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Original Article

Relationship between the Hip Abductor Muscles and Abduction Strength in Patients with Hip Osteoarthritis

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This study aimed to determine which muscle the gluteus maximus, gluteus medius, gluteus minimus (Gmin), or tensor fasciae latae (TFL) contributes most to hip abduction strength and to identify effective sites for cross-sectional area (CSA) Gmin and TFL measurement in hip osteoarthritis (OAhip) patients. Twenty-eight patients with OAhip were included. The muscle CSA and volume were determined using magnetic resonance imaging. Peak isometric strength was determined using hand-held dynamometry. Muscle volumes were normalized to the total muscle volume of hip abductors. Multiple regression analysis was performed. The difference between the CSA of Gmin and TFL was calculated, and correlations with volume and muscle strength were determined. Gmin volume was related to abductor muscle strength ($p = 0.042$). The peak CSA of the Gmin correlated with muscle volume and strength. The CSA of the TFL correlated with volume, with no difference between the CSA of the most protruding part of the lesser trochanter and peak CSA. Gmin volume was strongly related to abductor muscle strength. Peak CSA is a useful parameter for assessing the CSA of the Gmin among patients with OAhip. The CSA of the TFL should be measured at the most protruding part of the lesser trochanter.

Key words: gluteus minimus, tensor fasciae latae, cross-sectional area, muscle volume, hip osteoarthritis

Hip osteoarthritis (OAhip) is a chronic progressive disease that causes hip joint deformities. The age-standardized prevalence of radiographic and symptomatic OAhip is 19.6% [1,2]. Its main symptoms include decreased hip muscle strength, decreased range of motion (ROM), and pain during loading [3,4]. Additionally, the functional impairment associated with hip deformity can cause an abnormal gait [5,6], impair the ability to perform activities of daily living, and decrease the quality of life [7].

Patients with OAhip develop hip joint deformities, and the narrowing of the hip joint space is related to mechanical stress while gait [8]. It remains to be clarified whether the abnormal gait of patients with OAhip is a result of their attempt at reducing stress on the hip, but in clinical practice, treatment strategies aimed at improving gait are often implemented. The hip abductor muscle group, including the gluteus maximus (Gmax), gluteus medius (Gmed), gluteus minimus

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(Gmin), and tensor fasciae latae (TFL), is involved in determining the gait pattern in patients with OAhip. Effective interventions for the rehabilitation of this muscle group are needed.

Current clinical practice guidelines recommend therapeutic weight-bearing and resistance exercises for patients with OAhip [9]. Resistance training has been reported to reduce pain, stiffness, and self-reported disability and to improve muscle strength, physical function, and joint ROM [10, 11]. Therefore, resistance training aimed at increasing muscle volume should be performed for the hip abductor muscles to improve their strength, reduce abnormal gait, and decrease stress on the hip joint. Generally, the muscle that contributes the most to hip abduction is the Gmed. However, 2019 report on patients with OAhip evaluated muscle activity in gait and reported no change in Gmed muscle activity, but a change in Gmin activity instead [12]. We believe that the results of the 2019 study [12] differed from those of previous reports because we used needle electromyography instead of conventional surface electromyography to analyze the muscle activity of each muscle in detail. In recent years, muscle volume has been calculated from muscle cross-sectional area (CSA) obtained from magnetic resonance imaging (MRI) and other imaging data. However, there have been few reports examining the relationship between the volume of each muscle in the hip abductor muscle groupand muscle strength, and no such reports in patients with OAhip and advanced hip deformity. Identifying the muscle that is most involved in hip abduction strength may provide important insights into the progression of OAhip, and thereby contribute to the development of effective intervention strategies.

An objective assessment must be performed to identify intervention strategies for hip-abductor and other muscle dysfunction. MRI or computed tomography scanning can be used to non-invasively assess muscle volume and CSA [13-18]. Muscle volume has a strong correlation with muscle strength [19]. However, calculating muscle volume is time-consuming; it requires tracing the muscle from the measured CSA and summing all CSAs. Therefore, a simpler evaluation method is needed to identify measurement sites for CSA that reflect muscle volume and strength. Previous reports recommend measuring the Gmax just above the femoral head and the Gmed at the lowest end of the sacroiliac joint [17, 18]. However, the CSA measurement sites for the Gmin and TFL remain unclear. Although Ogawa *et al.* examined the relationship between the CSA and muscle volume of the Gmin and TFL, they did not evaluate the relationship between muscle strength and CSA [20], which was a limitation of their study; in fact, a valid measurement site for CSA that also reflects motor function remains unclear. If the measurement site of CSA, which reflects muscle volume and strength, could be identified, valid assessment sites could be proposed for the Gmin and TFL.

The primary objective of this study was to determine the relationship between the Gmax, Gmed, Gmin, and TFL muscle mass and abductor muscle strength in patients with OAhip and advanced hip deformity, and to determine which muscles contribute most to hip abductor muscle strength. The second objective was to investigate the relationship between the Gmin and TFL volume, muscle strength, and CSA, as well as to identify valid CSA measurement sites that reflect volume and muscle strength. Our findings could assist in the development of effective interventions and assessments for muscle strengthening in patients with OAhip.

Materials and Methods

Statement of ethics. This study was conducted in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards and was approved by the Ethics Committee of Niigata Bandai Hospital (approval no. 79). In addition, oral and written informed consent was obtained from all individuals participating in the study.

Research design. This was a cross-sectional observational study.

Participants. A total of 73 participants with OAhip and unilateral hip joint deformities were recruited between June 2017 and July 2019. The exclusion criteria were as follows: lower extremity pain in joints other than the affected hip joint (n = 26), advanced or end-stage OA in the contralateral hip joint according to the Japanese Orthopedic Association (JOA) criteria (n = 5) [21], history of hip disease other than OA, history of surgery on a joint of the lower extremity other than the hip, or insufficient data (n = 14). The final analysis included 28 participants (7 men and 21 women) with unilateral secondary OAhip without limited hip ROM who could maintain the prone and supine positions.

Measured parameters. The volume and fatty degeneration of the Gmax, Gmed, Gmin, and TFL were calculated. The measured CSAs of the Gmin included the peak CSA, CSA at the inferior margin of the sacroiliac joint, and CSA superior to the femoral head, as previously reported (Fig. 1) [17, 18]. The CSA of the Gmin muscle was measured from the inferior margin (lowest end) of the sacroiliac joint and just superior to the femoral head.

The measured CSAs of the TFL (Fig. 2) included the peak CSA, CSA superior to the greater trochanter, and CSA at the most protruding part of the lesser trochanter. The CSA of the TFL muscle was measured from just above the greater trochanter and the most protruding part of the lesser trochanter.

The leg length difference (spinal malleolar distance), muscle strength in all directions of the hip joint movement, and joint ROM were also measured.

Calculation of muscle volume and CSA using MRI. MRI measurements were obtained, and CSA and muscle volume were calculated using previously described methods [17, 18]. MRI scans were obtained using a Signa HDe system (GE Healthcare, Waukesha, WI, USA) under the following conditions: axial T1 fast-spin echo; field of view, 400 × 400; slice thickness, 3 mm, with no gaps between slices; echo time, 10.1 ms; repetition time, 450 ms; and voxel size, 320/400 × 192/400 × 3.0 ms. The participant was supine and in the prone position, stabilized in the center of the bed so that the line connecting the bilateral superior anterior iliac spines was perpendicular to the long edge of the bed. In addition, the hip joint at the midpoint of internal/external rotation was recorded [17, 18]. During the MRI, the line connecting the bilateral anterior superior iliac crests remained perpendicular to the bed to ensure proper participant positioning [17, 18]. MRI data were analyzed using ZedHip version 14 (Lexi Co., Tokyo). The peripheries of the Gmax, Gmed, Gmin, and TFL were traced, and the tracings were used to calculate the CSA of each muscle. The peak CSA was the slice with the largest CSA that was obtained. Muscle volume was calculated using the following formula: volume = (sum of all CSAs) × slice thickness.

The ratio of each muscle volume to the total muscle volume was calculated as follows: volume ratio = muscle volume/(total muscle volume of the Gmax, Gmed,

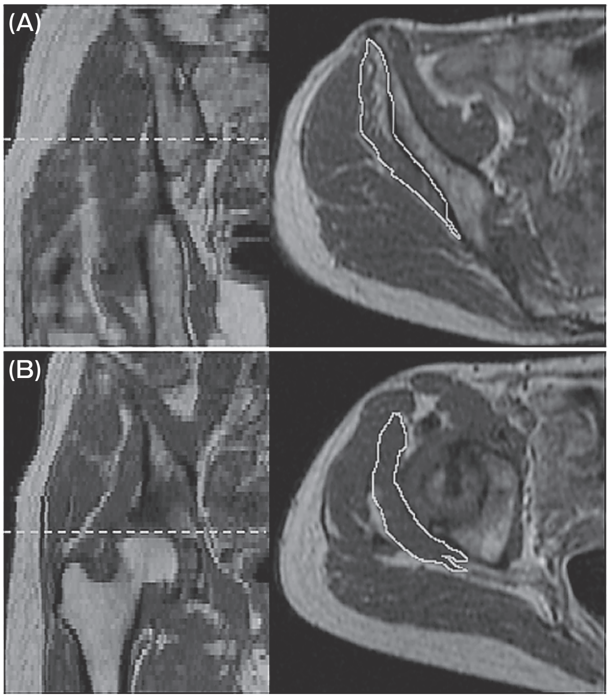

Fig. 1 Cross-sectional area of the gluteus minimus. The muscle cross-sectional area of the gluteus minimus was measured from the (A) lowest end of the sacroiliac joint and (B) just superior to the femoral head.

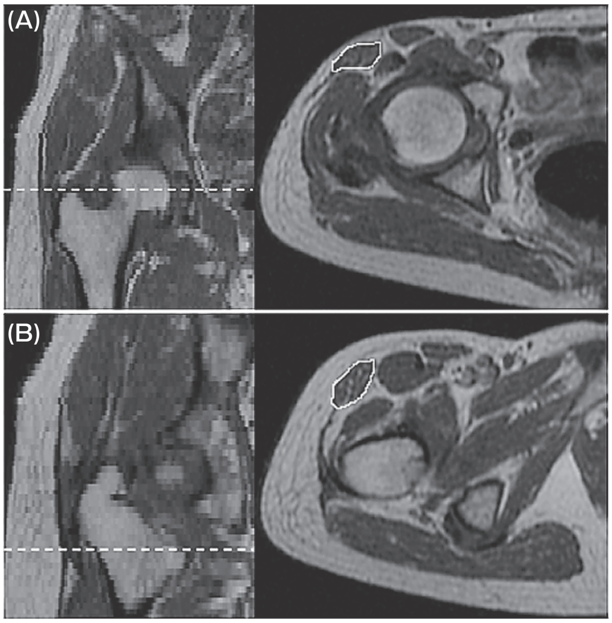

Fig. 2 Cross-sectional area of the tensor fasciae latae. The muscle cross-sectional area of the tensor fasciae latae was measured from (A) just above the greater trochanter and (B) the most protruding part of the lesser trochanter.

Gmin, or TFL). The ratio of each muscle volume to the total muscle volume of hip abductors was also calculated, excluding the gluteus maximus muscle, since it is the main action muscle of hip extension. We also calculated this ratio using the following equation: volume ratio of hip abductors = muscle volume/(total muscle volume of the Gmed, Gmin, and TFL).

The use of this equation to normalize muscle volume provides the mass percentage of each muscle in the hip abductor muscle group.

Evaluation of steatosis. The Goutallier classification method [22] was used to evaluate fatty degeneration in each muscle using the peak CSA, as previously described [16, 18, 23, 24]. Fatty degeneration was graded as follows: grade 0, normal muscle volume; grade 1, muscle containing some fatty streaks; grade 2, fatty infiltration with more muscle than fat; grade 3, equal amounts of muscle and fat; and grade 4, more fat than muscle.

ROM and isometric muscle strength measurements. The hip joint ROM was measured in all directions using a goniometer (University of Tokyo Type GS11-002; OG Wellness Technologies, Okayama, Japan), whereas isometric muscle strength was measured using a hand-held dynamometer (μTas F-1; Anima, Tokyo). The ROM was considered the maximum ROM. Muscle strength was measured using the reproducible and reliable method reported by Thorborg *et al.* [25]. Participants were placed in a non-gravity-dependent position for the measurements, as this position is less burdensome for patients with OAhip. The isometric strength was measured for two 5-second-long resisted contractions at an angle of 0° of hip abduction, and the highest value was used in the analysis. The abductor muscle force is created by the combined actions of the Gmax, Gmed, Gmin, and TFL; therefore, the abductor muscle strength was normalized by body weight, as described in previous studies [16, 26].

Abductor muscle strength was measured using a hand-held dynamometer as described previously [25]. The maximum voluntary isometric contraction was performed twice, and the larger of the two values was used.

Statistical analysis. All statistical analyses were performed using SPSS version 21 (IBM, Armonk, NY, USA). Continuous variables are reported as mean ± standard deviation. The normality of data distribution was evaluated using the Shapiro-Wilk test. The measurement sites for the CSAs of the Gmin and TFL were examined using the paired *t*-test or the Wilcoxon signed-rank sum test; the significance level was set at p-values of < 0.016 with Bonferroni correction. The relationships between the volume, strength, and CSAs of the Gmin and TFL were examined using Spearman's rank or Pearson's correlation coefficients; the significance level was set at p-values of < 0.016 with Bonferroni correction. The degree of fatty degeneration in each muscle was determined using Fisher's exact test; the significance level was set at $p < 0.008$ with Bonferroni correction.

A multiple regression analysis was used to examine which muscle had the greatest influence on abductor strength. The normality of variable distribution was verified using the Shapiro-Wilk test, and no dummy variables or variable transformations were used. The correlation matrix table was also checked, and no variables with r-values of > 0.9 were detected. A multiple regression analysis was performed using the stepwise method with abductor muscle strength/body weight as the dependent variable and each normalized muscle volume as the independent variable. The independent variable was selected based on the F-value probability and level of significance ($p < 0.05$).

Results

Most participants had advanced or end-stage hip deformity according to the JOA criteria (Table 1). The normalized muscle volumes of the Gmax, Gmed, Gmin, and TFL were 59.99 ± 3.92%, 26.31 ± 2.49%, 7.89 ± 2.54%, and 5.79 ± 1.40%, respectively. The muscle volumes normalized with only the Gmed, Gmin, and TFL were 66.07 ± 5.94%, 19.41 ± 5.70%, and 14.51 ± 3.35%, respectively (Table 1).

No significant difference between the peak CSA and the CSA measured at the inferior margin of the sacroiliac joint was identified for the Gmin (Table 2). The volume and strength of the Gmin were correlated with the peak CSA, but not with other CSAs (Table 3).

Furthermore, no significant difference in the peak CSA and the CSA measured at the most protruding part of the lesser trochanter was observed for the TFL (Table 2). The TFL volume was correlated with each CSA; however, muscle strength was not correlated with any CSA measurement (Table 3).

The degree of fatty degeneration in each muscle is shown in Table 4. Differences in fatty degeneration of each muscle were compared using Fisher's exact test. There was no significant difference between the Gmax and Gmed ($p = 0.632$) or between the Gmax and Gmin ($p = 0.013$). The Gmin was not significantly different from the TFL ($p = 0.461$) but had more advanced fatty degeneration than the Gmed ($p < 0.001$). The TFL showed more advanced fatty degeneration than the Gmax ($p < 0.001$) or the Gmed ($p < 0.001$).

A multiple regression analysis was conducted with a forward stepwise method. The dependent variable was the abductor muscle strength-to-weight ratio and the independent variables were each muscle volume-to-weight ratio. The regression equations were selected as follows. First, the analysis of the variance table for each model was checked for $p < 0.015$. The probability level for significance of the coefficients was $p < 0.015$, the standardized coefficient was 0.003, and the unstandardized coefficient was 0.009. Multiple regression analysis indicated that the Gmin volume was an independent predictor of abductor muscle strength in patients with OAhip ($p = 0.015$) based on the following regression equation: abductor muscle strength/w = $0.096 + 0.008 \times$ volume of the Gmin/(total volume of the Gmax, Gmed, Gmin, and TFL).

Table 1 Basic information on the participants

Variable	
Sex (male/female)	7/21
Age (years)	62.32 ± 7.41
Height (cm)	158.02 ± 6.45
Weight (kg)	55.03 ± 10.09
JOA radiographic stage	
Normal	0
Pre-arthritic stage	1
Early stage	0
Advanced stage	13
End-stage	14
Muscle volume (cm^3)	
Gluteus maximus	456.46 ± 111.88
Gluteus medius	199.35 ± 45.23
Gluteus minimus	58.64 ± 20.37
Tensor fasciae latae	42.93 ± 10.77
Normalized muscle volume (%)*	
Gluteus maximus	59.99 ± 3.92
Gluteus medius	26.31 ± 2.49
Gluteus minimus	7.89 ± 2.54
Tensor fasciae latae	5.79 ± 1.40
Normalized muscle volume of hip abductors (%)*2	
Gluteus medius	66.07 ± 5.94
Gluteus minimus	19.41 ± 5.70
Tensor fasciae latae	14.51 ± 3.35
Function of the hip joint	
Leg length difference (cm)	0.94 ± 0.85
Timed up and go test (sec)	8.40 ± 2.74
Pain in the loading hip joint during gait (visual analog scale: cm)	4.97 ± 2.54
Muscle power (kgf)	
Flexion	14.16 ± 4.63
Extension	15.35 ± 5.11
Abduction	8.94 ± 2.43
Adduction	9.43 ± 3.03
External rotation	9.93 ± 4.31
Internal rotation	9.85 ± 3.48
Range of motion (°)	
Flexion	101.60 ± 18.00
Extension	7.14 ± 4.79
Abduction	18.03 ± 9.36
Adduction	14.64 ± 4.69
External rotation	28.03 ± 13.96
Internal rotation	15.17 ± 16.47

JOA, Japanese Orthopedic Association.

*Normalized muscle volume (%) = muscle volume/[total muscle volume of gluteus maximus (Gmax), gluteus medius (Gmed), gluteus minimus (Gmin), and tensor fasciae latae (TFL)].

*2Volume ratio of hip abductors = muscle volume/(total muscle volume of the Gmed, Gmin, and TFL).

Discussion

Our study yielded the following novel findings: (1) The most protruding part of the lesser trochanter and the peak CSA around the inferior margin of the sacroiliac joint were the most effective sites for CSA measurement in the TFL and Gmin, respectively; and (2) the volume of the Gmin may be the most important contributor to abductor muscle strength in patients with OAhip.

First, regarding the verification of the measurement site for the CSA of the Gmin, only the peak CSA was significantly correlated with volume and strength (Table 3). The results of this study suggest that the peak CSA could be a useful index for estimating the volume and strength of the Gmin. No significant difference was identified between the peak CSA of the Gmin and the CSA measured at the inferior margin of the sacroiliac joint (Table 2). Therefore, by considering the inferior margin of the sacroiliac joint as a landmark and using the peak CSA that exists around it as an index, we can estimate the CSA that reflects the volume and muscle strength of the Gmin.

All CSAs of TFL were significantly correlated with

Table 2 Cross-sectional areas of the gluteus minimus and tensor fasciae latae

Gluteus minimus CSA (cm^2)		Difference	*P*-value
Peak (a)	1.34 ± 0.28	a>b†	0.494
Inferior margin of the sacroiliac joint (b)	1.32 ± 0.34	b>c	<0.001*
Superior to the femoral head (c)	0.61 ± 0.55	a>c	<0.001*
Tensor fasciae latae CSA (cm^2)			
Peak (e)	5.35 ± 1.43	e>f†	<0.001*
Superior to the greater trochanter (f)	3.15 ± 1.11	g>f†	<0.001*
Most protruding part of the lesser trochanter (g)	5.25 ± 1.28	e>g†	0.254

Data were compared using the Wilcoxon signed-rank test, unless otherwise noted.
†Paired-samples *t*-test. *Indicates $p<0.016$ (Bonferroni correction: 0.05/3). CSA, cross-sectional area.

Table 3 Relationships between cross-sectional area, muscle volume, and muscle strength

Gluteus minimus	Volume (cm^3)		Strength (kgf)	
	r	*P*-value	r	*P*-value
Volume	–	–	0.590	<0.001*
Peak CSA	0.538	0.003†*	0.574	0.001*
CSA at the inferior margin of the sacroiliac joint	0.327	0.089†	0.163	0.407
CSA superior to the femoral head	0.136	0.491†	−0.040	0.841†
Tensor fasciae latae	r	*P*-value	r	*P*-value
Volume (cm^3)	–	–	0.187	0.341
Peak CSA	0.853	<0.001*	−0.002	0.991
CSA superior to the greater trochanter	0.695	<0.001*	0.101	0.608
CSA at the most protruding part of the lesser trochanter	0.868	<0.001*	0.142	0.472

Data were compared using Pearson's correlation coefficient, unless otherwise noted.
†, Spearman's correlation. *Indicates $p<0.05$. CSA, cross-sectional area.

Table 4 Fatty degeneration of the Gmax, Gmed, Gmin, and TFL according to Goutallier classification

	Goutallier classification (Goutallier *et al*., 1994)				
	Grade 0	Grade 1	Grade 2	Grade 3	Grade 4
Gmax	2	11	9	4	2
Gmed	3	11	7	7	0
Gmin	0	3	8	9	8
TFL	0	0	8	11	9

Gmax, gluteus maximus; Gmed, gluteus medius; Gmin, gluteus minimus; TFL, tensor fasciae latae.

muscle volume but not with muscle strength. While the TFL contributes to hip abduction, its muscle fibers align differently than those from muscles involved in pure abduction (such as those of the Gmed and Gmin). Furthermore, the TFL is a small muscle that encompasses approximately 5.7% of the hip abductor group; it showed more advanced fat degeneration than the Gmax and Gmed. The TFL had a different muscle fiber type;

it was smaller and had more advanced fatty degeneration than other abductor muscles, leading us to suspect that there was no correlation between TFL volume or CSA and muscle strength. There was no significant correlation between each CSA and muscle strength, but there was a correlation with volume; specifically, peak CSA and CSA obtained at the most protruding part of the lesser trochanter had a large correlation coefficient ($r > 0.8$). There was no significant difference between peak CSA and CSA values obtained at the most protruding part of the lesser trochanter. These results suggest that the CSA of the TFL reflects the volume and is valid as an index when measured using the most protruding part of the lesser trochanter.

Next, multiple regression analysis revealed the contribution of the Gmin to abductor muscle strength. The Gmed is generally considered to be the most influential muscle in hip abductor strength. In previous studies using the CSA of healthy subjects as an indicator [27,28], the ratios of the Gmed, Gmin, and TFL to total muscle CSA were reported to be approximately 60-70% for the Gmed, 20-30% for the Gmin, and 4-10% for the TFL, with the Gmed being the largest among the muscles primarily involved in the abduction. In terms of moment arms, the Gmed and Gmin may also contribute significantly to abduction. Since the muscle with the more effective moment arm for abduction muscle force is usually considered to be the muscle with the larger muscle volume, Gmed is generally considered to make the greatest contribution to abduction muscle force, followed in order by Gmin and TFL.

However, in this study, the Gmin was selected by multiple regression analysis. One of the main reasons for this may be that the participants had OAhip. OAhip is a highly advanced hip deformity and is thought to be related to a decrease in Gmin muscle volume and a decrease in Gmin muscle exertion due to progressive fatty degeneration and changes at the moment arm associated with misalignment of the axis of motion.

In the present study, the percentage of total muscle volume attributable to the Gmin was 7.89 ± 2.54%. We measured the muscle volume ratio in the abductor muscle group excluding the Gmax, and calculated ratios of 66.07 ± 5.94% for the Gmed, 19.41 ± 5.70% for the Gmin, and 14.51 ± 3.35% for the TFL. In general, muscle mass is correlated with CSA, so we considered this with previous studies [27,28]. The ratio of the Gmed remained the same in patients with OAhip, but the ratio of the Gmin decreased and the ratio of the TFL increased. These results might indicate that while the Gmed did not change, the Gmin atrophied with progressive deformation, resulting in compensatory TFL muscle hypertrophy. This suggests that subjects with progressive deformation have more pronounced atrophy of the Gmin than of the Gmed. The Gmin is the second largest contributor to abductor muscle strength after the Gmed, so the decrease in muscle volume of the Gmin in the hip abductor muscle group may have affected abductor strength in our patients with OAhip.

Similarly, when assessing fat denaturation using the Goutallier classification [16,18,23,24], the Gmin had more advanced fatty degeneration than the Gmed. The progression of Gmin fatty degeneration likely led to a decrease in muscle mass as well as a decrease in muscle exertion. Additionally, the advanced deformity of the hip joint caused the axis of motion to shift from the joint center of the femoral head, which altered the moment arm and made muscle exertion difficult from a biomechanical point of view. For these reasons, the Gmin was selected as a predictor of abductor muscle strength.

The TFL, which experienced an increase in muscle mass relative to the decrease in muscle mass of the Gmin, is a muscle that is less involved in abduction in terms of moment arm compared to the Gmed and Gmin. In addition, although muscle hypertrophy occurred, TFL fatty degeneration was more advanced than that in the Gmax and Gmed, so TFL was expected to have only a minimal effect on abductor muscle strength.

The anatomy of the Gmin, along with the progression of advanced deformity, is a strong factor in the decrease in volume of the Gmin and the progression of fatty degeneration. Unlike the Gmax, Gmed, or TFL, the Gmin is attached to the hip joint capsule, which is located deep in the body [29-31]. Due to its presence and proximity to the joint, the Gmin is considered more susceptible to hip deformity and impingement than other periarticular muscles. Malloy *et al.* previously examined the difference in CSA between the impingement and contralateral sides in patients with unilateral femoroacetabular impingement syndrome and found significantly less Gmin CSA on the impingement side [32]. These results suggest that the Gmin may be more susceptible to hip deformity and impingement. Therefore, we hypothesize that the Gmin of patients with OAhip is strongly affected by hip deformity, and that as the muscle fiber length and moment arm change, there is insufficient muscle contraction, leading to the progression of atrophy and fatty degeneration. For future investigation, it is necessary to compare whether this change in the Gmin is characteristic of OAhip by conducting a study on patients with OAhip and healthy controls, and examining whether the same result is obtained in early OA when the hip deformity is mild. By clarifying this point, the importance of Gmin intervention in subjects with early deformity can be determined.

Our results indicated that the Gmin contributes to abductor muscle strength, which supports a recent study by Zacharias *et al*. who reported on gait in patients with OAhip and found that Gmed muscle activity was unchanged but Gmin muscle activity was altered [12]. This suggests that the Gmin not only is involved in abductor muscle strength, as verified in this study, but also has a significant impact on gait function. Clinically, this indicates that exercise therapy focused on the Gmin may prevent the progression of atrophy and fatty degeneration and contribute to the maintenance of muscle function in OAhip. This may also be effective in preventing muscle weakness and the characteristic claudication of OAhip. Exercises that effectively contract the Gmin have been demonstrated in previous studies [33], and effective muscle activity can be obtained by loading in the mild abduction position. Clinics with a large number of patients with mild deformities should intervene prophylactically to prevent deterioration of the Gmin. For patients with advanced deformity, it is important to intervene to maintain muscle function and to prepare for regaining hip function after surgical therapy such as total hip arthroplasty.

This study had some limitations. First, the sample size was small. In the future, a sufficiently large study will be needed to elucidate the detailed Gmin characteristics of patients with OAhip through comparison with healthy controls and early OAhip cases. In addition, while our results were obtained by measuring muscle strength at 0° hip abduction, different muscles may be involved in strength at different joint angles.

In conclusion, we proposed sites to measure the CSA of Gmin and TFL. We also suggested that the Gmin volume could be used as an index of the hip abduction muscle strength in patients with OAhip. The measurement sites for the CSA used in this study can be evaluated using non-invasive methods and may be useful to evaluate the overall muscle volume and strength. Lastly, given that the Gmin was related to muscle strength, early intervention to enhance the strength and volume of the Gmin may be particularly useful in the rehabilitation of patients with OAhip.

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