LENGTH CHANGE OF THE SHORT EXTERNAL ROTATORS OF THE HIP IN COMMON STRETCH POSITIONS: A CADAVERIC STUDY

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ABSTRACT

Background: Stretching of the deep rotators of the hip is commonly employed in patients with lumbosacral, sacroiliac, posterior hip, and buttock pain. There is limited research demonstrating the effectiveness of common stretching techniques on the short external rotators of the hip.

Purpose: The objective of this study was to evaluate length change during stretching of the superior and inferior fibers of the piriformis, superior gemellus, obturator internus, and inferior gemellus.

Study Design: Repeated-measures laboratory controlled cadaveric study.

Methods: Seventeen hip joints from nine embalmed cadavers (5 male; 4 female) with an age between 49-96 years were skeletonized. Polypropylene strings were attached from the origin to insertion sites of the short external rotators. The change of length (mm) noted by excursion of the strings was used as a proxy for change in muscle length, when the hip was moved from the anatomical position to four specific stretch positions: 1) 45° internal rotation from hip neutral flexion/extension, 2) 45° external rotation from 90° hip and knee flexion, 3) 30° adduction from 90° of hip and knee flexion, and 4) 30° of adduction with the hip and knee flexed so the lateral malleolus contacted the lateral femoral epicondyle of the contralateral limb, were recorded.

Results: There was a significant effect on string displacement by stretch position, $F(15,166) = 14.67$, $p < .0005$; Wilk's $\Lambda = .097$, partial $\eta^2 = .540$. The greatest displacement of the strings corresponding to the superior piriformis, inferior piriformis, and the superior gemellus occurred in 30° adduction from 90° of hip and knee flexion. The obturator internus and inferior gemellus had the largest string displacement with 45° internal rotation from neutral flexion/extension.

Conclusions: While all stretch positions caused a significant string displacement indicating length changes of the deep rotators of the hip, the three stretch positions that caused the greatest change were: 1) 30° adduction from 90° of hip and knee flexion, 2) 45° internal rotation from neutral flexion/extension, and 3) 45° external rotation with 90° hip and knee flexion.

Clinical Relevance: This study has clinical implications for the effectiveness of specific stretching techniques on the short external rotators of the hip with the potential to improve the validity of stretching protocols for patients with posterior hip or buttock pain. The piriformis and superior gemellus had a larger change in length when adducting the hip from 90° degrees of hip and knee flexion. The obturator internus and inferior gemellus had a greater length change when internally rotating the hip from neutral flexion/extension.

Level of Evidence: 3

Key words: anatomical modeling, posterior hip, reliability, stretching positions

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INTRODUCTION

Posterior hip pain is a common complaint of patients seeking treatment in an orthopedic clinical setting.^{1,2} The source of posterior hip symptoms is commonly referred from extra-articular structures including the lumbosacral spine, sacroiliac joint, and hip extensor and rotator muscles.^{3,4} Pain localized in the buttock (gluteal) region has been associated with shortening of the short hip external rotators.^{5,6} There are five muscles found in the deep gluteal region known as the short external rotators of the hip joint. They include the piriformis, superior and inferior gemelli, obturator internus, and quadratus femoris. There is limited research demonstrating the effect of common stretching techniques on lengthening of the short hip external rotators.⁷

The close fascial connection of the short external rotators plays an important role in the transmission of force and movement control from the torso to the lower extremities. Injury to the fascia and/or musculotendinous fibers can cause deficits in flexibility and range of motion.^{8,9} These limitations are frequently addressed through static stretching in order to overcome passive resistance and increase active range of motion.¹⁰ Static stretching has been shown to increase range of motion of the hamstring muscles in comparison to dynamic stretching when performed once a day for six weeks.^{11,12} Stretching programs have been shown to decrease symptoms relating to posterior hip and buttock pain.^{5,6} Commonly identified as “piriformis stretching,” these techniques seek to emphasize hip and knee flexion with adduction and external rotation of the hip and have been shown effective in lengthening of the piriformis muscle.^{5,13,14} Several studies have shown that the gemelli-obturator internus complex can cause significant posterior hip and buttock pain,¹⁵⁻¹⁷ but specific stretching techniques have not been validated for effectiveness on change of muscle length, to the knowledge of the authors. As a result of the close anatomical association of these five muscles,⁷ stretching is generally performed to lengthen all structures uniformly rather than in isolation. Four commonly performed stretches are shown in Figure 1. Although these techniques are frequently utilized in the clinical setting, there is limited research demonstrating the effectiveness of each stretch on change in length of the short external rotators of the hip.

The purpose of this study was to evaluate length change of the piriformis, superior gemellus, obturator internus, and inferior gemellus during four commonly performed stretching positions. Human cadaver specimens were examined to describe changes in the muscle length of the short external rotators in four supine positions: 1) 45° of internal rotation from a neutral anatomical position (45IR0), 2) 45° of external rotation from 90° hip and knee flexion (45ER90), 3) 30° of adduction from 90° of hip and knee flexion (30ADD90), and 4) 30° of adduction with the hip and knee flexed (PIRIFORM) so the lateral malleolus contacted the lateral femoral epicondyle of the contralateral limb. The results of this study could help clinicians select stretching positions that could be incorporated into treatment for patients with posterior hip or buttock pain.

METHODS

Design

Seventeen hip joints from nine formalin-embalmed cadavers (5 male; 4 female) with a lifespan between 49-96 years were included in this study. One hip joint was excluded due to a previous total hip arthroplasty. The lower extremities of the cadavers were skeletonized from the pelvis distally leaving only the short external rotators and capsuloligamentous structures intact. The origin and insertions of the superior (SP) and inferior fibers (IP) of the piriformis, superior gemellus (SG), obturator internus (OI), and inferior gemellus (IG) were identified by the primary investigator and secondary investigator to ensure proper location.¹⁸ The primary investigator had one year of dissection experience and the secondary investigator had nine years' experience at the time this study was performed. Polypropylene strings were attached from the insertion to origin sites of each muscle to represent the musculotendinous fibers of the short external rotators. The strings were secured at the insertion sites on the greater trochanter with a 1/8" screw. Each polypropylene string was then guided from the insertion through an eyelet screw located at each origin (Figure 2). After proper identification and pinning of the origin and insertion sites the muscles were excised. Each pelvis was then secured to a wood platform by two 12" screws, bilaterally placed through the anterior aspect of the ilium. Neutral positioning of the pelvis

Figure 1. Common stretching techniques for the short external rotators of the hip. 1) 45° internal rotation from a neutral position; 2) 45° external rotation from 90° hip and knee flexion; 3) 30° adduction from 90° of hip and knee flexion; 4) 30° of adduction with the hip and knee flexed so the lateral malleolus contacted the lateral femoral epicondyle of the contralateral limb.

on the board was ensured by a bubble level (Empire® Magnetic Tool Box Level, Mukwonago, WI) sited on the anterior superior iliac spines of each cadaver (Figure 3). The strings were then run through eyelet screws positioned at the edge of the wood platform (Figure 4). Each string was anchored off the table to ensure equal distribution of tension.

A third investigator positioned each cadaver into a neutral anatomical position (0° flexion/extension and 0° abduction/adduction). This positioning was confirmed through use of a standard 12-inch goniometer (Baseline® 12- inch Goniometer, White Plains, NY) for each cadaver. The primary investigator then marked the starting position of each

Figure 2. Polypropylene string placement from insertion to origin of the short external rotators. 1) superior piriformis; 2) inferior piriformis; 3) superior gemellus; 4) obturator internus; 5) inferior gemellus.

string by placing a black mark where the string and eyelet screw met at the end of the board. The cadavers were then moved into the four specific stretch positions: 1) 45IR0, 2) 45ER90, 3) 30ADD90, and 4) PIRIFORM (Figure 5). The primary investigator confirmed proper positioning by use of a bubble inclinometer (Baseline® Bubble Goniometer, Irvington, NY) for stretch position 1 and a standard 12-inch goniometer for the remaining three stretch positions (2-4). With each position maintained the primary investigator measured the change in length (mm) by excursion of the strings with a digital caliper (General® Digital Caliper, Secaucus, NJ) (Figure 6). Each stretch position was performed three times and separate measurements were taken from the established neutral position to ensure intrarater reliability. This study was approved by the ethics

Figure 3. Neutral positioning of the pelvis on wood platform with level placement bilaterally on the anterior superior iliac spines.

committee for anatomical studies of Duquesne University.

Statistical Analysis

Descriptive data are presented as mean length change $\pm$ standard deviation. Standard error of measurement (SEM) values were calculated to ensure test-retest reliability for each stretch position with 95% confidence intervals. SEM values are expressed in actual units of measurement (mm) to summarize the variation in length change during the three trials of each stretch position.¹⁹ A multivariate analysis of variance (MANOVA) was performed with post-hoc testing to determine the effect of the four stretching techniques on the length change of each muscle. Wilk's Λ was utilized to show the relation of error variance in comparison to total variance of the

Figure 4. Polypropylene string orientation through eyelet screws on the wood platform.

stretching positions. All data was analyzed using a common statistical software program (IBM SPSS Statistics, Version 23, Armonk, NY).

RESULTS

SEM values for intra-rater reliability are presented in Table 1. The SEM values of 1.05mm (45ER90), 1.00mm (30ADD90), 0.63mm (PIRIFORM), 0.62mm (45IR0) demonstrated strong consistency of measurement for the three trials of each stretch position. There was a significant effect on string displacement corresponding to stretch position, $F(15,166) = 14.67$, $p < .0005$; Wilk's $\Lambda = .097$, partial $\eta^2 = .540$. The average length changes for each stretch position are presented in Table 2. The three stretch positions that caused the greatest string displacement of the corresponding short external rotators were: 1) 30ADD90, 2) 45IR0, and 3) 45ER90. PIRIFORM caused the least amount of length change for any of the muscles ($p < 0.05$).

DISCUSSION

This study was designed to assess the effect of four stretching positions on change in length of the short hip external rotators. While all stretch positions resulted in length change to the short external rotators, the greatest length changes for the SP, IP, and the SG occurred in 30° adduction from 90° of hip and knee flexion. The OI and IG had the greatest length change with 45° internal rotation from neutral flexion/extension. When selecting stretching as an intervention to lengthen the short hip external rotators, the three stretch positions that caused the greatest length change were: 1) 30° adduction from 90° of hip and knee flexion, 2) 45° internal rotation from neutral flexion/extension, and 3) 45° external rotation with 90° hip and knee flexion. This is the first study that assessed the effects of four commonly performed stretching techniques on length changes of the short hip external rotators.

The results of this study found the three most proximal muscles fiber models (SP, IP, and SG) had the greatest change in length when positioned in 30ADD90 (SP: 30.7mm, SD 10.2mm; IP: 23.7mm, SD 7.8mm; SG: 20.8mm, SD 5.4mm) followed by 45IR0 (SP: 22.2mm, SD 5.9mm; IP: 20.6mm, SD 5.3mm; SG: 17.4mm, SD 3.0mm) and 45ER90 (SP: 19.4mm, SD 10.2mm; IP: 10.4mm, SD 7.8mm; SG: 9.4mm, SD 7.0mm). The two distal muscles (OI and IG) had the greatest length change in 45IR0 (OI: 18.2mm, SD 7.7mm; IG: 15.5mm, SD 3.3mm) followed closely by 30ADD90 (OI: 17.1mm, SD 6.0mm; IG: 14.7mm, SD 7.2mm). The PIRIFORM stretch caused minimal lengthening of the short external rotators, specifically in the piriformis (SP: 7.7mm, SD 5.7mm; IP: 2.5mm, SD 3.7mm).

The short external rotators are ideally aligned to compress the articular surfaces of the hip joint.⁷ These postural muscles¹⁸ stabilize the hip in a manner similar to the rotator cuff at the glenohumeral joint. During cutting and propulsion type movements the short external rotators are regularly contracted for dynamic stability of the hip.⁷ Due to the strain transmitted during rotational activities, stretching of these muscles is commonly employed in athletes with chronic posterior hip and buttock pain.⁴⁻⁶ Previous cadaveric studies have shown that up to 120° of hip flexion increased the excursion of the short hip

Figure 5. Stretching positions for change of length measurements of the short external rotators. 1) 45° internal rotation from a neutral position (with bubble inclinometer); 2) 45° external rotation from 90° hip and knee flexion; 3) 30° adduction from 90° of hip and knee flexion; 4) 30° of adduction with the hip and knee flexed so the lateral malleolus contacted the lateral femoral epicondyle of the contralateral limb.

external rotators and was further increased with the inclusion of adduction and external rotation.^{20,21} The greatest increase in lengthening of the piriformis and gemelli-obturator internus complex was observed when the limb was positioned in adduction between

60° and 105° of hip flexion.²¹ Similarly, the results of the present study demonstrated the greatest length change of the piriformis and SG when the hip was flexed to 90° with 30° of hip adduction (30ADD90). External rotation with 105° of hip flexion has been

Figure 6. Measurement of length change with digital caliper and maintained string tension.

shown to increase lengthening of the piriformis,²¹ but has a shortening effect when the hip is abducted.²⁰ By maintaining a neutral frontal plane this current study showed an increase in length change of the short external rotators with 45° of external rotation from 90° of hip flexion (45ER90). Internal rotation from anatomical neutral to 30° has been shown to gradually increase lengthening of the piriformis and obturator internus.²⁰ The results of the current study

corresponded to the results previously described with 45° of internal rotation from anatomical neutral (45IR0) causing the largest observed length change of the OI and IG. While previous authors reported length change for several movements of the hip they did not assess ranges of motion specifically associated with the four stretching techniques evaluated in this study. The results of this study offer evidence to validate the inclusion of the 30ADD90, 45IR0, and 45ER90 in protocols designed for stretching of the piriformis, SG, OI, and IG.

There are limitations to this study that need to be considered when interpreting the results. First, this study utilized formalin-embalmed cadavers for data collection. The use of embalmed cadavers in anatomical research has been shown to cause increased soft tissue stiffness and decreased joint flexibility in comparison to fresh-frozen cadavers.²² While all specimens in this study were successfully positioned for each measurement, the surrounding musculature had to be removed for proper string placement. This study does not account for individual limitations in range of motion that could be present due to the surrounding musculature. The capsuloligamentous structures were kept intact to maintain normal femoral head motion in the acetabulum during each stretch position. Joint stiffness related to preserving these structures could have caused a limitation in the measured movement of the short external rotators. Stretching techniques performed in the clinical setting may vary depending on the flexibility, range of motion, and anatomical limitations of an individual.

An additional limitation to this study was the use of a goniometer for determination of hip range of motion during the evaluated stretching techniques. Previous studies have validated the use of

Table 1. Standardized error of measurement values for intra-rater reliability.		
Stretch Position	SEM Values (mm)	95% Confidence Intervals
30ADD90	1.00	19.42 – 23.40
45IR0	0.62	17.56 – 20.03
45ER90	1.05	7.35 – 11.51
PIRIFORM	0.63	(-0.22) – 2.48
30ADD90 = 30° adduction from 90° of hip and knee flexion, 45IR0 = 45° internal rotation from a neutral anatomical position, 45ER0 = 45° external rotation from 90° hip and knee flexion, PIRIFORM = supine piriformis test, SEM= standardized error of measurement.		

Table 2. Mean and standard deviation for the changes in length from the anatomical position to four stretch positions.

Muscle	Stretch Position	Mean Change in Length (mm)	Standard Deviation (mm)
Superior piriformis	30ADD90	30.7	10.2
	45IR0	22.2	5.9
	45ER90	19.4	10.2
	PIRIFORM	7.7	5.7
Inferior piriformis	30ADD90	23.7	7.5
	45IR0	20.6	5.3
	45ER90	10.4	7.7
	PIRIFORM	2.5	3.7
Superior gemellus	30ADD90	20.8	5.4
	45IR0	17.4	3.0
	45ER90	9.4	7.0
	PIRIFORM	1.7	3.1
Obturator internus	30ADD90	17.1	6.0
	45IR0	18.2	7.7
	45ER90	5.0	6.6
	PIRIFORM	-1.5	3.7
Inferior gemellus	30ADD90	14.7	7.2
	45IR0	15.5	3.3
	45ER90	3.0	7.7
	PIRIFORM	-4.3	4.6
30ADD90 = 30° adduction from 90° of hip and knee flexion, 45IR0 = 45° internal rotation from a neutral anatomical position, 45ER0 = 45° external rotation from 90° hip and knee flexion, PIRIFORM = supine piriformis test.			

a goniometer for measurements of hip flexion and external rotation,^{23,24} but no evidence has been presented for evaluation of hip adduction.¹³ This study attempted to account for this limitation by stabilizing each cadaver to limit pelvic rotation and tilt as well as the initial neutral positioning of each hip. Slight differences in measured adduction could have caused an increase or decrease in the measurement of length change for the short external rotators. Clinicians commonly use more than 30° of hip adduction during the PIRIFORM stretching technique, however, the cadaver specimens were unable to consistently be moved beyond this range of motion. Therefore, 30° of adduction was utilized as the standard range of motion for this study. Additionally, the PIRIFORM is performed in the clinical setting with the patient in a prone position. In the current study, this stretching technique was performed with the cadaver positioned supine. While this positioning was found to be most effective for administration in this study, it could have caused a limitation in the measured movement of the short external rotators when compared to the technique performed from a prone position. Absolute reliability was evaluated through the calculation of SEM for each stretch position to ensure consistency of measurement. This statistic evaluated the reliability in actual units of

measurement (mm) to show the variation in length change during the three trials of each stretch position.¹⁹ The SEM showed a low value range of 1.05mm to 0.62mm which established effective test-retest reliability for all four positions.

Several cadaveric studies have been performed to assess length change in order to evaluate movement of the muscles in relation to the posterior approach for total hip arthroplasty,^{20,25,26} as well as peak strength and stretch as it relates to normal, gait-related movements.^{21,27} These studies utilized string modeling for representation of musculature, in order to assess the excursion or lengthening of the short external rotators, respectively.^{20,21,25,27} The use of string models has previously been validated and demonstrated the effectiveness of dividing muscles into different sections in order to accurately show movement.²⁵ The present study utilized this technique with only the piriformis being divided into a superior and inferior section based on the origin location of the anterior surface of the sacrum and greater sciatic notch.^{7,18}

CONCLUSION

While all stretch positions caused a length change for the deep rotators of the hip, the three stretch

positions that caused the greatest change in the short external rotators were 30° adduction from 90° of hip and knee flexion, 45° internal rotation from a neutral anatomical position, and 45° external rotation from 90° hip and knee flexion. The piriformis and SG had the greatest length change when adducting the hip 30° from 90° degrees of hip and knee flexion. The OI and IG had the greatest length change when internally rotating the hip 45° from neutral flexion/extension. These results have clinical implications for choices of the proposed stretches to effectively elongate the short external rotators of the hip in the clinical setting. Further studies are needed to validate the use of these stretches in patients who present with posterior hip and/or buttock pain.

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