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Original article

Effectiveness of ultrasonographic skeletal muscle assessment in patients after total knee arthroplasty

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ABSTRACT

Objectives: This study aimed to characterize the skeletal muscles of patients who underwent total knee arthroplasty (TKA) using ultrasonography in order to investigate the effectiveness of ultrasonographic skeletal muscle assessment after TKA.

Methods: This study included 50 TKA patients (TKA group) and 41 residents with osteoarthritis who have not received TKA (non-TKA group). Ultrasonography was used to assess the characteristics of several different muscles. Various postoperative outcomes were evaluated. Muscle thickness (MT) and echo intensity (EI) results were compared among operated knees in the TKA group, nonoperated knees in the TKA group, and more severely affected knees in the non-TKA group. For the TKA group, multiple regression was conducted to examine the association between skeletal muscle characteristics of operated knees and postoperative outcomes.

Results: The MTs of the vastus medialis, vastus intermedius, and rectus femoris (RF) were significantly smaller and the RF-EI was significantly greater for both operated and nonoperated knees in the TKA group compared with the non-TKA group ($P < 0.017$). Several parameters of physical function were significantly poorer in the TKA group than in the non-TKA group ($P < 0.05$). Multiple regression demonstrated that RF-MT was associated with knee range of motion, knee strength, and physical functional performance in the TKA group ($P < 0.05$).

Conclusions: The quantity and quality of skeletal muscles were lower in the TKA group than in the non-TKA group. Ultrasonography may be useful for assessing skeletal muscles in TKA patients because MT assessed with ultrasonography was associated with various parameters of physical function.

1. Introduction

Total knee arthroplasty (TKA) is strongly recommended as an effective and cost-effective treatment for patients with knee osteoarthritis (OA) who have severe symptoms or functional limitations [1]. With increasing numbers of surgeries performed and younger patients requiring surgery [2], the functional prognosis of patients after TKA is expected to be increasingly important. It has been reported that patients have less leg strength and lower gait speed than healthy elderly people even after TKA [3] and the incidence of falls in these patients is comparable to the incidence in elderly people [4]. Since falls in TKA patients may lead to fracture around the prosthesis, which can substantially deteriorate their activities of daily living and quality of life (QoL) [5], it is important to improve physical functional performance and prevent falls and fractures in order to obtain a favorable prognosis.

The strength of the muscles surrounding the operated knee is a physical performance-related factor in TKA patients. It is known to be an important determinant of the ability to walk and climb stairs [6] and is associated with postoperative patient satisfaction [7]. A longitudinal study reported that quadriceps strength 28 days after TKA is approximately 62% lower than preoperative values, which was mainly attributed to a decrease in the number of recruited motor units and muscle cross-sectional area [8]. In addition, a

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cross-sectional study reported that quadriceps volume is the largest contributor to muscle strength for patients at 10 or more months after TKA [9]. These findings suggest the importance of assessing and strengthening skeletal muscles in TKA patients.

In previous studies, the skeletal muscles of TKA patients were assessed mainly using magnetic resonance imaging (MRI) and computed tomography. Although these imaging techniques have high precision, they are not suitable for daily practice because the equipment is expensive and is difficult to use. Other tools for skeletal muscle assessment include dual-energy X-ray absorptiometry (DXA) and bioelectrical impedance analysis (BIA), which are commonly used for diagnosis of sarcopenia [10], but DXA is also difficult to use. Although BIA is easy to use, it is difficult to provide accurate measurements in TKA patients because it uses impedance and the implants can cause measurement errors.

Ultrasonography may be useful for skeletal muscle assessment in TKA patients. Ultrasonography is a noninvasive and low-cost technique that can be used in most clinical settings. It can estimate qualitative deterioration such as fatty changes and fibrosis based on echo intensity (EI). It has been reported that muscle thickness (MT) measurements made with ultrasonography are valid and highly correlated with measurements made with MRI and DXA [11,12]. In addition, MT and EI are both associated with muscle strength and physical functional performance [12–14].

There have been no studies that have used ultrasonography in TKA patients. Therefore, it remains unknown which features of skeletal muscles can be assessed with ultrasonography and whether the results of ultrasonographic skeletal muscle assessment are associated with postoperative patient satisfaction and physical functional performance in TKA patients. In this study, in order to investigate the clinical effectiveness of ultrasonographic skeletal muscle assessment after TKA, we aimed to (1) characterize skeletal muscles using ultrasonography and (2) verify the association between the characteristics of skeletal muscles observed using ultrasonography with postoperative patient satisfaction and physical functional performance in TKA patients.

2. Methods

2.1. Participants

This study was a cross-sectional observational study. TKA patients were eligible for this study if (1) their underlying disease was OA, (2) they could walk without assistance, and (3) they underwent TKA over 6 months ago, because physical functional performance reaches a steady state at 6 months after TKA [3]. Exclusion criteria were (1) revision TKA, (2) bilateral TKA, (3) history of a fracture in the lower extremities within the past 10 years, (4) concomitant neurological disease, (5) severe locomotive organ disorder, (6) psychiatric disorder, and (7) uncontrolled cardiovascular disease. Of 83 TKA patients who visited our hospital for periodic follow-up between October 2016 and March 2018, 50 who did not meet any of the exclusion criteria were included in the analysis. An anterior straight incision and the medial parapatellar approach were used in all participants. All participants underwent a general rehabilitation protocol consisting of range of motion (ROM) exercises, lower extremity muscle strengthening exercise, gait training, etc., before being discharged. The operated knee and unoperated knee of each participant were assessed.

The control (non-TKA) group consisted of 41 individuals diagnosed as having knee OA who have not received any surgical intervention. They were recruited from 35 people who participated in a health promotion project implemented by the municipal government of Kurayoshi, Tottori Prefecture, in October and November 2018 and 21 people who participated in a health promotion project for residents with knee disorders implemented by the municipal government of Yonago, Tottori Prefecture in December 2018 and January 2019. The same inclusion and exclusion criteria as those for the TKA group were adopted, except for TKA-related criteria. For the non-TKA group, the knee with more severe symptoms was used in this study. This study was approved by the Ethics Committee of Tottori University Hospital before commencement (No. 17B016).

2.2. Sample size calculation

Since the purpose of this study was to compare skeletal muscle characteristics and physical functional performance between the TKA and non-TKA groups, the sample size was determined based on a previous study of differences in MT between OA patients and healthy elderly people [15]. This study was designed to detect difference in quadriceps MT between TKA and non-TKA groups based on this previous study. The effect size and standard deviation were assumed to be 0.3 and 0.3, respectively. The calculated sample size required 17 participants per group with an α error level of 5% (2-sided) and power of 80%. We conducted continuous sampling to meet this sample size and balance the male-to-female ratio between the groups. Ultimately, there were 50 participants in the TKA group and 41 participants in the non-TKA group.

2.3. Ultrasonographic measurements

Using B-mode short-axis images obtained with the Noblus ultrasound system (Hitachi, Ltd., Tokyo, Japan), we assessed subcutaneous fat thickness (FT), MT, and muscle EI. The vastus medialis (VM), vastus intermedius (VI), and rectus femoris (RF) were assessed. The gain, depth, and focus were set to 18 GB, 4 cm, and 2 cm, respectively. Participants were placed in the supine position with both knees extended and relaxed. A 5- to 20-MHz transducer was used. A water-soluble permeable gel was applied to the head of the transducer. The transducer was kept perpendicular to the skin surface with the minimum pressure required to obtain clear images. During measurement, the operator took care to take measurements at the same sites for all participants, placing the transducer at the same positions. The measurement sites were specified as 5 cm medial to the distal 1/5 of the line connecting the anterior superior iliac spine with the superior edge of the patella for VM and the midpoint of the line connecting the anterior superior iliac spine with the superior edge of the patella for FT, VI, and RF (Fig. 1) [15]. Based on the ultrasound images, the distance from the skin to the superficial fascia (FT), distance from the femur to the fascia immediately above the VM (VM-MT), distance from the femur to the fascia immediately above the VI (VI-MT), and distance from the fascia immediately above the VI to the fascia immediately above the RF (RF-MT) were estimated. Each site was imaged twice and MTs were measured using the electronic caliper equipped in the ultrasound system. Since it was difficult to obtain accurate EIs for deep sites, EI was assessed only for VM (VM-EI) and RF (RF-EI). ImageJ software (National Institutes of Health, Bethesda, MD, USA) was used for image processing. For each muscle, the region of interest was set as wide as possible but excluded the surrounding fascia and bone. EI was defined as the average grayscale value of the region of interest, which was calculated using a standard histogram function. Grayscale values range from 0 (black) to 255 (white), with higher values representing more fat and fibrous tissue within the muscle. The mean measurement from 2 ultrasound images was used for analysis. The intrarater reliability of MT and EI assessments using this procedure has been reported to be 0.90 and 0.91, respectively [13].

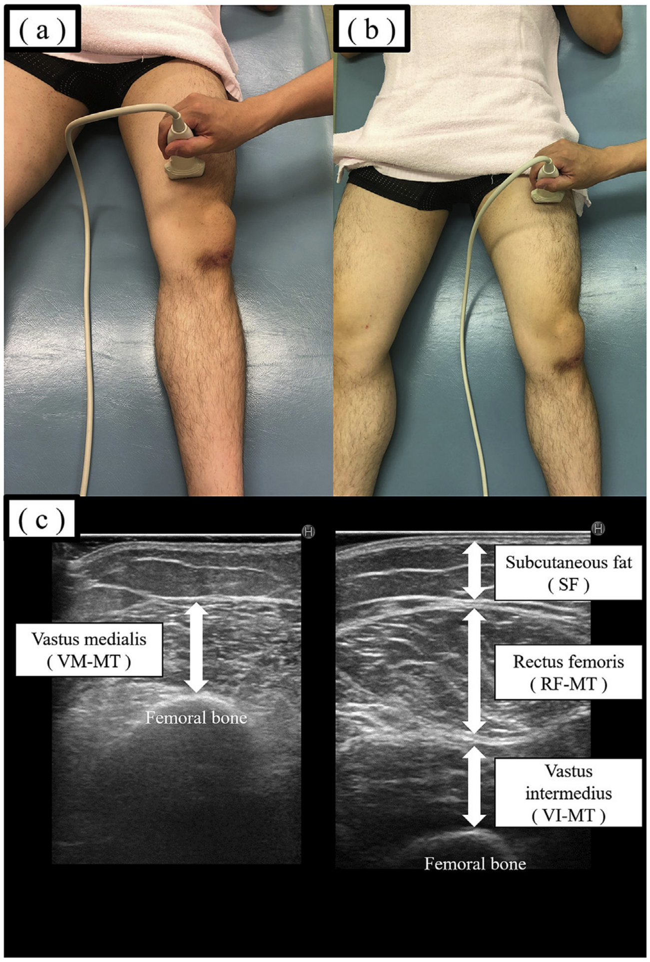

Fig. 1. Sites of muscle measurement using ultrasonography. (a) Site of vastus medialis measurement. (b) Sites of subcutaneous fat, vastus intermedius, and rectus femoris measurement. (c) Representative ultrasonography images. MT, muscle thickness. Written informed consent for publication was obtained from patient.

2.4. Assessment of basic characteristics

For participants in the TKA group, medical records were used to ascertain age, sex, height, weight, body mass index (BMI), Kellgren-Lawrence (KL) grade, preoperative femoro-tibial angle, TKA implant type, preoperative knee ROM, comorbidities, presence or absence of arthralgia, and smoking habit.

For participants in the non-TKA group, we conducted physical measurements and interviews to ascertain their age, sex, height, weight, BMI, KL grade, comorbidities, presence or absence of arthralgia, and smoking habit.

2.5. Knee pain

Knee pain was evaluated using the visual analogue scale (VAS). Participants recorded the most severe level of pain over the past 3 days by making a handwritten mark on a 100-mm line that represents a continuum between the 2 ends of the scale, with “no pain” on the left end (0 mm) and “worst pain you have ever experienced” on the right end (100 mm).

2.6. Knee ROM

Measurements were performed according to the *Range of joint motion and method of measurement* by the Japanese Orthopaedic Association. The femur was the stationary axis and the fibula was the moving axis. The ROM of the knee was measured in the supine position, with the knee flexed and extended by the participants themselves as far as possible.

2.7. Knee strength

Isometric knee extension strength was measured using a handheld dynamometer (HHD, μ−Tas F-1; ANIMA Co., Ltd., Tokyo, Japan). Measurement of isometric muscle strength using an HHD has been reported to have high intrarater reliability [16]. Measurements were performed with each participant in a sitting position with a towel placed under the thighs to keep the thighs horizontal and the hip and knee joints flexed at 90°. The participants kept their torso perpendicular to the examination table and placed their hands on the examination table at their sides. The HHD sensor that receives muscle outputs was placed on the anterior surface of distal lower leg. The participants performed two isometric maximal voluntary contractions, each lasting approximately 1 min, during measurement, with the sensor tied to the table leg with a fixing belt. The mean of two measurements was used for analysis. Torque values (Nm) obtained by adjusting the force applied on the sensor (N) based on the length of lower leg (m) were used for analysis.

2.8. Physical functional performance

Physical functional performance was assessed using the Timed Up and Go test (TUG), 30-s chair stand test (30-CST), and stair climb test (SCT). The reliability and validity of these tests have been verified previously [17]. Gait speed was also evaluated.

For TUG, we measured the time it took for each participant to stand up from a 44-cm-tall chair with armrests, walk to a mark 3 m away from the chair, turn back to the chair, and sit. Participants walked at a normal speed and a walking aid was used as needed. Two measurements were performed, and the mean was used for analysis.

For 30-CST, participants performed an exercise using a 44-cm-tall chair without armrests. Each cycle of the exercise consisted of completely standing up from the chair with the arms folded until complete extension of the hip and knee joints and sitting on the chair until the buttocks were completely touching the seat. The number of cycles each participant could perform within 30 s was counted. This test was performed only once for each participant.

For SCT, training stairs with 4 steps of 16 cm each were used. The time required for each participant to safely step up and down the stairs as quickly as possible was measured. The participants were allowed to use a handrail or walking aid as needed. The time from when each participant stepped up the stairs until he or she placed both feet on the floor was measured. The measurement was performed only once after each participant sufficiently practiced the stepping exercise. It has been reported that the intrarater reliability for SCT under the same conditions as those of the present study is 0.94–0.96 [18]. Since it was difficult to prepare the same test environment for the non-TKA group, this test was performed only in the TKA group.

For gait speed, we measured the time it took for each participant to walk through a 10-m flat walking lane, which included a 3-m acceleration lane and a 3-m deceleration lane, at a comfortable speed. Gait speed was calculated based on the measured time.

2.9. Health-related QoL (Japanese Knee Osteoarthritis Measure)

The Japanese Knee Osteoarthritis Measure (JKOM) is a diseasespecific measure for knee disorders that reflects the Japanese cultural lifestyle. Its validity and reliability have been verified [19]. It is a self-administered questionnaire that includes 25 questions divided into the categories of pain and stiffness, activities of daily living, participation in social activities, and general health condition. Participants selected 1 of 5 answers for each question (0 = best condition, 4 = worst condition).

2.10. Statistical analysis

Medians and interquartile ranges were used as representative values of data. We compared the characteristics of participants in the TKA and non-TKA groups using the Mann-Whitney U-test for continuous variables of basic characteristics (e.g., age) and the chi-square test for categorical variables (e.g., sex). MT and EI of the operated and unoperated knees in the TKA group and the more severely affected knee in the non-TKA group were compared using the Kruskal-Wallis test (significance level, $P < 0.05$). In addition, as a *post hoc* test, the Mann-Whitney U-test was used for pairwise comparisons of the three types of knees. The Bonferroni correction was used to adjust the significance level for multiple comparisons ($P < 0.017$). Intraclass correlation coefficients (ICCs, 1,1) of FT, MT, and EI measurements were also calculated. Clinical outcomes of the operated knee in the TKA group were compared with those in the non-TKA group using the Mann-Whitney U-test.

Multiple regression with forced entry was performed to investigate associations among VM-MT, VI-MT, RF-MT, VM-EI, and RF-EI of operated knees in the TKA group with clinical outcomes. In order to avoid overfitting due to the small sample size, we used each skeletal muscle index independently. Age, sex, BMI [20,21], and postoperative time [22], which might affect both skeletal muscles and TKA outcomes, were used as covariates. All of the independent and dependent variables were logarithmically transformed and adjusted so that the residuals were normally distributed before analysis (Fig. 2). Statistical analysis was conducted using IBM SPSS Statistics ver. 24.0 (IBM Co., Armonk, NY, USA), at a significance level of 5%.

3. Results

3.1. Participant characteristics

The characteristics of participants are summarized in Table 1. The prevalence of hypertension was significantly higher in the TKA group. The preoperative KL grade was significantly higher in the TKA group compared with the non-TKA group. No other significant differences were observed between the groups.

3.2. Ultrasonographic measurements

The results of ultrasonographic measurements in the TKA and non-TKA groups are shown in Table 2. No significant difference was observed in FT between the groups. There was no difference in MT between the operated and nonoperated knees in the TKA group. VM-MT, VI-MT, and RF-MT of operated and nonoperated knees were significantly lower than those in the non-TKA group.

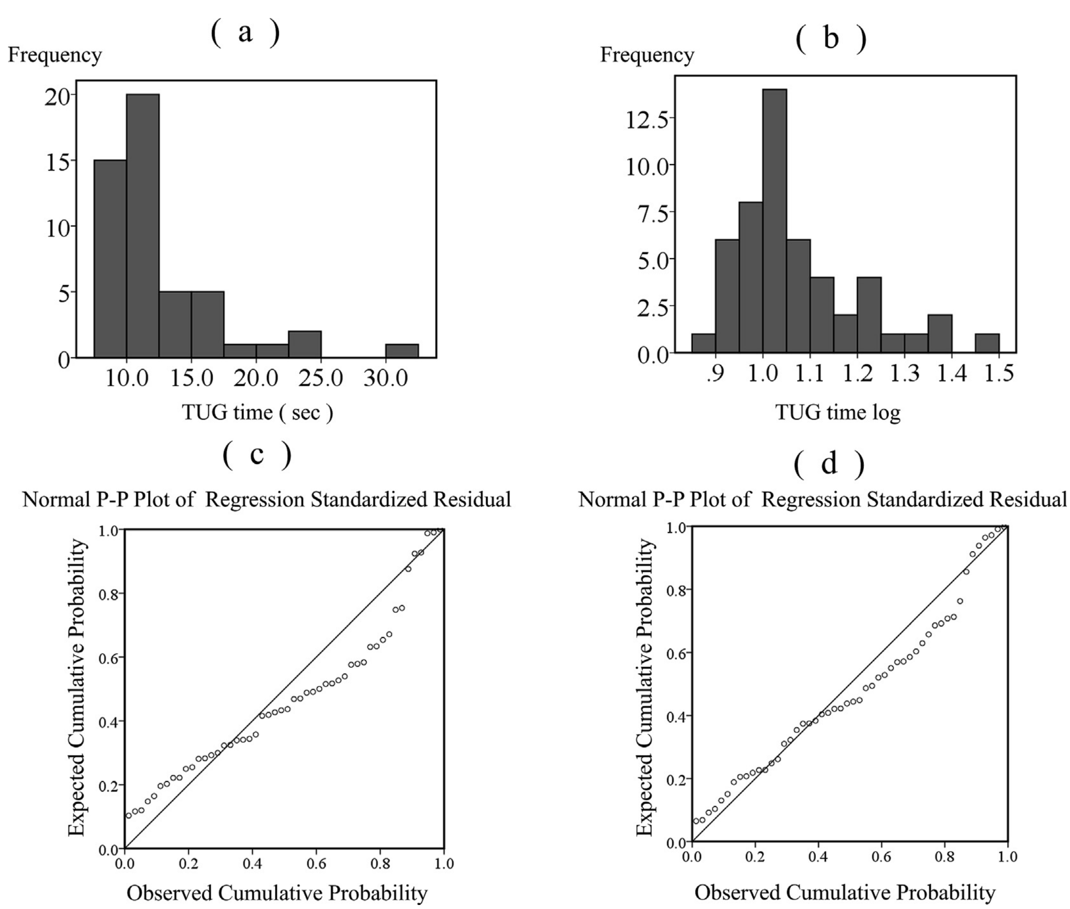

Fig. 2. Logarithmic transformation and distribution of residuals. Timed Up and Go test (TUG) data are used for illustration above. Residuals from linear regression (c) for TUG times (a). Residuals from linear regression for TUG times (d) were approximately normally distributed after logarithmic transformation (b).

Table 1
Participant characteristics.

Characteristic	TKA group (n = 50)	Non-TKA group (n = 41)	P-value
Age, yr	76.0 (70.8–81.0)	77.0 (70.5–82.5)	0.382
Female sex	44 (88.0)	36 (87.8)	0.612
Height, cm	151.7 (146.0–160.3)	152.5 (148.0–165.6)	0.271
Weight, kg	55.6 (50.9–62.1)	55.6 (49.1–62.8)	0.908
Body mass index, kg/m^2	24.4 (22.1–26.6)	23.7 (22.2–27.3)	0.753
Hypertension, %	50.0	24.4	0.017
Diabetes, %	18.0	12.2	0.321
Hyperlipidemia, %	20.0	9.8	0.145
Other medical conditions, %	26.0	14.6	0.143
Shoulder pain, %	4.0	9.8	0.403
Low back pain, %	30.0	19.5	0.334
Hip pain, %	6.0	4.9	1.000
Foot pain, %	8.0	2.5	0.374
Smoking habit, %	2.0	0.0	1.000
Preoperative KL grade of the operated knee	3 (3–4)	3 (2–3)[a]	0.015
KL grade of the nonoperated knee	3 (2–3)		0.973
Postoperative time, mo	18.0 (6.0–64.3)	–	–
TKA implant (PS)	45 (90.0)	–	–
Preoperative FTA, degree	185.0 (182.0–190.0)	–	–
Preoperative knee extension range of motion, degree	−10 (−10 to 0)	–	–
Preoperative knee flexion range of motion, degree	120 (110–125)	–	–

Values are presented as median (interquartile range) or number of participants (%) unless otherwise indicated.
TKA, total knee arthroplasty; KL, Kellgren-Lawrence; PS, posterior stabilization; FTA, femoro-tibial angle.
[a] Compared between the operated knee in the TKA group and the more severely affected knee in the non-TKA group and between the nonoperated knee in the TKA and the more severely affected knee in the non-TKA group.

Table 2
Ultrasonographic measurements.

Variable	TKA group (n = 50)		Non-TKA group (n = 41)	P-value comparing 3 groups
	Operated knee	Nonoperated knee		
Thickness (cm)				
Subcutaneous fat	0.76 (0.50–1.00)	0.66 (0.46–1.01)	0.60 (0.36–0.81)	0.069
Vastus medialis	0.79 (0.69–0.97)[a]	0.80 (0.76–1.04)[a]	1.21 (1.00–1.69)	<0.001
Vastus intermedius	0.90 (0.76–1.04)[a]	0.89 (0.67–1.08)[a]	1.31 (1.15–1.63)	<0.001
Rectus femoris	0.94 (0.83–1.20)[a]	0.97 (0.75–1.23)[a]	1.37 (1.18–1.63)	<0.001
Echo intensity (AU)				
Vastus medialis	123.0 (109.5–138.0)	113.4 (104.9–132.4)	118.0 (105.9–128.6)	0.217
Rectus femoris	117.7 (99.5–130.3)[b]	115.9 (101.7–129.9)[a]	99.0 (89.9–110.1)	<0.001

Values are presented as median (interquartile range).
TKA, total knee arthroplasty; AU, arbitrary units.
[a] Difference vs. the non-TKA group, $P < 0.001$.
[b] Difference vs. the non-TKA group, $P = 0.001$.

The VM-EI of operated and nonoperated knees in the TKA group was not significantly different from the VM-EI in the non-TKA group, respectively. The RF-EI of operated and nonoperated knees in the TKA group was significantly higher than the RF-EI in the non-TKA group, respectively. The ICC (1,1) for ultrasonographic measurements of FT, MT, and EI ranged from 0.91 to 0.97.

3.3. Clinical outcomes

The clinical outcomes of the TKA and non-TKA groups are shown in Table 3. Knee pain VAS was significantly higher in the non-TKA group than in the TKA group. The ranges of motion for knee extension and knee flexion were significantly lower in the TKA group than in the non-TKA group. Isometric knee extension strength, 30-CST, and gait speed were significantly lower in the TKA group than in the non-TKA group. TUG was significantly slower in the TKA group than in the non-TKA group. Although pain and stiffness as determined by the JKOM score were significantly lower in the TKA group than in the non-TKA group, there was no significant difference in the total JKOM score between the groups.

3.4. Associations between skeletal muscle characteristics assessed with ultrasonography and clinical outcomes

Table 4 shows the results of the multiple regression analysis for associations between skeletal muscle characteristics assessed using ultrasonography and clinical outcomes. Data were adjusted for age logarithmically transformed (_L), BMI_L, postoperative time_L, and sex. VM-MT_L was not associated with any clinical outcomes. VI-MT_L was associated with SCT_L only. RF-MT_L was associated with knee extension ROM_L, knee strength_L, TUG_L, 30-CST_L, SCT_L, and gait speed_L, but not significantly associated with any other clinical outcomes. VM-EI_L and RF-EI_L were not associated with any of the clinical outcomes.

4. Discussion

In this study, we assessed the characteristics of skeletal muscles using ultrasonography and compared them between the TKA and non-TKA groups. Compared with the non-TKA group, the TKA group had lower VM-MT, VI-MT, and RF-MT and higher RF-EI. However, no significant difference was observed in VM-EI,

Table 3
Clinical measurements.

Variable	TKA group (n = 50)	Non-TKA group (n = 41)	P-value
Knee pain VAS, mm	14.0 (0.0–27.3)	32.0 (12.0–50.5)	0.006
Extension ROM, degree	−8.0 (−13.3 to 4.8)	0.0 (−10.0 to 0)	0.009
Flexion ROM, degree	108.0 (97.0–120.0)	130.0 (118.5–136.0)	<0.001
Knee strength, Nm	36.8 (28.9–48.3)	47.3 (38.6–62.1)	0.004
TUG, s	10.7 (9.7–13.1)	7.5 (6.4–9.1)	<0.001
30-CST, number of times	13.0 (11.0–17.0)	16.0 (13.0–19.5)	0.014
SCT, s	9.3 (7.7–14.1)	–	–
Gait speed, m/s	1.06 (0.89–1.24)	1.31 (1.13–1.57)	<0.001
JKOM pain and stiffness, score	3.0 (1.0–5.3)	6.5 (4.0–9.0)	<0.001
JKOM total, score	15.0 (10.0–21.3)	15.0 (7.5–23.0)	0.601

Values are presented as median (interquartile range).
TKA, total knee arthroplasty; VAS, visual analog scale; ROM, range of motion; TUG, Timed Up and Go test; 30-CST, 30-s chair stand test; SCT, stair climb test; JKOM, Japanese Knee Osteoarthritis Measure.

suggesting that TKA patients had lower skeletal muscle quantity and quality. The findings of this study can provide the basis for future research because there have been no previous studies regarding ultrasonographic assessment of MT and EI in TKA patients and comparison with OA patients who have not received any surgical intervention.

A previous study revealed that more severe KL grade was associated with decreased quadriceps mass [15]. Therefore, it seems reasonable that skeletal muscle quantity and quality were lower in the TKA group than in the non-TKA group because the TKA group had a higher KL grade before surgery. The findings of the present study as well as a previous longitudinal observational study reporting that skeletal muscle mass of TKA patients decreases by approximately 10% after surgery [8] suggest that skeletal muscle mass remains low and intramuscular fat remains elevated after TKA. Consequently, skeletal muscle quantity and quality in TKA patients were inferior to those in the non-TKA group. One possible reason is decreased physical activity after surgery. Even though TKA patients have less pain and increased satisfaction with physical performance after surgery, their physical activity levels remain low after surgery [23]. Since less physical activity can result in quantitative and qualitative deterioration of skeletal muscles [24], the condition of the skeletal muscles in the TKA group may be attributed to reduced physical activity.

Similar to a previous study that found TKA patients had lower postoperative physical functional performance than healthy elderly people [3], the present study also showed that TKA patients had lower postoperative physical functional performance than OA patients who have not received any surgical intervention. In general, knee pain is a cause of motor dysfunction [25], and it was worse in the non-TKA group than in the TKA group. A recent study in patients who had not undergone TKA showed that knee muscle strength is a better objective measure of motor function than pain [26]. In the present study, knee pain during exercise was not evaluated in detail, and the effect of knee pain could not be completely excluded. However, knee extension muscle strength was significantly greater in the non-TKA group than in the TKA group; this suggests the worse motor function in the TKA group may have been related to factors that impair muscle strength.

Multiple regression was used to investigate the association between skeletal muscle characteristics and clinical outcomes after all variables were logarithmically transformed and adjusted for age, sex, BMI, and postoperative time. RF-MT was associated with many physical functional parameters, but it was not associated with pain, JKOM score, and flexion ROM. The association between RF-MT and mobility capability found in the present study was also shown in a previous study of OA patients awaiting surgery [27]. A previous study showed no difference in terms of post-surgical muscle strength and ROM between the medial parapatellar approach used in the present study and quadriceps sparing, even though the latter is less surgically invasive [28]. The present study showed that RF-MT was associated with knee extension strength and ROM, suggesting that RF plays an important role in maintaining knee extension in TKA patients treated with the parapatellar approach, despite the fact that this method involves invasive VM treatment, because RF has a long lever arm that provides an advantage in exerting muscle strength. In fact, VM muscle activity during walking decreased more than RF muscle activity after surgery in TKA patients [29]. Knee extension function may be affected by the alignment of the lower limbs after surgery, but postoperative displacement of the lower limb functional axis was not found to affect the ROM or motor function of the knee joint [30]. However, one study showed that changes in the postoperative distal femoral angle affected quadriceps muscle strength [31], and in the patient group for the present study in which the preoperative knee position was varus, changes in alignment due to surgery were also observed in the postoperative knee. This may have an impact on subsequent knee function.

On the other hand, VM-EI and RF-EI were not associated with physical functional performance. There is no consensus on the association between physical functional performance and EI. One study reported an association between RF-EI and TUG in OA patients [27] while another study reported that the association between physical functional performance and EI was unclear [15]. Since muscle EI is affected by aging and MT [32], the indirect effects of aging and MT may have made the association between physical functional performance and EI unclear. It has been reported that hip replacement causes fatty changes in muscles [33]. Therefore, a similar change might occur in the muscles after TKA; EI may increase regardless of physical functional performance. Thus, we considered MT to be a more useful index of the association between skeletal muscle characteristics and physical functional performance than muscle EI in TKA patients.

Postoperative pain and flexion ROM were not associated with any of the skeletal muscle parameters assessed using ultrasound in TKA patients. This is probably because, as reported in previous studies, joint structure has a strong effect on postoperative pain and flexion ROM [34,35]. Therefore, evaluating such associations in TKA patients might be less important. We can say the same for the evaluation of QoL, including JKOM, which is affected by pain [36].

This study has some limitations. First, it was a cross-sectional study, so causal relationships between skeletal muscle characteristics and clinical outcomes cannot be identified. Longitudinal studies are warranted to identify associations between skeletal muscle characteristics assessed with ultrasound and clinical outcomes. Second, this study excluded early postoperative patients;

Table 4
Multiple regression analysis of associations between skeletal muscle characteristics assessed using ultrasonography and clinical measurements.

Variable	VM-MT_L		VI-MT_L		RF-MT_L		VM-EI_L		RF-EI_L	
	β (95% CI)	P-value	β (95% CI)	P-value	β (95% CI)	P-value	β (95% CI)	P-value	β (95% CI)	P-value
Knee pain VAS_L	0.42 (−1.81 to 2.65)	0.832	0.06 (−2.26 to 2.37)	0.962	0.34 (−1.76 to 2.43)	0.749	0.43 (−3.60 to 4.46)	0.831	0.68 (−2.41 to 3.78)	0.659
Extension ROM_L	0.11 (−0.42 to 0.64)	0.811	0.26 (−0.28 to 0.81)	0.335	0.52 (0.05–1.00)	0.030	−0.75 (−1.68 to 0.18)	0.111	−0.17 (−0.91 to 0.56)	0.637
Flexion ROM_L	−0.08 (−0.12 to 0.29)	0.288	0.03 (−0.19 to 0.25)	0.792	0.14 (−0.05 to 0.33)	0.169	−0.13 (−0.51 to 0.24)	0.482	−0.14 (−0.43 to 0.15)	0.331
Knee strength_L	0.25 (−0.15 to 0.65)	0.216	0.39 (−0.02 to 0.80)	0.059	0.39 (0.02–0.75)	0.038	−0.37 (−1.10 to 0.36)	0.315	−0.04 (−0.61 to 0.53)	0.894
TUG_L	−0.27 (−0.62 to 0.07)	0.118	−0.34 (−0.69 to 0.009)	0.056	−0.20 (−0.33 to −0.07)	0.004	0.32 (−0.31 to 0.95)	0.305	−0.14 (−0.63 to 0.35)	0.574
30-CST_L	0.30 (−0.06 to 0.65)	0.099	0.24 (−0.13 to 0.61)	0.195	0.40 (0.08–0.72)	0.017	−0.63 (−1.27 to −0.03)	0.095	−0.26 (−0.76 to 0.24)	0.306
SCT_L	−0.49 (−0.07 to 0.16)	0.390	−0.51 (−0.99 to −0.02)	0.042	−0.86 (−1.24 to −0.48)	<0.001	0.12 (−0.77 to 1.002)	0.790	−0.16 (−0.84 to 0.52)	0.645
Gait speed_L	0.28 (−0.07 to 0.63)	0.113	0.32 (−0.04 to 0.68)	0.076	0.49 (0.18–0.79)	0.002	−0.23 (−0.87 to 0.42)	0.482	0.17 (−0.33 to 0.66)	0.505
JKOM_L	−0.02 (−0.70 to 0.67)	0.950	−0.31 (−1.01 to 0.39)	0.382	−0.44 (−1.06 to 0.19)	0.164	0.64 (−0.58 to 1.85)	0.296	0.11 (−0.05 to 0.17)	0.174

Covariates: log (age), sex, log (body mass index), and log (postoperative time).
_L, logarithmically transformed; CI, confidence interval; VM, vastus medialis; VI, vastus intermedius; RF, rectus femoris; MT, muscle thickness; EI, echo intensity; VAS, visual analog scale; ROM, range of motion; TUG, timed up and go test; 30-CST, 30 s chair stand test; SCT, stair climb test; JKOM, Japanese Knee Osteoarthritis Measure.

intensive physical therapy soon after surgery was found to improve postoperative outcomes in TKA patients [37], but we did not assess the impact of postoperative physical therapy duration or content on outcomes and skeletal muscle function. Finally, the findings of this study cannot be generalized due to selection bias because the participants were limited to patients at a single facility and people who voluntarily participated in health classes. Nevertheless, the results of this study are considered valid because selection bias was reduced by balancing age and the male-to-female ratio between the groups.

5. Conclusions

This study suggested that reduced skeletal muscle quantity and quality, which persist after surgery, may impact postoperative physical functional performance in TKA patients despite pain relief and QoL improvement after surgery. It also revealed that RF-MT is associated with postoperative knee extension function and physical functional performance based on an evaluation of the association between skeletal muscle condition characterized using ultrasound and clinical outcomes, suggesting that RF-MT can be a favorable index for skeletal muscle assessment after TKA. It is important to assess skeletal muscles in TKA patients; this study suggests that ultrasonography is a useful tool for such assessments.

Conflicts of interest

No potential conflict of interest relevant to this article was reported.

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References

[1] Zhang W, Moskowitz RW, Nuki G, Abramson S, Altman RD, Arden N, et al. OARSI recommendations for the management of hip and knee osteoarthritis, Part II: OARSI evidence-based, expert consensus guidelines. Osteoarthr Cartil 2008;16:137–62.
[2] Price AJ, Alvand A, Troelsen A, Katz JN, Hooper G, Gray A, et al. Knee replacement. Lancet 2018;392:1672–82.
[3] Bade MJ, Kohrt WM, Stevens-Lapsley JE. Outcomes before and after total knee arthroplasty compared to healthy adults. J Orthop Sport Phys Ther 2010;40:559–67.
[4] Riddle DL, Golladay GJ. A longitudinal comparative study of falls in persons with knee arthroplasty and persons with or at high risk for knee osteoarthritis. Age Ageing 2016;45:794–800.
[5] Canton G, Ratti C, Fattori R, Hoxhaj B, Murena L. Periprosthetic knee fractures. A review of epidemiology, risk factors, diagnosis, management and outcome. Acta Biomed 2017;88:118–28.
[6] Valtonen A, Pöyhönen T, Heinonen A, Sipilä S. Muscle deficits persist after unilateral knee replacement and have implications for rehabilitation. Phys Ther 2009;89:1072–9.
[7] Furu M, Ito H, Nishikawa T, Nankaku M, Kuriyama S, Ishikawa M, et al. Quadriceps strength affects patient satisfaction after total knee arthroplasty. J Orthop Sci 2016;21:38–43.
[8] Mizner RL, Petterson SC, Stevens JE, Vandenborne K, Snyder-Mackler L. Early quadriceps strength loss after total knee arthroplasty. The contributions of muscle atrophy and failure of voluntary muscle activation. J Bone Joint Surg Am 2005;87:1047–53.
[9] Meier WA, Marcus RL, Dibble LE, Foreman KB, Peters CL, Mizner RL, et al. The long-term contribution of muscle activation and muscle size to quadriceps

weakness following total knee arthroplasty. J Geriatr Phys Ther 2009;32: 79–82.
[10] Cruz-Jentoft AJ, Bahat G, Bauer J, Boirie Y, Bruyère O, Cederholm T, et al. Sarcopenia: revised European consensus on definition and diagnosis. Age Ageing 2019;48:16–31.
[11] Sanada K, Kearns CF, Midorikawa T, Abe T. Prediction and validation of total and regional skeletal muscle mass by ultrasound in Japanese adults. Eur J Appl Physiol 2006;96:24–31.
[12] Berger J, Bunout D, Barrera G, de la Maza MP, Henriquez S, Leiva L, et al. Rectus femoris (RF) ultrasound for the assessment of muscle mass in older people. Arch Gerontol Geriatr 2015;61:33–8.
[13] Fukumoto Y, Ikezoe T, Yamada Y, Tsukagoshi R, Nakamura M, Mori N, et al. Skeletal muscle quality assessed from echo intensity is associated with muscle strength of middle-aged and elderly persons. Eur J Appl Physiol 2012;112: 1519–25.
[14] Rech A, Radaelli R, Goltz FR, da Rosa LH, Schneider CD, Pinto RS. Echo intensity is negatively associated with functional capacity in older women. Age (Dordr) 2014;36:9708.
[15] Taniguchi M, Fukumoto Y, Kobayashi M, Kawasaki T, Maegawa S, Ibuki S, et al. Quantity and quality of the lower extremity muscles in women with knee osteoarthritis. Ultrasound Med Biol 2015;41:2567–74.
[16] Wang CY, Olson SL, Protas EJ. Test-retest strength reliability: hand-held dynamometry in community-dwelling elderly fallers. Arch Phys Med Rehabil 2002;83:811–5.
[17] Dobson F, Hinman RS, Hall M, Terwee CB, Roos EM, Bennell KL. Measurement properties of performance-based measures to assess physical function in hip and knee osteoarthritis: a systematic review. Osteoarthr Cartil 2012;20: 1548–62.
[18] Lin YC, Davey RC, Cochrane T. Tests for physical function of the elderly with knee and hip osteoarthritis. Scand J Med Sci Sport 2001;11:280–6.
[19] Akai M, Doi T, Fujino K, Iwaya T, Kurosawa H, Nasu T. An outcome measure for Japanese people with knee osteoarthritis. J Rheumatol 2005;32:1524–32.
[20] Abe T, Thiebaud RS, Loenneke JP, Loftin M, Fukunaga T. Prevalence of site-specific thigh sarcopenia in Japanese men and women. Age (Dordr) 2014;36:417–26.
[21] Pua YH, Seah FJ, Seet FJ, Tan JW, Liaw JS, Chong HC. Sex differences and impact of body mass index on the time course of knee range of motion, knee strength, and gait speed after total knee arthroplasty. Arthritis Care Res 2015;67: 1397–405.
[22] Nilsdotter AK, Toksvig-Larsen S, Roos EM. A 5 year prospective study of patient-relevant outcomes after total knee replacement. Osteoarthr Cartil 2009;17:601–6.
[23] Kahn TL, Schwarzkopf R. Does total knee arthroplasty affect physical activity levels? Data from the Osteoarthritis Initiative. J Arthroplast 2015;30:1521–5.
[24] Fukumoto Y, Yamada Y, Ikezoe T, Watanabe Y, Taniguchi M, Sawano S, et al. Association of physical activity with age-related changes in muscle echo intensity in older adults: a 4-year longitudinal study. J Appl Physiol (1985) 2018;125:1468–74.
[25] Davison MJ, Ioannidis G, Maly MR, Adachi JD, Beattie KA. Intermittent and constant pain and physical function or performance in men and women with knee osteoarthritis: data from the osteoarthritis initiative. Clin Rheumatol 2016;35:371–9.
[26] Nur H, Sertkaya BS, Tuncer T. Determinants of physical functioning in women with knee osteoarthritis. Aging Clin Exp Res 2018;30:299–306.
[27] Núñez M, Nuñez E, Moreno JM, Segura V, Lozano L, Maurits NM, et al. Quadriceps muscle characteristics and subcutaneous fat assessed by ultrasound and relationship with function in patients with knee osteoarthritis awaiting knee arthroplasty. J Clin Orthop Trauma 2019;10:102–6.
[28] Chiang H, Lee CC, Lin WP, Jiang CC. Comparison of quadriceps-sparing minimally invasive and medial parapatellar total knee arthroplasty: a 2-year follow-up study. J Formos Med Assoc 2012;111:698–704.
[29] Hubley-Kozey CL, Hatfield GL, Astephen Wilson JL, Dunbar MJ. Alterations in neuromuscular patterns between pre and one-year post-total knee arthroplasty. Clin Biomech (Bristol, Avon) 2010;25:995–1002.
[30] Stucinskas J, Robertsson O, Sirka A, Lebedev A, Wingstrand H, Tarasevicius S. Moderate varus/valgus malalignment after total knee arthroplasty has little effect on knee function or muscle strength. Acta Orthop 2015;86:728–33.
[31] Loyd BJ, Jennings JM, Falvey JR, Kim RH, Dennis DA, Stevens-Lapsley JE. Magnitude of deformity correction may influence recovery of quadriceps strength after total knee arthroplasty. J Arthroplast 2017;32:2730–7.
[32] Akima H, Yoshiko A, Tomita A, Ando R, Saito A, Ogawa M, et al. Relationship between quadriceps echo intensity and functional and morphological characteristics in older men and women. Arch Gerontol Geriatr 2017;70:105–11.
[33] Kawasaki M, Hasegawa Y, Okura T, Ochiai S, Fujibayashi T. Muscle damage after total hip arthroplasty through the direct anterior approach for developmental dysplasia of the hip. J Arthroplast 2017;32:2466–73.
[34] Alves Jr WM, Migon EZ, Zabeu JL. Pain following total knee arthroplasty - a systematic approach. Rev Bras Ortop 2015;45:384–91.
[35] Sugitani K, Arai Y, Takamiya H, Terauchi R, Nakagawa S, Ueshima K, et al. Factors affecting range of motion after total knee arthroplasty in patients with more than 120 degrees of preoperative flexion angle. Int Orthop 2015;39: 1535–40.
[36] Gunaratne R, Pratt DN, Banda J, Fick DP, Khan RJK, Robertson BW. Patient dissatisfaction following total knee arthroplasty: a systematic review of the literature. J Arthroplast 2017;32:3854–60.
[37] Bandholm T, Kehlet H. Physiotherapy exercise after fast-track total hip and knee arthroplasty: time for reconsideration? Arch Phys Med Rehabil 2012;93: 1292–4.