activity and decrease muscle tone.[9] However, effects from this systemic muscular relaxation would have been observed in all ranges of motion. During the Right Sidelying Adductor Pull Back exercise, activation of the left adductor group leads to reciprocal inhibition of the antagonist left hip abductor muscles, the gluteus medius and tensor fascia latae. Prior research has connected activity of the stimulation of the adductor group with reciprocal inhibition of the tensor fascia latae.[37] This exercise could serve as a form of proprioceptive neuromuscular facilitation (PNF), increasing the extensibility of the hip abductor muscles and allowing for greater adduction range of motion.[24]

Another possible mechanism of increasing hip adduction range of motion is an alteration of the arthrokinematics at the femoro-acetabular joint. While the proposed mechanism of the PRI involves changing the position of the acetabulum via change of innominate position at the SIJ, it is possible that these exercises affect the position of the femoral head in the acetabulum. Research has shown that exercises that correct anterior translation of the humeral head improve shoulder range of motion by restoring proper arthrokinematic motion to the glenohumeral joint.[10] It is possible that the change observed in this study was due to the repositioning of the femoral head in the acetabulum, allowing for the proper inferior glide and superior roll required for adduction. Further studies are needed to explore these potential alternative mechanisms.

Limitations

There was no attempt at blinding the investigator or participants in this study design. The principal investigator also implemented the intervention exercise series. Thus, bias could have been present in evaluation of range of motion measures after completion of the intervention series. Further studies should blind the investigator to the session (intervention v. control). As previously discussed, the use of the palpation-digitization system to evaluate innominate position in the neutral stance has not been well supported. While the observed reliability within each session was strong, further research is needed to compare this technique to computed tomography or radiography in order to validate the use of this technique. Comparison to radiographic techniques is also needed to explore the differences in within-session and between-session reliability of the transverse innominate rotation angles; it is unclear if the poor between-session reliability was due to shifting of the innominate bones between days or inability of the palpation-digitization technique to capture an accurate measure of transverse innominate rotation.

Prior research and the theoretical basis of the PRI have acknowledged the three-dimensional nature of movement of the innominate on the sacrum. Our study only examined innominate position in the sagittal and transverse planes. Potentially, the change in adduction range of motion could have been due to repositioning of the innominate in the frontal plane. Analysis of frontal plane motion would likely involve comparison of different bony landmarks of the pelvis, such as the ischial tuberosities or the pubic bones. Due to the depth of these landmarks, palpation-digitization does not appear to be a feasible technique for measuring innominate position in the frontal plane.

Likewise, any motion of the innominate occurring at the SI joint is inherently a tri-planar motion. To study this motion, we attempted to reduce this tri-planar motion to its planar components. It is possible that a change could be observed in a combined, three-dimensional vector of innominate motion that was unable to be detected in the sagittal or transverse planes, individually. Assessing three-dimensional motion of the innominate would require advanced analysis in linear algebra and thus was beyond the scope of this study.

Further, use of a more homogenous sample could have potentially provided stronger reliability and less variability in innominate rotation angles. As noted, males and females have significant differences in pelvic and sacro-iliac anatomy; a larger sample size would have allowed for separate analysis of males and females, as well as comparison between sexes. Screening for body-mass index (BMI), may have produced more precise measurement of innominate position angles, as palpation of bony landmarks was more difficult on participants with a higher BMI.

Clinical Implications

These results provide strong support for use of the PRI repositioning exercise series to increase hip adduction range of motion, and the retention of these changes after the walking task support the claim that this intervention can provide short-term benefits beyond the treatment table. A change in left Adduction Drop Test result was observed in 83.5 percent of participants, providing a clear and easily observable change within one treatment. This intervention does not require expensive equipment and can be applied to a wide range of patient populations. However, this study was done on a sample of healthy, active, college-aged subjects. Participants who reported back pain or hip pain that had limited athletic activity in the past six months were excluded from this study. Thus, this study cannot offer any recommendation for or against using the PRI intervention in the treatment of patients with low back or hip pain.

However, this increase in adduction range of motion is theorized to provide a significant benefit in the treatment of painful conditions in the low back and hip due to asymmetry of the lumbo-pelvic-hip complex (LPHC). The PRI proposes that individuals displaying left AIC dominance, and thus left anterior innominate rotation, compensate by shifting their center of mass towards their right leg. It is theorized that restoration of proper pelvic position, and thus hip adduction range of motion, allows for more equal forces to be absorbed through the right and left legs; increased adduction of the left limb centralizes the center of mass. This restored symmetry is said to help correct muscle imbalances affecting the LPHC, which are present in a host of painful conditions of the low back and hips. This study supports the use of the intervention to increase left hip adduction range of motion; further research is needed to explore the effects of this intervention and increased range of motion on patients experiencing pain.

REFERENCES

1. Adhia, D. B., Bussey, M. D., Mani, R., Jayakaran, P., Aldabe, D., & Milosavljevic, S. (2012). Inter-tester reliability of non-invasive technique for measurement of innominate motion. *Manual Therapy*, *17*(1), 71–76. https://doi.org/10.1016/j.math.2011.09.005

2. Adhia, D. B., Bussey, M. D., Ribeiro, D. C., Tumilty, S., & Milosavljevic, S. (2013). Validity and reliability of palpation-digitization for non-invasive kinematic measurement - A systematic review. *Manual Therapy*, *18*(1), 26–34. https://doi.org/10.1016/j.math.2012.06.004

3. Adhia, D. B., Mani, R., Milosavljevic, S., Tumilty, S., & Bussey, M. D. (2016). Does repeated palpation-digitization of pelvic landmarks for measurement of innominate motion introduce a systematic error? - A psychometric investigation. *Manual Therapy*, *21*, 282–286. https://doi.org/10.1016/j.math.2015.09.009

4. Adhia, D. B., Milosavljevic, S., Tumilty, S., & Bussey, M. D. (2016). Innominate movement patterns, rotation trends and range of motion in individuals with low back pain of sacroiliac joint origin. *Manual Therapy*, *21*, 100–108. https://doi.org/10.1016/j.math.2015.06.004

5. Adhia, D. B., Tumilty, S., Mani, R., Milosavljevic, S., & Bussey, M. D. (2016). Can hip abduction and external rotation discriminate sacroiliac joint pain? *Manual Therapy*, *21*, 191–197. https://doi.org/10.1016/j.math.2015.08.002

6. Bagwell, J. J., Fukuda, T. Y., & Powers, C. M. (2016). Sagittal plane pelvis motion influences transverse plane motion of the femur: Kinematic coupling at the hip joint. *Gait and Posture*, *43*, 120–124. https://doi.org/10.1016/j.gaitpost.2015.09.010

7. Bedi, A., Warren, R. F., Wojtys, E. M., Oh, Y. K., Ashton-Miller, J. a., Oltean, H., & Kelly, B. T. (2014). Restriction in hip internal rotation is associated with an increased risk of ACL injury. *Knee Surgery, Sports Traumatology, Arthroscopy*, 1–8. https://doi.org/10.1007/s00167-014-3299-4

8. Boyle, K. L. (2011). Managing a female patient with left low back pain and sacroiliac joint pain with therapeutic exercise: A case report. *Physiotherapy Canada*, *63*(2), 154–163. https://doi.org/10.3138/ptc.2009-37

9. Brannon Russell, M. E., Hoffman, B., Stromberg, S., & Carlson, C. R. (2014). Use of Controlled Diaphragmatic Breathing for the Management of Motion Sickness in a Virtual Reality Environment, 269–277. https://doi.org/10.1007/s10484-014-9265-6
10. Bullock, M. P., Foster, N. E., & Wright, C. C. (2005). Shoulder impingement: the effect of sitting posture on shoulder pain and range of motion. *Manual Therapy*, *10*, 28–37. https://doi.org/10.1016/j.math.2004.07.002

11. Bussey, M. D., Yanai, T., & Milburn, P. (2004). A non-invasive technique for assessing innominate bone motion. *Clinical Biomechanics*, *19*(1), 85–90. https://doi.org/10.1016/j.clinbiomech.2003.09.005

12. Bussey, M. D., Bell, M. L., & Milosavljevic, S. (2009). The influence of hip abduction and external rotation on sacroiliac motion. *Manual Therapy*, *14*(5), 520–525. https://doi.org/10.1016/j.math.2008.08.009

13. Bussey, M. D., Milosavljevic, S., & Bell, M. L. (2009). Sex differences in the pattern of innominate motion during passive hip abduction and external rotation. *Manual Therapy*, *14*(5), 514–519. https://doi.org/10.1016/j.math.2008.09.004

14. Cibulka, M. T., Delitto, a, & Koldehoff, R. M. (1988). Changes in innominate tilt after manipulation of the sacroiliac joint in patients with low back pain. An experimental study. *Physical Therapy*, *68*(9), 1359–1363.

15. Cooperstein, R., & Lew, M. (2009). The relationship between pelvic torsion and anatomical leg length inequality: a review of the literature. *Journal of Chiropractic Medicine*, *8*(3), 107–118. https://doi.org/10.1016/j.jcm.2009.06.001

16. Dagenais, S., Caro, J., & Haldeman, S. (2008). A systematic review of low back pain cost of illness studies in the United States and internationally. *Spine Journal*, *8*(1), 8–20. https://doi.org/10.1016/j.spinee.2007.10.005

17. Dalton, S. L., Kerr, Z. Y., & Dompier, T. P. (2015). Epidemiology of Hamstring Strains in 25 NCAA Sports in the 2009-2010 to 2013-2014 Academic Years. *The American Journal of Sports Medicine*, *43*(11), 2671–9. https://doi.org/10.1177/0363546515599631

18. Ellera Gomes, J. L., Palma, H. M., & Ruthner, R. (2014). Influence of hip restriction on noncontact ACL rerupture. *Knee Surgery, Sports Traumatology, Arthroscopy*, *22*(1), 188–191. https://doi.org/10.1007/s00167-012-2348-0

19. Felix, T., Dilani, M., Warren, R., & Julie, A. (2015). The relationship between the piriformis muscle, low back pain, lower limb injuries and motor control training among elite football players.

20. Franke, H., & Fryer, G. (2015). Muscle energy technique for non-specific low-back pain. *The Cochrane …*, (2). https://doi.org/10.1002/14651858.CD009852.pub2.www.cochranelibrary.com

21. Gnat, R., Spoor, K., & Pool-Goudzwaard, A. (2015). The influence of simulated transversus abdominis muscle force on sacroiliac joint flexibility during asymmetric moment application to the pelvis. *Clinical Biomechanics*, *30*(8), 827–831. https://doi.org/10.1016/j.clinbiomech.2015.06.006

22. Goode, A., Hegedus, E. J., Sizer, P., Brismee, J.-M., Linberg, A., & Cook, C. E. (2008). Three-dimensional movements of the sacroiliac joint: a systematic review of the literature and assessment of clinical utility. *The Journal of Manual & Manipulative Therapy*, *16*(1), 25–38. https://doi.org/10.1179/106698108790818639

23. Harris-Hayes, M., Sahrmann, S. A., & Van Dillen, L. R. (2009). Relationship between the hip and low back pain in athletes who participate in rotation-related sports. *Journal of Sport Rehabilitation*, *18*(1), 60–75. https://doi.org/10.2964/jsik.kuni0223

24. Hindle, K. B., Whitcomb, T. J., Briggs, W. O., & Hong, J. (2012). Proprioceptive Neuromuscular Facilitation (PNF): Its Mechanisms and Effects on Range of Motion and Muscular Function by, *31*(March), 105–113. https://doi.org/10.2478/v10078-012-0011-y

25. Hodges, P. W., McLean, L., & Hodder, J. (2014). Insight into the function of the obturator internus muscle in humans: Observations with development and validation of an electromyography recording technique. *Journal of Electromyography and Kinesiology*, *24*(4), 489–496. https://doi.org/10.1016/j.jelekin.2014.03.011

26. Hootman, J. M., Dick, R., & Agel, J. (2007). Epidemiology of collegiate injuries for 15 sports: Summary and recommendations for injury prevention initiatives. *Journal of Athletic Training*, *42*(2), 311–319.

27. Hruska, R. (2005).Myokinematic restoration: an integrated approach to treatment of patterned lumbo-pelvic-femoral pathomechanics. Course manual. Postural Restoration Institute.

28. Hruska, R. (2005).Pelvic restoration: an integrated approach to treatment of patterned pubo-sacral pathomechanics. Course manual. Postural Restoration Institute.

29. Knutson, G. A. (2005). Anatomic and functional leg-length inequality: a review and recommendation for clinical decision-making. Part I, anatomic leg-length inequality: prevalence, magnitude, effects and clinical significance. *Chiropractic & Osteopathy*, *13*, 11. https://doi.org/10.1186/1746-1340-13-11

30. Krismer, M., & van Tulder, M. (2007). Low back pain (non-specific). *Best Practice and Research: Clinical Rheumatology*, *21*(1), 77–91. https://doi.org/10.1016/j.berh.2006.08.004

31. Lavignolle, B., Vital, J. M., Senegas, J., Destandau, J., Toson, B., Bouyx, P., … Calabet, A. (1983). An approach to the functional anatomy of the sacroiliac joints in vivo. *Anatomia Clinica*, *5*(3), 169–176. https://doi.org/10.1007/BF01799002

32. Leung, F. T., Mendis, M. D., Stanton, W. R., & Hides, J. A. (2015). The relationship between the piriformis muscle, low back pain, lower limb injuries and motor control training among elite football players. *Journal of Science and Medicine in Sport*, *18*(4), 407–411. https://doi.org/10.1016/j.jsams.2014.06.011

33. Li, X., Ma, R., Zhou, H., Thompson, M., Dawson, C., Nguyen, J., & Coleman, S. (2015). Evaluation of Hip Internal and External Rotation Range of Motion as an Injury Risk Factor for Hip, Abdominal and Groin Injuries in Professional Baseball Players. *Orthopedic Reviews*, *7*(4), 6142. https://doi.org/10.4081/or.2015.6142

34. Manchikanti, L., Singh, V., Pampati, V., Damron, K. S., Barnhill, R. C., Beyer, C., & Cash, K. A. (2001). Evaluation of the relative contributions of various structures in chronic low back pain. *Pain Physician*, *4*(4), 308–16. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/16902676

35. Mather, R. C., Koenig, L., Kocher, M. S., Dall, T. M., Gallo, P., Scott, D. J., … Group, M. K. (2013). Societal and economic impact of anterior cruciate ligament tears. *The Journal of Bone and Joint Surgery*, *95*(19), 1751–1759. https://doi.org/10.2106/JBJS.L.01705

36. McGrath, M. C. (2006). Palpation of the sacroiliac joint: An anatomical and sensory challenge. *International Journal of Osteopathic Medicine*, *9*(3), 103–107. https://doi.org/10.1016/j.ijosm.2006.03.001

37. Nakano, S., & Wada, C. (2016). Influence of electrical stimulation on hip joint adductor muscle activity during maximum effort. *The Journal of Physical Therapy Science*, (28), 1633–1635.

38. Nussbaumer, S., Leunig, M., Glatthorn, J. F., Stauffacher, S., Gerber, H., & Maffiuletti, N. A. (2010). Validity and test-retest reliability of manual goniometers for measuring passive hip range of motion in femoroacetabular impingement patients. *BMC Musculoskeletal Disorders*, *11*, 194. https://doi.org/10.1186/1471-2474-11-194

39. Palazzo, C., Ravaud, J.-F., Papelard, A., Ravaud, P., & Poiraudeau, S. (2014). The Burden of Musculoskeletal Conditions. *PLoS ONE*, *9*(3), e90633. https://doi.org/10.1371/journal.pone.0090633

40. Puhakka, K. B., Melsen, F., Jurik, A. G., Boel, L. W., Vesterby, A., & Egund, N. (2004). MR imaging of the normal sacroiliac joint with correlation to histology. *Skeletal Radiology*, *33*(1), 15–28. https://doi.org/10.1007/s00256-003-0691-4

41. Rebello da Veiga, T., Custódio da Silva, A., Gomes da Silva, R. T., Carvalho, S. L. M., Orsini, M., & Silva, J. G. (2015). Intra-observer reliability in three-dimensional kinematic analysis of sacroiliac joint mobility. *Journal of Physical Therapy Science*, *27*(4), 1001–4. https://doi.org/10.1589/jpts.27.1001

42. Rich Tenney, H., Boyle, K. L., & DeBord, A. (2013). Influence of hamstring and abdominal muscle activation on a positive Ober's test in people with lumbopelvic pain. *Physiotherapy Canada*, *65*(1), 4–11. https://doi.org/10.3138/ptc.2011-33

43. Robey, J. H., & Boyle, K. (2013). The role of prism glass and postural restoration in managing a collegiate baseball player with bilateral sacroiliac joint dysfunction: a case report. *International Journal of Sports Physical Therapy*, *8*(5), 716–28. Retrieved from http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=3811731&tool=pmcentrez&rendertype=abstract

44. Ross, J. R., Nepple, J. J., Philippon, M. J., Kelly, B. T., Larson, C. M., & Bedi, A. (2014). Effect of changes in pelvic tilt on range of motion to impingement and radiographic parameters of acetabular morphologic characteristics. *The American Journal of Sports Medicine*, *42*(10), 2402–2409. https://doi.org/10.1177/0363546514541229

45. Ryan, J., DeBurca, N., & Mc Creesh, K. (2014). Risk factors for groin/hip injuries in field-based sports: a systematic review. *British Journal of Sports Medicine*, *48*(14), 1089–1096. https://doi.org/10.1136/bjsports-2013-092263

46. Schwarzer, A. C., Aprill, C. N., & Bogduk, N. (1995). The sacroiliac joint in chronic low back pain. *Spine*. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/7709277

47. Sinacore, D., Cromer, G., & Delitto, A. (1998). Unilateral hip rotation range of motion asymmetry in patients with sacroiliac joint regional pain. *Manual Therapy*, *3*, 1998. https://doi.org/10.1097/00007632-199805010-00009

48. Tainaka, K., Takizawa, T., Kobayashi, H., & Umimura, M. (2014). Limited hip rotation and non-contact anterior cruciate ligament injury: A case-control study. *Knee*, *21*(1), 86–90. https://doi.org/10.1016/j.knee.2013.07.006

49. Wilk, K. E., Meister, K., & Andrews, J. R. (2002). Current concepts in the rehabilitation of the overhead throwing athlete. *The American Journal of Sports Medicine*, *30*(1), 136–151. https://doi.org/10.1177/03635465020300011201

50. Zelle, B. a, Gruen, G. S., Brown, S., & George, S. (2005). Sacroiliac Joint Dysfunction: Evaluation and Management. *Clinical Journal of Pain*, *21*(5), 446–455. https://doi.org/10.1097/01.ajp.0000131413.07468.8e