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Reduced Hip Adduction is Associated with Improved Function after Movement Pattern Training in Young People with Chronic Hip Joint Pain

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Abstract

Study Design—Ancillary analysis, Time-Controlled Randomized Clinical Trial

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The protocol for this study was approved by the Human Research Protection Office of Washington University School of Medicine.

This study was not entered into the clinical trial registry. At the time of study start, it was determined that this study did not meet the criteria for registration. The participants in this study were enrolled from 2011–2013 and the data was collected 2011–2014.

Background—Movement pattern training (MPT) has been shown to improve function among patients with chronic hip joint pain (CHJP).

Objective—Determine the association among treatment outcomes and mechanical factors associated with CHJP.

Methods—Twenty-eight patients with CHJP, 18–40 years, participated in MPT, either immediately after assessment or after a wait-list period. MPT included task-specific training to reduce hip adduction motion during functional tasks and hip muscle strengthening. Hip-specific function was assessed using modified Harris Hip Score (MHHS) and Hip disability and Osteoarthritis Outcome Score (HOOS). 3D kinematic data were used to quantify hip adduction motion, dynamometry to quantify abductor strength, and magnetic resonance imaging to measure femoral head sphericity using alpha angle. Paired t-tests assessed change from pre- to post-treatment. Spearman correlations assessed associations.

Results—There was significant improvement in MHHS and HOOS ($P = .02$), adduction motion ($P = .045$) and abductor strength ($P = .01$) between pre- and post-treatment. Reduction in hip adduction motion ($r = -0.67$, $P < .01$) and lower body mass index ($r = -0.38$, $P = .049$) correlated with MHHS improvement. Alpha angle and abductor strength change were not correlated with change in MHHS or HOOS.

Conclusion—After MPT, patients reported improvements in pain and function that was associated with their ability to reduce hip adduction motion during functional tasks.

Level of Evidence—Therapy, level 2b

Keywords

femoroacetabular impingement; hip dysplasia; kinematics; movement system; rehabilitation

Chronic hip joint pain (CHJP), is a major cause of hip dysfunction in the young to middle aged adult, resulting in significant limitations in activity participation.^{5, 7, 26} Chronic hip joint pain, often associated with diagnoses such as femoroacetabular impingement, development dysplasia of the hip, chondral lesions, and acetabular labral tears, commonly presents during the early, pre-radiographic stage of osteoarthritis. Without proper treatment, these conditions are believed to progress to hip osteoarthritis,^{2, 15, 22, 28} a leading cause of reduced quality of life and loss of function for older people. There is a clear need for effective treatment strategies for people with CHJP to improve their function and potentially prevent or delay the onset of osteoarthritis.

Despite recent advances in our understanding of the hip conditions that contribute to CHJP, uncertainty still exists regarding the best treatment approach, in part, due to the limited available evidence, particularly for rehabilitation.^{1, 3, 10, 24, 30} The preponderance of literature is focused on surgical interventions and is primarily observational.¹⁰ There are no published randomized clinical trials (RCTs) to compare surgical to nonsurgical treatment outcomes. Despite this lack of evidence from high-quality studies, the number of surgical procedures to treat CHJP has grown exponentially.^{4, 23} Although rehabilitation provides a relatively inexpensive alternative to surgery, additional studies are needed to establish its

effectiveness and better understand the mechanical factors associated with treatment outcomes.

Movement pattern training (MPT) is a rehabilitation approach with the goal of reducing stresses on the hip joint by optimizing lower extremity and hip biomechanics during functional tasks.¹² MPT, as applied in this study, incorporates 2 primary components: 1) provide each person with *task-specific training* to correct impaired movement patterns during daily and patient-specific tasks, in particular the pattern of excessive hip adduction motion and 2) *strengthen weak hip musculature* thought to contribute to the impaired movement patterns. We previously reported the results of a feasibility RCT using MPT.¹² In the feasibility study,¹² patients with CHJP were randomized into one of 2 groups, an immediate treatment group who received MPT immediately after pretreatment testing and a wait-list control group, who then received MPT after a 6 week observational period. We demonstrated that people with CHJP reported improvements in function and a reduction in hip adduction motion after participating in MPT compared to those in the wait-list group.¹² Surprisingly, there was no significant difference between groups in hip muscle strength improvements.

The goal of the current study was to determine the association among treatment outcomes and mechanical factors proposed to be associated with CHJP, including lower extremity movement patterns, hip abductor strength, and femoral head sphericity associated with cam-type femoroacetabular impingement. We therefore, used data collected from *all patients who completed MPT*, including those who completed MPT immediately after baseline testing and those who were initially randomized to the wait-list group, then allowed to participate in MPT after the initial study phase.¹² Based on our previous findings of MPT on patient-reported function and movement patterns¹² we hypothesized that a reduction in hip adduction motion would be associated with an improvement in patient-reported outcomes (PROs). We also hypothesized that increased muscle strength after treatment and a smaller alpha angle, representing a normal femoral head neck sphericity would be associated with an improvement in PROs.

METHODS

Study design

This study presents ancillary data to a feasibility randomized clinical trial (RCT) using a time-controlled design.¹² FIGURE 1 provides an overview of the entire study design. Methods and results of the feasibility RCT comparing those patients who received MPT to those randomized to a wait-list have been published previously.¹² After completion of their waiting period and post-wait/pretreatment testing, patients initially randomized to the wait-list group participated in MPT. The data for all patients receiving MPT was pooled to perform the analysis in this study. This pooled data allowed additional analyses to investigate the mechanical factors associated with the treatment outcomes.

Participants

Potential participants included in this study were recruited between 2011 and 2013, from the community using public announcements, Washington University's School of Medicine research volunteer database and referrals from Washington University School of Medicine's clinical practice including orthopaedic surgery, physical medicine and rehabilitation, and physical therapy. To be eligible, patients had to be 18–40 years old and report CHJP, defined as anterior groin or deep hip joint pain present at least for the past 3 months. Hip joint pain had to be reproducible with the flexion, adduction, internal rotation (FADIR) test. Exclusion criteria included: 1) body mass index (BMI) greater than 30 kg/m² to allow reliable kinematic testing, 2) prior hip fracture or surgery, 3) contraindications for magnetic resonance imaging (MRI), 4) pregnancy, 5) neurological involvement that impaired coordination or balance, and 6) low back or knee pain limiting the ability to perform functional tasks. Potential participants were also screened for differential diagnosis and excluded if screening results indicated lumbar spine radiculopathy. This study was approved by the Human Research Protection Office of Washington University School of Medicine, and all patients signed an informed-consent statement prior to participating in the study.

Pretreatment Assessment

After consent was obtained, the patients participated in pretreatment assessment that included completion of questionnaires to document demographic information and PROs used to quantify hip-specific physical function and activity level. After a 5 minute warm-up using a stationary bike or treadmill, laboratory testing was completed that included 3D kinematic assessment to quantify lower extremity motion and resistance tests using hand-held dynamometry to quantify hip abductor strength. MRI was used to assess acetabular and femoral bony morphology.

Intervention

Movement pattern training included 6 one-hour supervised sessions and performance of a home program over a 6 week period. The MPT protocol included task-specific training to optimize lower extremity movement patterns during functional tasks and patient-specific tasks, and hip muscle strengthening. Specific details of the MPT protocol including instructions provided to the patient and criteria to progress functional tasks and strengthening exercises are provided in our previous report.¹² Briefly, the primary goal of task-specific training was to optimize the patient's lower extremity movement pattern during functional tasks. The primary movement impairment targeted was excessive hip adduction motion. A physical therapist provided instruction in the performance of daily functional tasks and patient-specific tasks. Patient-specific tasks included those reported by the patient to be symptom-provoking, such as fitness and work related tasks. After instruction in a more optimal movement strategy, the patient would practice performance of the task. The physical therapist provided feedback until the patient was able to perform the task independently¹³ and without increasing their hip joint pain. The patient was then instructed to use these modifications as they performed their tasks throughout the day.

Hip muscle strengthening included progressive resistance exercises targeting the hip abductors, external rotators, and flexors. Patients were progressed based on their

performance. Once they were able to complete 2 sets of 20 repetitions independently as determined by the physical therapist,¹³ they were progressed to the next level of difficulty. To be independent in an exercise, the patient had to demonstrate proper performance of the exercise with activation of the targeted muscle and without compensatory strategies. Muscle activation was verified by palpation where possible. The home exercise program included those exercises the patient could perform independently and without an increase in their hip joint pain. The patient was instructed to perform their home exercise program one time per day.

At each supervised session, the physical therapist observed the patient's performance of their assigned functional tasks and strengthening exercises. If the patient performed their functional tasks independently, the physical therapist would instruct them in new, more challenging tasks. If the patient was not independent in performing the task, the physical therapist provided additional instruction. Strengthening exercises were also progressed as previously described. Prior to each supervised session, the patient documented their adherence to their home exercise program by answering the following question, "Since your last treatment session, what percentage of your prescribed exercises did you perform?"

Posttreatment Assessment

After completion of the treatment phase, the patients returned for laboratory testing. The patient participated in the same testing procedures for questionnaire completion and kinematic and strength assessment used during pretreatment assessment. We did not repeat the MRI acquisition because we did not expect bony morphology to change during the 6 week timeframe.

Variables measured

Two PROs, modified Harris Hip Score (MHHS)⁶ and Hip disability and Osteoarthritis Outcome Score (HOOS),¹⁹ were used to assess pain and hip-specific physical function. The values for MHHS and the HOOS subscales, including Pain, Symptoms, Activities of Daily Living (ADL), Sport and Recreation (Sport), and Quality of Life (QOL) range from 0 to 100 with lower scores indicating lower levels of physical function. The MHHS and HOOS have high test-retest reliability^{16, 18, 25} and acceptable content validity.^{18, 25} Values for minimum important change (MIC) for nonsurgical management are not available, however Kemp et al¹⁸ established values for MIC for people with CHJP who have undergone arthroscopic surgery. The MIC values for MHHS and HOOS Subscales of Pain, Symptoms, ADL, Sport and QOL are 8, 9, 9, 6, 10, and 11 respectively.

Kinematic data for a single leg squat were captured using an 8-camera 3D motion capture system (Vicon, Los Angeles, CA). Retro-reflective markers were placed on anatomical landmarks of the pelvis and lower extremities. After a static calibration trial, the patient was instructed in the performance of the single leg squat and allowed to practice the motion prior to testing. Three trials of the single leg squat were then collected. Visual3D software (C-motion, Inc., Rockville, MD) was used to build segmental models of the pelvis and lower limb and to calculate joint kinematics. The kinematic variable, determined *a priori*, was hip adduction motion, represented by the hip adduction angle at peak hip flexion. Using our

described methods, we assessed test-retest reliability of peak hip adduction angle during the single leg squat for a sample of 7 asymptomatic individuals and obtained an intraclass correlation coefficient ($ICC_{3,3}$)²⁷ of 0.72 and standard error of measurements (SEM) of 1.69°.¹²

Hip abductor strength was tested in side lying with the hip in 15° of abduction.¹⁴ A break test was performed using a microFET3 hand-held dynamometer (Hoggan Health Industries, Salt Lake City, UT). Three trials testing maximal effort were averaged. Torque was then calculated by multiplying the force by the moment arm (distance between the hip and application of the dynamometer) of the external resistance. The test-retest reliability for hip abductor strength¹⁴ was an $ICC_{3,3}$ ²⁷ of 0.94 and SEM of 0.47.

Femoral head sphericity, an indicator of cam femoroacetabular impingement, was assessed using MRI.¹¹ Using a 3D gradient echo pelvic MRI sequence, a radial reformat was performed at 30° increments along the femoral neck axis to obtain alpha angle measurements at the 3, 2, 1, and 12 o'clock positions.²⁰ The maximum value of the 4 measured angles was used for analysis. Interrater reliability for our measures of alpha angle¹¹ were and $ICC_{2,1}$ ²⁷ of 0.78 and SEM of 2.6°.

Data Analysis

Patient demographics were compared for patients who did and those who did not provide posttreatment data by unpaired t-test (for age and BMI), Wilcoxon's 2-sample test (for ordinal variables), or Fisher's exact test (for categorical variables). Change was calculated by subtracting pretreatment from posttreatment values. Paired t-tests were used to assess change between visits in MHHS, HOOS subscales, hip adduction motion, and hip abductor strength. Spearman correlation coefficients were used to assess the relationship between change in PROs and change in hip adduction motion, change in hip abductor strength, and pretreatment alpha angle, age, and BMI.

A secondary analysis, calculating separate Spearman correlations for each group, was performed to determine the relationship between hip adduction motion reduction and scores on the PROs for those patients who reduced their hip adduction motion compared to those who did not. Unpaired t-tests were used to assess differences among variables that may be related to treatment response between those who did and did not reduce hip adduction motion. These variables included baseline hip adduction motion, baseline abductor strength, and adherence to home exercise program. *P*-values of less than .05 were considered statistically significant.

RESULTS

Thirty-five patients were enrolled and randomized in the initial phase.¹² Seven patients, 2 in the immediate group and 5 in the waitlist group, did not participate in treatment or posttesting, yielding 28 participants in the final analysis. There were no differences in demographics (TABLE 1), pain reports, or PROs between those who participated in treatment and those who did not. After treatment, there was significant improvement in all

PROs, hip adduction motion, and hip abductor strength compared to pretreatment values (TABLE 2).

Greater reduction in hip adduction motion after treatment ($r=-0.67$, $P<.01$) correlated with greater improvement in MHHS (FIGURE 2 and TABLE 3). A lower BMI ($r=-0.38$, $P=.049$) was also associated with greater improvement in MHHS. No significant association was noted between change in hip adduction motion and change in HOOS subscales when assessed for all patients. Alpha angle, age, and change in hip abductor strength were not associated with change in scores on PROs (TABLE 3).

Subgroup analyses demonstrated that for those patients who had reduced hip adduction motion after treatment ($n=18$), the amount of hip adduction motion reduction was associated with improvement in HOOS subscales of Pain ($r=-0.50$, $P=.04$), Symptoms ($r=-0.48$, $P=.04$), Sports ($r=-0.47$, $P=.05$), and QOL ($r=-0.59$, $P=.01$; TABLE 3). TABLE 4 provides pre and posttreatment outcomes for each subgroup and TABLE 5 the between group comparisons among factors related to treatment response. Mean $\pm$ SD baseline hip adduction motion was greater among those who were able to reduce their hip adduction compared to those who did not (21.9 ± 7.0 versus 16.8 ± 3.2 , $P=.02$). Self-report treatment adherence was higher among those who reduced their hip adduction motion, however this was not significant. There were no between group differences in baseline hip abductor strength.

DISCUSSION

Participation in MPT resulted in significant improvements in pain and function for individuals with CHJP. However, not all patients improved, with the patient's ability to reduce hip adduction motion after MPT being strongly associated with greater improvement. This suggests that normalizing this movement pattern may be an important component to rehabilitation. Surprisingly, improvements in hip abductor strength after treatment and femoral head sphericity were not associated with improvements in pain or function. Our results suggest that MPT may be an appropriate approach to non-operative management for people with CHJP and that the effectiveness may be associated with the patient's potential to reduce hip adduction during functional tasks.

To our knowledge, this is the first study to investigate the relationship among mechanical factors and post-rehabilitation improvement among people with CHJP. Our current sample is too small to fully assess the relationship among all pre and posttreatment factors and outcomes; therefore, we focused our analysis on those mechanical factors for which we had *a priori* hypotheses. As expected, we found a greater reduction in hip adduction motion was associated with a greater improvement in hip-specific function.

Rehabilitation for CHJP has previously focused primarily on strengthening or flexibility exercises targeting muscle weakness or extensibility deficits.^{8,9,17} Although patients in our study demonstrated muscle weakness,¹⁴ muscle strength was not associated with improvements in pain and function. Because of these relationships, we believe improvements in pain and function primarily were due to the training component of MPT

that incorporated decreasing excessive hip adduction angle into task-specific activities rather than the hip strengthening exercises.

The goal of task-specific training is to optimize lower extremity biomechanics during daily tasks, such as walking and stair ambulation, and patient-specific tasks, such as fitness and work-related activities. Impaired movement patterns, when present, are often observed across multiple tasks.^{21, 29} Based on the theory that repeated performance of an impaired movement pattern may lead to altered hip joint stresses and subsequent pain, we believe it is important to address all daily and patient-specific tasks during treatment, particularly those tasks reported to produce or increase hip symptoms. During pretreatment assessment, each patient identified specific tasks that were symptom-provoking. These tasks were prioritized during treatment, and training was provided to optimize the patient's movement strategy used while performing these tasks. Patients were then encouraged to practice these optimal movement strategies as they performed their tasks throughout the day, resulting in frequent practice. Despite the lack of association between change in hip abductor strength and improvement in pain and function, we cannot rule out that performing hip strengthening exercises did not contribute to the improved movement pattern.

In this study, 9 participants did not demonstrate a reduction in hip adduction motion, and interestingly, reported no improvement in the MHHS. Understanding the factors associated with the ability to reduce hip adduction motion may assist in determining who may best benefit from the MPT approach. Based on our secondary analysis, comparing those who reduced hip adduction motion and those who did not (TABLE 5), a potential factor of interest may be the patient's pretreatment value of hip adduction motion. Those with lower values of hip adduction at the pretreatment visit would have less ability to reduce hip adduction motion and therefore, reducing hip adduction motion may not be the ideal treatment target for this subgroup. Accordingly, we determined that hip adduction motion at pretreatment differed between those who reduced their hip adduction motion after treatment and those who did not (mean $\pm$ SD, 21.9 $\pm$ 7.0 $^{\circ}$ versus 16.8 $\pm$ 3.5 $^{\circ}$, $P=.02$). Based on our data, however we are unable to recommend a specific value of hip adduction motion that may predict a patient's posttreatment outcomes.

Given the hip abductors are the primary muscles that control hip adduction during a weight bearing tasks; one would expect that stronger hip abductor muscles would play a role in the ability to reduce hip adduction motion and thus improve pain and function, however this does not seem to be supported by our data (TABLES 3 and 5). It is noted that even though strength improved after treatment, patients in our study demonstrated continued weakness compared to an asymptomatic control group.¹⁴ Therefore, our results should be interpreted with some caution given the relatively small changes in strength that took place from pre to post treatment and the relative remaining hip muscle weakness, suggesting the need for a more optimal volume or duration of the strength training program. Other factors that may contribute to the ability to reduce hip adduction motion may need to be considered, for example, the timing of muscle activation during functional tasks, which would not be represented in our strength measures. Finally, the patient's adherence to their home exercise program may influence the patient's ability to reduce hip adduction motion. Self-report

adherence was higher (70% compared to 60%) among those who reduced their hip adduction motion, however this difference was not significant.

The maximum alpha angle measure, used to quantify cam impingement, was not associated with patient outcomes, suggesting the MPT approach may be appropriate for patients with and without cam impingement. Given our small sample, we are hesitant to conclude that bony morphology is not associated with treatment prognosis and recommend further investigation. Other osseous abnormalities, such as pincer impingement and acetabular dysplasia, should also be considered. Among our sample, 8 patients demonstrated imaging findings consistent with cam impingement (alpha angle $\geq 60^\circ$), 2 demonstrated a pincer impingement (lateral center edge angle $\geq 40^\circ$) and 1 demonstrated acetabular dysplasia (lateral center edge angle $\geq 20^\circ$). Given the low prevalence of pincer impingement and acetabular dysplasia in our sample, we chose to focus the analysis on cam impingement.

Limitations

Our findings should be considered in light of several limitations. We are unable to state if the reported change in hip adduction motion or score on the MHHS after treatment is clinically meaningful. To our knowledge, the MIC for hip adduction motion has yet to be determined. The MIC for the MHHS is based on a sample that has undergone arthroscopic surgery and therefore may not be directly applicable to non-operative treatment. Nevertheless, the strong association noted between hip adduction motion reduction and improvement in function supports the use of rehabilitation to target impaired movement patterns. Our sample is small, with the vast majority of the patients being women, which limits the generalizability of our results. Patients with CHJP enrolled in this study represent a heterogeneous population; some patients had bony abnormalities while others did not. Bony morphology did not appear to be associated with treatment outcomes in our sample, however a larger study would be needed to definitively determine the effect of bony abnormalities on treatment prognosis. We do not know the optimal dosage of MPT. It is possible that a longer duration of treatment may result in greater improvements. Finally, we are unable to comment on the individual contributions of task-specific training or muscle strengthening.

CONCLUSION

Participation in MPT to reduce hip adduction motion resulted in significant improvements in pain and function among patients with CHJP. Our study suggests that MPT may be an appropriate approach for people with CHJP, including those with femoroacetabular impingement. A better understanding of the factors that contribute to treatment outcomes will improve our ability to match patients to appropriate treatment strategies.

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KEY POINTS**Findings**

Participation in MPT to reduce hip adduction motion, resulted in significant improvements in pain and function among patients with CHJP. The patient's ability to reduce hip adduction motion was associated with greater improvements.

Implications

Movement pattern training, targeting hip adduction motion during daily tasks and patient-specific tasks, should be considered in the non-surgical management of patients with CHJP.

Caution

The sample size was small with the vast majority of patients being women, thus limiting the generalizability of the results.

FIGURE 1. Study flow diagram. Abbreviations: BMI: body mass index; MRI, magnetic resonance imaging

FIGURE 2.

Relation of change in hip adduction to change in Modified Harris Hip Score (MHHS) between pretreatment and posttreatment ($r=-0.67$, $P<.01$). Subgroups are identified for patients with reduced hip adduction motion (red plus) post-intervention and for those with increased hip adduction motion (blue circle). *Indicates 2 participants with similar values.

TABLE 1

Pre-treatment demographics for study participants.

Variable	All Enrolled Patients N=35	Patients Providing Posttreatment Data N=28	Patients who did not participate in treatment N=7	P Value*
Demographics				
Sex	29F:6M	24F:4M	5F:2M	.58 ^{//}
Limb side	19R:16L	15R:13L	4R:3L	1.0 ^{//}
Pain involved side	13R:9L:13B	10R:6L:12B	3R:3L:1B	.33 ^{//}
Age, years[†]	28.3±5.2	27.7±5.2	30.9±4.4	.13 [†]
BMI, kg/m²[†]	24.4±2.9	24.2±2.8	25.4±3.2	.32 [†]
UCLA[‡]	9 (3–10)	9 (3–10)	9 (4–10)	1.0 [#]
Pain report				
Duration, years[§]	2.0 (0.4–10)	1.8 (0.4–10)	2.0 (0.4–10)	.79 [#]
Avg pain[§]	3.5 (1–8)	3.0 (1–8)	4.0 (1–6)	.61 [#]
Worst pain[§]	6.0 (2–10)	6.0 (2–10)	6.0 (4–10)	.58 [#]

Abbreviations: Avg, average; B, bilateral; BMI, body mass index; F, female; M, male; L, left; R, right; UCLA, University of California Los Angeles Activity Score;

* Comparison between patients providing posttreatment data and patients who did not participate in treatment.

[†] Values are mean ± SD.[‡] Values are median (range). UCLA: patients are asked to rate their activity level over the previous 6 months. 0=wholly inactive, dependent on others; 10= regularly participates in impact sports.[§] Values are median (range). Pain rated by patients using a verbal numerical pain rating scale. 0=no pain; 10=worst pain imaginable^{//} P value by Fisher's exact test.^{††} P value by Unpaired t-test.[#] P value by Wilcoxon test.

TABLE 2

Pre and post-treatment outcomes

Variable	Pretreatment Mean $\pm$ SD	Posttreatment* Mean $\pm$ SD	Change [†] Mean $\pm$ SD	P Value [‡]
Patient-reported outcomes				
MHHS [§]	83.1 $\pm$ 9.8	87.2 $\pm$ 10.9	4.1 $\pm$ 8.9	.02
HOOSPain [§]	76.8 $\pm$ 13.4	82.7 $\pm$ 10.9	5.9 $\pm$ 11.3	.01
HOOSSymptoms [§]	71.7 $\pm$ 19.4	81.3 $\pm$ 15.4	9.6 $\pm$ 9.8	<.001
HOOSADL [§]	87.6 $\pm$ 12.7	93.6 $\pm$ 9.8	6.0 $\pm$ 9.5	.003
HOOSSport [§]	74.3 $\pm$ 18.0	83.3 $\pm$ 17.5	9.0 $\pm$ 15.1	.005
HOOSQOL [§]	64.7 $\pm$ 17.3	71.0 $\pm$ 17.3	6.3 $\pm$ 10.1	.003
Hip Kinematics(°)				
Adduction	20.2 $\pm$ 6.4	17.8 $\pm$ 5.9	-2.4 $\pm$ 6.0	.045
Hip Muscle Strength ^{//}				
ABDs	6.6 $\pm$ 1.7	7.5 $\pm$ 2.0	0.9 $\pm$ 1.7	.01

Abbreviations: ABDs, abductors with the hip abducted 15°; HOOS, Hip Disability and Osteoarthritis Outcome Score; HOOSADL, function in activities of daily living; HOOSSport, function in sports and recreation; HOOSQOL, function in quality of life; MHHS, Modified Harris Hip Score.

* Due to technical difficulties, posttreatment PROs were lost for one participant and post-treatment kinematics were lost for another.

[†] Change is calculated by subtracting the pretreatment value from the posttreatment value.

[‡] P value by paired t-tests.

[§] Patient-reported outcome measures with 100=no disability.

^{//} Torque values (Nm) were normalized by body weight (N) $\times$ height (m) $\times$ 100.

TABLE 3
Association of mechanical variables and change in Patient-Reported Outcome measures (PRO) between pre and post-treatment.*

Change [†] in patient-reported outcomes [‡]	Change [‡] in hip adduction [‡]		Additional variables			
	All	Patients who reduced hip adduction [§] n = 18	Patients who did not reduce hip adduction n = 8	Change [‡] in Hip Abductor strength	Maximum Alpha angle at pretreatment	BMI at pretreatment
MHHS	-0.67 (<.01)	-0.48 (.04)	0.19 (.65)	0.26 (.19)	0.02 (.92)	-0.38 (.049)
HOOSPain	-0.32 (.11)	-0.50 (.04)	0.12 (.78)	-0.14 (.48)	-0.15 (.48)	-0.11 (.60)
HOOSSymptoms	-0.20 (.32)	-0.48 (.04)	0.26 (.54)	-0.14 (.49)	-0.04 (.86)	-0.03 (.89)
HOOSADL	-0.24 (.23)	-0.31 (.21)	-0.16 (.71)	-0.10 (.62)	-0.02 (.94)	-0.17 (.39)
HOOSSport	-0.34 (.09)	-0.47 (.05)	-0.12 (.77)	0.03 (.87)	-0.11 (.58)	-0.23 (.25)
HOOSQOL	-0.35 (.08)	-0.59 (.01)	-0.10 (.82)	-0.31 (.12)	-0.18 (.37)	-0.21 (.30)

Abbreviations: BMI, body mass index; HOOS, Hip Disability and Osteoarthritis Outcome Score; HOOSADL, function in activities of daily living; HOOSSport, function in sports and recreation; HOOSQOL, function in quality of life; MHHS, Modified Harris Hip Score.

* Values represent Spearman Correlation Coefficients (P-value).

[†]Change is calculated by subtracting the pretreatment value from the posttreatment value.

[‡]Due to technical difficulties, posttreatment PROs were lost for one participant and posttreatment kinematics were lost for another.

TABLE 4

Pre and post-treatment outcomes

Variable	Patients who reduced hip adduction n = 18			Patients who did not reduce hip adduction n = 9		
	Pretreatment Mean $\pm$ SD	Posttreatment* Mean $\pm$ SD	Change† Mean $\pm$ SD	Pretreatment Mean $\pm$ SD	Posttreatment* Mean $\pm$ SD	Change† Mean $\pm$ SD
Patient-reported outcomes						
MHHS§	83.1 $\pm$ 10.2	89.3 $\pm$ 9.6	6.2 $\pm$ 9.3	83.3 $\pm$ 10.3	81.4 $\pm$ 12.5	-1.9 $\pm$ 3.8
HOOSPain§	80.4 $\pm$ 11.6	85.6 $\pm$ 7.7	5.1 $\pm$ 12.1	69.7 $\pm$ 15.4	75.3 $\pm$ 14.4	5.6 $\pm$ 8.8
HOOSymptoms§	75.3 $\pm$ 18.9	84.7 $\pm$ 12.5	9.4 $\pm$ 11.2	63.1 $\pm$ 20.2	72.5 $\pm$ 19.3	9.4 $\pm$ 6.8
HOOSADL§	89.1 $\pm$ 12.0	95.9 $\pm$ 6.1	6.8 $\pm$ 10.5	83.5 $\pm$ 14.6	87.5 $\pm$ 14.3	4.0 $\pm$ 7.8
HOOSSport§	79.2 $\pm$ 17.3	87.8 $\pm$ 13.8	8.7 $\pm$ 14.9	63.3 $\pm$ 16.5	71.1 $\pm$ 20.3	7.8 $\pm$ 16.6
HOOSQOL§	67.5 $\pm$ 15.9	74.1 $\pm$ 14.3	6.6 $\pm$ 10.9	58.6 $\pm$ 21.0	62.6 $\pm$ 22.2	4.0 $\pm$ 8.0
Hip Kinematics(°)						
Adduction	21.9 $\pm$ 7.0	16.5 $\pm$ 6.7	-5.4 $\pm$ 4.7	16.8 $\pm$ 3.2	20.3 $\pm$ 3.0	3.5 $\pm$ 3.4
Hip Muscle Strength//						
ABDs	6.5 $\pm$ 1.5	7.6 $\pm$ 1.9	1.2 $\pm$ 1.8	6.9 $\pm$ 2.3	7.1 $\pm$ 2.4	0.2 $\pm$ 1.3

Abbreviations: ABDs, abductors with the hip abducted 15°; HOOS, Hip Disability and Osteoarthritis Outcome Score; HOOSADL, function in activities of daily living; HOOSSport, function in sports and recreation; HOOSQOL, quality of life; MHHS, Modified Harris Hip Score.

* Due to technical difficulties, posttreatment PROs were lost for one participant and post-treatment kinematics were lost for another.

† Change is calculated by subtracting the pretreatment value from the posttreatment value.

§ Patient-reported outcome measures with 100=no disability.

// Torque (Nm) values were normalized by body weight (N) $\times$ height (m) $\times$ 100.

TABLE 5

Between group comparison among variables that may be related to the ability to reduce hip adduction.

Variable	Patients who reduced hip adduction n = 18 Mean ± SD	Patients who did not reduce hip adduction n = 9 Mean ± SD	P Value
Hip Kinematics(°)			
Baseline Adduction	21.9 ± 7.0	16.8 ± 3.2	.02 [*]
Hip Muscle Strength[‡]			
Baseline ABDs	6.5 ± 1.5	6.9 ± 2.3	.57 [‡]
Treatment adherence (%)[§]	70.2 ± 20.3	59.6 ± 16.1	.23 [‡]

Abbreviations: ABDs, abductors with the hip abducted 15°.

^{*} Unpaired t-test with Satterthwaite adjustment for unequal variances

[‡] Unpaired t-test

[‡] Torque (Nm) values were normalized by body weight (N) × height (m) × 100.

[§] Prior to each treatment session, the patient documented their adherence to their home exercise program by answering the following question, “Since your last treatment session, what percentage of your prescribed exercises did you perform?” The percentages reported at each visit were averaged and used for analysis.