

ORIGINAL ARTICLE

Asymmetry of the Cross-sectional Area of the Gluteus Medius Muscle Persists Eight Years after Total Hip Arthroplasty for Osteoarthritis of the Hip

Kazuko Isshiki, PT, MS ^{a,b} Tetsuya Jinno, MD, PhD ^c Junya Aizawa, PT, PhD ^d Ryohei Takada MD, PhD ^e
Tomoko Sakai, MD, PhD ^a Tetsuya Tachibana, MD ^c and Atsushi Okawa, MD, PhD ^a

Objectives: The objective of the present study was to compare the cross-sectional areas (CSAs) of the gluteus medius on the affected and unaffected sides to assess long-term changes after total hip arthroplasty (THA). **Methods:** The data for 23 women who were diagnosed with unilateral hip osteoarthritis and who underwent primary THA via the posterolateral approach were retrospectively reviewed. The demographic data of the patients and the Japanese Orthopaedic Association hip scores were obtained from medical records. The CSA of the gluteus medius was measured on computed tomography images obtained at three different time points: preoperatively, 3 years postoperatively, and 8 years postoperatively. **Results:** The CSA of the gluteus medius on the affected side was significantly greater than the preoperative value at 3 ($P<0.005$) and 8 years postoperatively ($P<0.001$). The mean increase in the CSA relative to the preoperative value was 24.0% at 3 years and 37.5% at 8 years postoperatively. There was no significant change in the CSA of the unaffected side at any time point. The CSA of the gluteus medius was significantly smaller on the affected side than on the unaffected side preoperatively ($P<0.001$), 3 years postoperatively ($P<0.001$), and 8 years postoperatively ($P<0.003$). **Conclusions:** Because the gluteus medius is important for achieving stability when walking, it is important to maintain or increase the CSA of the gluteus medius by regular or long-term rehabilitation interventions (such as maintaining abductor muscle strength) from the early stages of osteoarthritis and to provide guidance on effective training both before and after THA.

Key Words: abductor; CT images; medium to long-term; post-THA; women

INTRODUCTION

Total hip arthroplasty (THA) is the most commonly performed orthopedic surgical procedure for patients with hip osteoarthritis (OA). In Japan, 59,029 THA procedures were carried out in 2017.¹ In recent years, the durability of THA implants has improved,^{2,3} and their lifetime is estimated to be 25 years in 58% of patients.⁴ In 2020, the mean lifespan

for Japanese people reached its highest level ever, at 81.6 years for men and 87.7 years for women. Coupled with the improvements in implant durability, this means that the number of patients with long-term THA implants is projected to increase.

The characteristics of hip joint dysfunction in hip OA patients include reduced hip abductor muscle strength,^{5,6} hip pain, and decreased gait function.⁵ As OA progresses, the

Received: July 29, 2021, Accepted: December 1, 2021, Published online: December 25, 2021

^a Department of Rehabilitation Medicine, Tokyo Medical and Dental University, Tokyo, Japan

^b Department of Physical Therapy, Faculty of Health Sciences, Ryotokuji University, Chiba, Japan

^c Department of Orthopaedic Surgery, Dokkyo Medical University, Saitama Medical Center, Saitama, Japan

^d Department of Physical Therapy, Faculty of Health Sciences, Juntendo University, Tokyo, Japan

^e Department of Orthopaedic Surgery, Tokyo Medical and Dental University, Tokyo, Japan

Correspondence: Tomoko Sakai, MD, PhD, Department of Rehabilitation Medicine, Tokyo Medical and Dental University, 1-5-45 Yushima, Bunkyo-ku, Tokyo 113-8519, Japan, E-mail: t_sakai.orth@tmd.ac.jp

Copyright © 2021 The Japanese Association of Rehabilitation Medicine



This is an open-access article distributed under the terms of the Creative Commons Attribution Non-Commercial No Derivatives (CC BY-NC-ND) 4.0 License. <http://creativecommons.org/licenses/by-nc-nd/4.0/>

volume of the gluteus medius also decreases.⁷⁾ Of the hip abductor muscles, the gluteus medius is the most important in that it stabilizes the femoral head in the acetabulum⁸⁾ and acts to maintain the horizontal position of the pelvis during walking. Weakness of the gluteus medius is a major cause of gait abnormalities and is seen as the Trendelenburg sign, the Duchenne sign, and the Trendelenburg inverse sign. In post-THA rehabilitation, it is therefore common to assess the strength of the gluteus medius and related structures and to use this as the basis for exercises and guidance with the aim of improving gait function. Patients who have undergone post-THA rehabilitation have significantly improved muscle strength and gait function compared with patients who have not undergone such rehabilitation.^{9–11)}

One study, however, found that even 10 years after surgery, hip abductor muscle strength in THA patients was 9.5% lower on the THA side compared with a control group matched for age and sex, and their maximum walking speed was 14.8% lower; both findings were significant.¹²⁾ Nonetheless, in a study of the post-THA cross-sectional area (CSA) of the hip muscles,¹³⁾ the CSA of the gluteus medius at a mean of 4 years postoperatively was significantly larger than that at 3 weeks postoperatively. However, the subjects of that study were patients who had undergone bilateral THAs. A few studies of the long-term outcomes of THA patients have reported clinical outcomes based on factors such as hip abductor muscle strength, balance, and gait speed. These studies suggested that, although the muscle strength of THA patients approached that of healthy individuals over time, functional impairment may persist in the medium to long term;^{12,14)} however, there are no reports on the long-term changes in hip muscle CSA.

The objective of the present study was to compare the gluteus medius CSAs of the affected and unaffected sides over time to assess the long-term changes in unilateral THA patients. We hypothesized that the CSA of the gluteus medius on the affected side would increase compared with that before THA and that the preoperative and postoperative CSAs of the gluteus medius on the affected side would be smaller than that of the unaffected side, with this asymmetry persisting over the medium and long term post-THA.

MATERIALS AND METHODS

This retrospective study was conducted following the approval of the Research Ethics Committee of the Tokyo Medical and Dental University (M2009-608) and in accordance with the World Medical Association Declaration of Helsinki.

Informed consent was obtained in writing from all participants included in this study.

The data of patients who were diagnosed with unilateral end-stage hip OA and who underwent primary THA between July 2002 and November 2004 were reviewed. In all cases, THA was conducted via the posterolateral approach using cementless implants. Patients to whom any of the following applied were excluded from the study: bilateral THAs, revision arthroplasty, previous trunk or leg surgery, history of a central nervous system disorder or other disease affecting gluteus medius CSA, history of any postoperative complications including periprosthetic fracture, dislocation, nerve injury, infection, and serious medical conditions. Because the majority (close to 83%) of THA patients for OA in Japan are women,^{1,15)} male patients were excluded from this study to avoid the effects of sex and to simplify the analysis. Also excluded were patients whose pelvis was clearly seen to be tilted during the CT scan from which the CSA was measured, as were those with issues with the CT data, such as pronounced halation making it difficult to trace the CSA. Patients with leg lengthening of 1.5 cm or more were excluded to minimize the effect of the difference in CT slice levels. The date of surgery, the age at surgery, patient height, patient weight, the affected side, CT scan dates, amount of leg lengthening, medical history, and the Japanese Orthopaedic Association (JOA) hip score were obtained from the patients' medical records. These data were used to calculate the body mass index and the time from surgery to CT scans. The amount of leg lengthening was calculated using the preoperative and postoperative anteroposterior pelvic radiographs. Postoperative anteroposterior and lateral pelvic radiographs were compared with those taken immediately postoperatively, and the stability of the implant was evaluated. The JOA hip score is the most widely used score in Japan and consists of four subcategories: pain (0–40 points), range of motion (0–20 points), walking ability (0–20 points), and activities of daily living (ADL; 0–20 points). The highest score is 100 points, which means that the hip joint function is good; the JOA hip score is reported to correlate strongly with the Harris Hip Score.^{16,17)}

The CSA of the gluteus medius was measured on CT images scanned at three different times: preoperatively, 3 years postoperatively, and 8 years postoperatively. The CT scanning conditions were 120 kV, 300 mA, 4.0-s scan time, and 1-mm slice thickness. Postoperative CT scans were those performed to screen for osteolysis following THA.¹⁸⁾

CSA measurements were carried out by importing the CT images into a three-dimensional image processing viewer

(ZioCube, Ziosoft, Tokyo, Japan). The top of the femoral head on the unaffected side was used as an anatomical landmark, with measurements conducted using a horizontal slice at this level. The exterior circumference of the gluteus medius was manually traced, and the CSA was measured. Following the method of Arokoski et al.,¹⁹⁾ each trace was carried out three times and the mean value was used for CSA analysis. The preoperative value of the CSA was taken as 100%, and the mean rates of change over time in the CSA at 3 and 8 years postoperatively were calculated. The mean percentage difference between the CSA of the affected side and that of the unaffected side at each time point was also calculated.

CSA measurements were made by a single investigator, but to verify the validity of these measurements, their inter-investigator reliability between two different investigators was evaluated. These two investigators measured the CSAs of 10 patients, and their intraclass correlation coefficients (ICCs) were calculated. To evaluate intra-investigator reliability, the same investigator also measured the CSAs for a second time after an interval of more than 6 months, and the ICCs were calculated.

The normality of the JOA hip score and the CSA data was tested using the Shapiro-Wilk test, with $P < 0.05$ considered significant. Because the JOA hip scores 3 years and 8 years after THA did not follow normal distributions, the changes over time in the JOA hip score were compared using Wilcoxon's signed-rank test. The significance level was set at 0.025 after Bonferroni's correction for the two combinations. Moreover, because the CSA of the unaffected side after THA did not follow a normal distribution, the changes over time of the CSAs of the affected and unaffected sides and the differences between the affected and unaffected sides at the same time points were compared using Wilcoxon's signed-rank test in the following nine combinations: the affected side preoperatively and 3 years postoperatively, preoperatively and 8 years postoperatively, and 3 years and 8 years postoperatively; the unaffected side preoperatively and 3 years postoperatively, preoperatively and 8 years postoperatively, and 3 years and 8 years postoperatively; and the affected and unaffected sides preoperatively, 3 years postoperatively, and 8 years postoperatively. The significance level was set at 0.005 after Bonferroni's correction for the nine combinations; the SPSS software package (version 26, IBM Japan, Tokyo, Japan) was used for all statistical analyses.

RESULTS

Patient selection is shown in **Fig. 1**. Ninety-five patients were diagnosed with unilateral hip OA and underwent primary THA during the period under analysis. After excluding 19 men, 2 patients who had previous trunk or leg surgery, 3 patients who had a history of periprosthetic fracture, and 22 patients who had a history of central nervous disorder or other disease affecting the muscle CSA, 49 patients' CT data were confirmed. Of these, 13 were excluded because they had not undergone CT scans at around 3 or 8 years postoperatively, 1 because the second scan was performed at 1 year 6 months postoperatively, and 12 because of CSA measurement problems (in 6, part of the gluteus medius was missing from the CT image, in 3 the pelvis was severely tilted, in 2 the CSA could not be measured because of halation, and in 1 the CT slice thickness was 10 mm), leaving an analysis population of 23 patients. No patients had leg lengthening of 1.5 cm or more. **Table 1** shows the basic attributes and patient data for these study subjects. These patients had had a symptomatic hip for an average of 5 years (range, 1–50 years) before undergoing THA. For five patients, the time of onset of symptoms was unclear.

Table 2 shows the total JOA hip score at each time point. The JOA hip score was significantly higher at 3 years ($P < 0.001$) and at 8 years postoperatively ($P < 0.001$) compared with preoperatively. No patient scored 0 points for pain on the JOA hip score at 3 years and 8 years postoperatively; all subjects felt no pain when walking and had a pain score of 30 points or higher. The walking ability of the JOA score averaged 19.1 ± 1.5 points after 3 years and 19.3 ± 1.7 points after 8 years, and all subjects were able to walk for about 30 min, or more than 2 km, with no difficulty in daily outdoor activities.

Pre- and post-THA rehabilitation was implemented by a physiotherapist in accordance with the clinical pathways. Rehabilitation started on the second postoperative day with full weight bearing. On the third postoperative day, range-of-motion exercises, muscle-strengthening exercises, and ambulation exercise using a walker or a cane were started. Patients were discharged an average of 20 days (range, 13–33) after surgery. The average number of rehabilitation sessions carried out after discharge from the hospital was 0.2 (range, 0–3). During hospitalization, it was ensured that patients understood the dislocation limb position and the movements to avoid the dislocation limb position. Moreover, patients were instructed to continue strengthening exercises around the hip joint and lower limbs after discharge. All im-

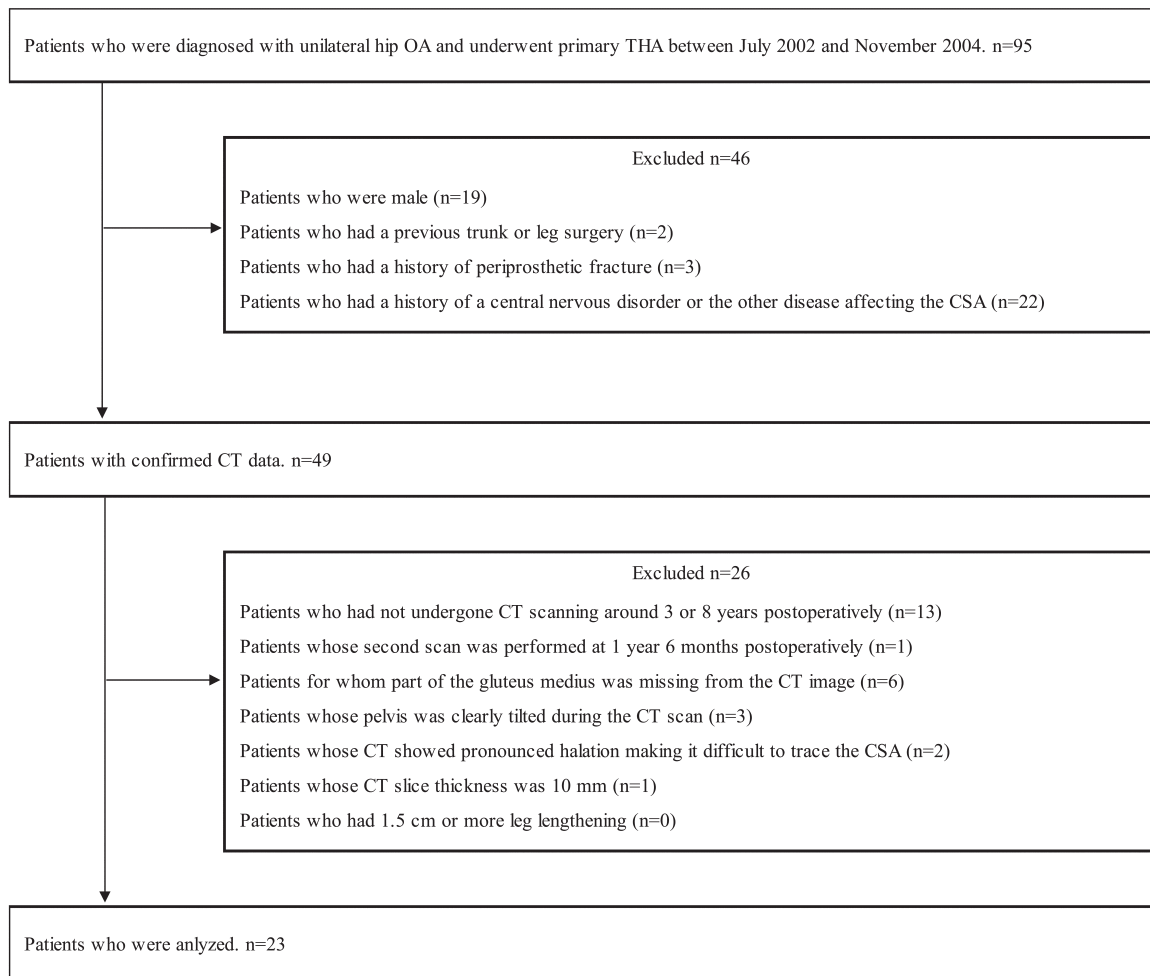


Fig. 1. Flow chart of patient selection.

Table 1. Patient demographics

Parameter	Value
Age at surgery (years)	62.0 ± 8.3
Height (cm)	151.4 ± 4.6
Weight (kg)	52.7 ± 10.8
Body mass index (kg/m ²)	23.1 ± 5.1
Affected side (right/left)	9/14
Days from preoperative CT to surgery (days)	18.8 (6.0–27.5)
Days from surgery to CT 3 years postoperatively (days)	1094.2 (1091.0–1101.0)
Days from surgery to CT 8 years postoperatively (days)	3129.1 (2919.0–3285.0)
Amount of leg lengthening (mm)	8.4 ± 4.5

Values expressed as means ± standard deviation or medians (interquartile range).

plants were radiographically confirmed to be bone-ingrown stable throughout the observation period.

The inter-investigator reliability of CSA measurements [ICC (2, 1)] was 0.978, and the intra-investigator reliability [ICC (1, 1)] was 0.998, indicating that the reliabilities were

extremely high.

Table 3 shows the median values and interquartile ranges of the CSAs of the gluteus medius on the affected and unaffected sides at each time point and the percentage difference of the CSA of the affected side compared with the unaffected

Table 2. Japanese Orthopaedic Association hip score

	Total score
Preoperatively	55.6 ± 15.6
3 years postoperatively	93.2 ± 6.5**
8 years postoperatively	94.2 ± 5.3**

Values are expressed as means ± standard deviation.

**P<0.001, significantly different compared with preoperatively, Wilcoxon signed-rank test.

side. The CSA on the affected side was significantly greater than the preoperative value at 3 years ($P < 0.005$) and 8 years postoperatively ($P < 0.001$). The mean increase in the CSA relative to the preoperative value was 24.0% at 3 years and 37.5% at 8 years postoperatively. There was no significant change in the CSA of the unaffected side at any time point (**Table 3, Fig. 2**). The CSA on the affected side was significantly smaller than that on the unaffected side preoperatively ($P < 0.001$), at 3 years postoperatively ($P < 0.001$), and at 8 years postoperatively ($P < 0.003$) (**Table 3, Fig. 2**).

DISCUSSION

In the present study, the CSAs of the gluteus medius on the affected and unaffected sides were evaluated using CT images scanned preoperatively and at 3 and 8 years postoperatively. The most noteworthy result was that, although the CSA of the gluteus medius on the affected side was significantly higher at both 3 and 8 years postoperatively than it had been preoperatively, it remained smaller than the unaffected side at both 3 and 8 years postoperatively.

Uemura et al.¹³⁾ compared the CSA of the gluteus medius in 40 THA patients at 3 weeks and ≥ 2 years postoperatively (2–8.5 years, mean 4 years) and found that, at ≥ 2 years postoperatively, the CSA of the gluteus medius had increased by 11%. In the present study, the CSA had increased by 24% at 3 years postoperatively, a significant increase, and this finding that muscle volume can recover even when more than 2 years have elapsed since THA was similar to Uemura's¹³⁾ result. However, the rate of increase of the gluteus medius CSA differed between the two studies. The subjects of Uemura's study had been experiencing symptoms in the opposite hip that were mild enough to be ignored when their initial THA was performed; however, they all subsequently underwent THA of the opposite hip, making them bilateral OA patients. In the present study, all patients underwent unilateral THA because patients with bilateral OA were excluded. This difference in subjects may account for the difference in the rate of increase of the CSA of the gluteus medius between

Uemura's study and the present study. From the viewpoint of the difference between the unaffected and affected sides, the present figure of an approximately 25% difference appears appropriate.

The present subjects were also monitored postoperatively for longer than were those of Uemura et al., and to the best of our knowledge, no other study has carefully investigated the CSA of the gluteus medius over such a long period. In the present study, the third CSA measurement was carried out using CT images created ≥ 8 years postoperatively (IQR 8–9 years, mean 8.5 years). The CSA at this point had increased significantly by 37.5% compared with its preoperative value. The increase in the CSA at 8 years postoperatively compared with that at 3 years postoperatively was not significant. However, in 82% of subjects, it was larger at 8 years postoperatively than at 3 years postoperatively, indicating that the CSA of the gluteus medius on the affected side continues to increase even after more than 3 years have elapsed since surgery.

No other study has reported changes over time in the CSA of the gluteus medius on the unaffected side of unilateral THA patients. One study²⁰⁾ did measure the gluteus medius and the gluteus minimus together pre-THA and 2 years postoperatively and found that there was no significant difference between the two time points. In the present study, only the gluteus medius was measured, and there was no significant change in the CSA of the unaffected side at 3 years postoperatively compared with preoperatively.

In a study of gluteus medius atrophy in 185 healthy adults aged ≥ 50 years with no history of hip surgery or fracture, atrophy of the gluteus medius was strongly correlated with age.²¹⁾ Atrophy was found to be present in approximately 40% of individuals aged 60–69 years and in 80% of those aged ≥ 70 years. The force that can be exerted by a muscle is proportional to its CSA, and the amount of fatty infiltration may thus affect muscle function.²⁰⁾ Given that the mean age at THA of the subjects of the present study was 62 years, their mean age when the CSA was measured for the third time 8 years later was 70 years; consequently, age-related fatty degeneration of the muscle might have also occurred in the gluteus medius on the unaffected side. Although it was not possible to evaluate the degree of fatty degeneration in the present study, there was no significant difference in the CSA of the unaffected side at 8 years postoperatively compared with preoperatively. The hip abductor muscle strength is still reduced on the THA side even 10 years post-THA¹²⁾; therefore, in THA patients, the unaffected side bears a relatively larger proportion of the body weight than does the

Table 3. Cross-sectional area (cm²) of the gluteus medius

	Affected side	Unaffected side	Difference (%)	P-value
Preoperatively	8.6 (6.3–10.5)	12.9 (11.4–13.8)	–33.3	<0.001 ^{††}
3 years postoperatively	10.1 (8.0–12.7)*	12.6 (11.6–15.0)	–19.8	<0.001 ^{††}
8 years postoperatively	10.4 (8.6–13.7)**	12.9 (11.7–14.0)	–19.4	0.003 [†]

Values are expressed as medians (interquartile range).

Differences were analyzed using the Wilcoxon signed-rank test.

*P<0.005, **P<0.001, significantly different compared with preoperatively.

[†]P<0.005, ^{††}P<0.001, the affected and unaffected sides were significantly different.

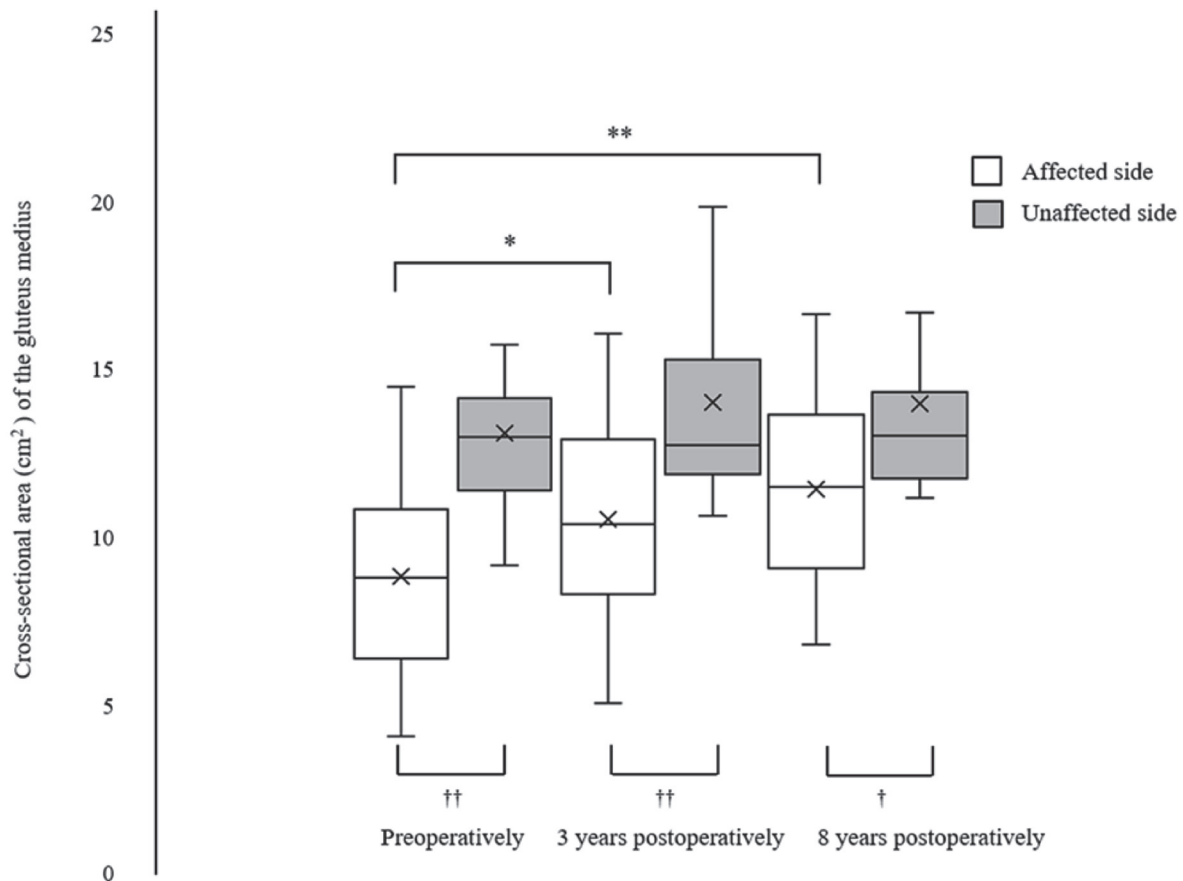


Fig. 2. Asymmetry of the cross-sectional area of the gluteus medius. The box plots show the interquartile ranges of the muscle cross-sectional area for each measurement point. Crosses show the averages. Differences were analyzed using the Wilcoxon signed-rank test. *P<0.005, **P<0.001, significantly different compared with before surgery. [†]P<0.005, ^{††}P<0.001, significant difference between the affected side and the unaffected side.

affected side, and this may be why the CSA on the unaffected side did not decrease.

In the present study, the CSA of the gluteus medius on the affected side was significantly smaller than that of the unaffected side at all time points (preoperatively and 3 and 8 years postoperatively). Arokoski et al.¹⁹⁾ used MRI to

measure the CSAs of the pelvic and hip muscles of the more and less affected hips of 27 patients with hip OA assessed by Kellgren-Lawrence grading and Li's OA scale. They found that the CSA of the more affected hip was 9% smaller than that of the less affected hip, and this difference was significant. In the present study, the preoperative CSA of the

affected side was 33.3% smaller than that of the unaffected side. The reason that the difference between the two sides was so much larger than that found by Arokoski et al.¹⁹⁾ may have been that the 27 patients in their study included 12 with bilateral OA. Zacharias et al.⁷⁾ measured the volume of the gluteus medius in 20 hip OA patients using MRI and found that the volume on the affected side was significantly lower than that on the unaffected side. Momose et al.²²⁾ measured, using CT images, the CSA and three-dimensional muscle volume of the gluteus medius of 50 hip OA patients and reported that these were significantly smaller on the OA side in all cases. Although previous studies^{7,22)} have measured the muscle volume and the present study measured the CSA, the results were comparable.

A study comparing the CSA of the affected hip muscles with those on the unaffected side 2 years after THA for unilateral OA²⁰⁾ concluded that the CSA on the THA side was smaller than that on the unaffected side, but that the abductor muscles, comprising the gluteus medius and gluteus minimus, together did not differ significantly between sides at 2 years postoperatively. In the present study, it was found that the CSA of the gluteus medius on the THA side 3 years postoperatively was significantly smaller by 19.8% than that on the unaffected side (**Table 3**). However, not only did that previous study include the gluteus minimus, but it also found that there was no difference between the CSAs of the abductor muscles on the affected and unaffected sides prior to THA, and both these factors may have contributed to the differences with the present study.

In previous studies of unilateral THA patients, the longest period for which the CSA of the hip muscles was monitored was 2 years postoperatively²⁰⁾; consequently, the medium- to long-term changes in the CSA following THA were unknown. In the present study, the CSA of the gluteus medius on the affected side had not reached the size of the unaffected side even 8 years post-THA. It was not possible to assess the extent to which this represents a clinical issue. However, a study that compared 58 THA patients with a control group at 10 years postoperatively found the following significant differences: hip abductor strength evaluated using a handheld dynamometer was 9.5% lower in THA patients, the one-leg standing time was 42.1% shorter, and the maximum walking speed was 14.8% slower.¹²⁾ The force exerted by the hip abductor muscles acts to provide horizontal support for the pelvis during walking, particularly during the mid-stance phase, and since this force is responsible for keeping the trunk level, improving the CSA as much as possible is demonstrably important. Before THA, hip pain is one of

the factors that reduces the activities of daily living, including walking, of hip OA patients. This reduction in activity decreases the frequency with which the gluteus medius is used and reduces the load placed on the muscles, potentially inducing structural changes, such as increased fat infiltration of the muscle; these changes may make the recovery of muscle mass more difficult.

The relatively larger load applied on the unaffected side may also continue into the postoperative period. This suggests that regular or long-term rehabilitation interventions are required to maintain and increase the CSA of the gluteus medius in THA patients. Such an approach should emphasize maintaining abductor muscle strength during the early stages of OA and providing guidance on effective gluteus medius training both before and after THA.

There were some limitations in the present study. The first was the small number of subjects. This small number resulted because subjects had to be unaffected by all the exclusion criteria, have CT data from all three measurement time points, and have no issues with CSA measurements. A second limitation was that all the subjects were women. However, in Japan, women account for a substantially larger proportion of THA patients for hip OA at every age group,^{1,15)} and the present subjects were representative of the general Japanese patient population. Third, there were no evaluations of the factors that could affect CSA, such as muscle strength and patient activity levels. Previous studies have reported that CSA is associated with lower limb muscle strength and walking speed.^{19,22)} Analysis that includes all factors that affect muscle CSA is required for further study. However, no patient had postoperative complications, and their JOA scores suggested that their activity levels would have been maintained. Fourth, there was an issue related to CSA measurements in that after THA the presence of implants meant that blinding with respect to the THA and unaffected sides was not feasible. However, the ICCs for both intra-investigator and inter-investigator reliabilities were high. Finally, in the present study, the CSAs of muscles other than the gluteus medius were not investigated. However, it is plausible that the CSAs of muscles in a single patient may be correlated, and therefore the repeated two-way ANOVA method used to examine multiple muscles in previous similar studies may not be statistically appropriate. Consequently, to preserve statistical power with a limited sample size, it was decided to compare only measurements of the gluteus medius, which is one of the most important muscles for improving gait function. Further studies with a larger sample size to investigate issues such as the association with other

leg muscles are required.

CONCLUSION

This is the first study to have evaluated the CSA of the gluteus medius over an 8-year period in patients following THA for unilateral hip OA. The CSA of the gluteus medius on the THA side was larger at 3 and 8 years postoperatively than that prior to THA, but it did not recover to the same size as that on the unaffected side at any time point. Because the gluteus medius is important for achieving stability when walking, it is important to maintain or increase the CSA of the gluteus medius by regular or long-term rehabilitation interventions. Such interventions should aim to maintain abductor muscle strength from the early stages of OA and to provide guidance on effective gluteus medius training both before and after THA.

ACKNOWLEDGMENTS

The authors would like to express their sincere gratitude to Yoshiyuki Sasaki, DDS, PhD, Department of Maxillofacial Surgery, Graduate School of Medical and Dental Sciences, Tokyo Medical and Dental University, for his guidance in the selection of statistical methods for this study. The authors are also deeply grateful to Tadashi Masuda, PhD, Fukushima University, for his many useful suggestions.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this article.

REFERENCES

- Katano H, Ozeki N, Kohno Y, Nakagawa Y, Koga H, Watanabe T, Jinno T, Sekiya I: Trends in arthroplasty in Japan by a complete survey, 2014–2017. *J Orthop Sci* 2021;26:812–822. DOI:10.1016/j.jos.2020.07.022, PMID:32933832
- Bedard NA, Callaghan JJ, Stefl MD, Liu SS: Systematic review of literature of cemented femoral components: what is the durability at minimum 20 years followup? *Clin Orthop Relat Res* 2015;473:563–571. DOI:10.1007/s11999-014-3876-3, PMID:25138469
- Ateschrang A, Weise K, Weller S, Stöckle U, de Zwart P, Ochs BG: Long-term results using the straight tapered femoral cementless hip stem in total hip arthroplasty: a minimum of twenty-year follow-up. *J Arthroplasty* 2014;29:1559–1565. DOI:10.1016/j.arth.2014.02.015, PMID:24656056
- Evans JT, Evans JP, Walker RW, Blom AW, Whitehouse MR, Sayers A: How long does a hip replacement last? A systematic review and meta-analysis of case series and national registry reports with more than 15 years of follow-up. *Lancet* 2019;393:647–654. DOI:10.1016/S0140-6736(18)31665-9, PMID:30782340
- Rasch A, Byström AH, Dalen N, Berg HE: Reduced muscle radiological density, cross-sectional area, and strength of major hip and knee muscles in 22 patients with hip osteoarthritis. *Acta Orthop* 2007;78:505–510. DOI:10.1080/17453670710014158, PMID:17966005
- Marshall AR, Noronha M, Zacharias A, Kapakoulakis T, Green R: Structure and function of the abductors in patients with hip osteoarthritis: systematic review and meta-analysis. *J Back Musculoskeletal Rehabil* 2016;29:191–204. DOI:10.3233/BMR-150614, PMID:26406195
- Zacharias A, Pizzari T, English DJ, Kapakoulakis T, Green RA: Hip abductor muscle volume in hip osteoarthritis and matched controls. *Osteoarthritis Cartilage* 2016;24:1727–1735. DOI:10.1016/j.joca.2016.05.002, PMID:27163446
- Al-Hayani A: The functional anatomy of hip abductors. *Folia Morphol (Warsz)* 2009;68:98–103. PMID:19449297
- Gilbey HJ, Ackland TR, Wang AW, Morton AR, Touchet T, Tapper J: Exercise improves early functional recovery after total hip arthroplasty. *Clin Orthop Relat Res*. 2003; 408:193–200. DOI:10.1097/00003086-200303000-00025, PMID: 12616059
- Wang AW, Gilbey HJ, Ackland TR: Perioperative exercise programs improve early return of ambulatory function after total hip arthroplasty: a randomized, controlled trial. *Am J Phys Med Rehabil* 2002;81:801–806. DOI:10.1097/00002060-200211000-00001, PMID:12394990
- Heiberg KE, Bruun-Olsen V, Ekeland A, Mengshoel AM: Effect of a walking skill training program in patients who have undergone total hip arthroplasty: followup one year after surgery. *Arthritis Care Res* 2012;64:415–423. DOI:10.1002/acr.20681, PMID:22170790

12. Ninomiya K, Hirakawa K, Ikeda T, Nakura N, Suzuki K: Patients 10 years after total hip arthroplasty have the deficits in functional performance, physical activity, and high fall rate compared to healthy adults. *Phys Ther Res* 2018;21:53–58. DOI:10.1298/ptr.E9941, PMID:30697510
13. Uemura K, Takao M, Sakai T, Nishii T, Sugano N: Volume increases of the gluteus maximus, gluteus medius, and thigh muscles after hip arthroplasty. *J Arthroplasty* 2016;31:906–912.e1. DOI:10.1016/j.arth.2015.10.036, PMID:26652475
14. Sicard-Rosenbaum L, Light KE, Behrman AL: Gait, lower extremity strength, and self-assessed mobility after hip arthroplasty. *J Gerontol A Biol Sci Med Sci* 2002;57:M47–M51. DOI:10.1093/gerona/57.1.M47, PMID:11773212
15. Jingushi S, Ohfuji S, Sofue M, Hirota Y, Itoman M, Matsumoto T, Hamada Y, Shindo H, Takatori Y, Yamada H, Yasunaga Y, Ito H, Mori S, Owan I, Fujii G, Ohashi H, Iwamoto Y, Miyanishi K, Iga T, Takahira N, Sugimori T, Sugiyama H, Okano K, Karita T, Ando K, Hamaki T, Hirayama T, Iwata K, Nakasone S, Matsuura M, Mawatari T: Multiinstitutional epidemiological study regarding osteoarthritis of the hip in Japan. *J Orthop Sci* 2010;15:626–631. DOI:10.1007/s00776-010-1507-8, PMID:20953923
16. Fujisawa M, Naito M, Asayama I: A comparative study of hip joint functional scoring systems between Japanese Orthopaedic Association hip score and Harris hip score (Japanese). *Orthop Surg* 2001;52:628.
17. Harris WH: Traumatic arthritis of the hip after dislocation and acetabular fractures: treatment by mold arthroplasty. An end-result study using a new method of result evaluation. *J Bone Joint Surg Am* 1969;51:737–755. DOI:10.2106/00004623-196951040-00012, PMID:5783851
18. Takada R, Jinno T, Koga D, Yamauchi Y, Asou Y, Muneta T, Okawa A: Limited significance of screening computed tomography after cementless total hip arthroplasty with highly cross-linked polyethylene at 7–10 years of follow-up. *Mod Rheumatol* 2016;26:757–760. DOI:10.3109/14397595.2015.1131136, PMID:26708312
19. Arokoski MH, Arokoski JP, Haara M, Kankaanpää M, Vesterinen M, Niemitukia LH, Helminen HJ: Hip muscle strength and muscle cross sectional area in men with and without hip osteoarthritis. *J Rheumatol* 2002;29:2185–2195. PMID:12375331
20. Rasch A, Byström AH, Dalén N, Martinez-Carranza N, Berg HE: Persisting muscle atrophy two years after replacement of the hip. *J Bone Joint Surg Br* 2009;91-B:583–588. DOI:10.1302/0301-620X.91B5.21477, PMID:19407289
21. Chi AS, Long SS, Zoga AC, Read PJ, Deely DM, Parker L, Morrison WB: Prevalence and pattern of gluteus medius and minimus tendon pathology and muscle atrophy in older individuals using MRI. *Skeletal Radiol* 2015;44:1727–1733. DOI:10.1007/s00256-015-2220-7, PMID:26260535
22. Momose T, Inaba Y, Choe H, Kobayashi N, Tezuka T, Saito T: CT-based analysis of muscle volume and degeneration of gluteus medius in patients with unilateral hip osteoarthritis. *BMC Musculoskelet Disord* 2017;18:457. DOI:10.1186/s12891-017-1828-2, PMID:29141630