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RESEARCH

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Preoperative computed tomography assessment of peri-hip muscles in patients with femoral neck fracture and its impact on postoperative walking function

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Abstract

Background The role of preoperative peri-hip muscles in postoperative walking ability for patients with femoral neck fractures is unclear. This study investigated the influence of these muscles on postoperative walking function using computed tomography (CT).

Methods A retrospective analysis was conducted on 58 patients (12 male, 46 female) who underwent bipolar hemiarthroplasty for femoral neck fractures between January 2018 and July 2021. Patients were followed up for at least six months postoperatively and categorized into two groups: the independent walking group (41 patients) and the non-walking group (17 patients). Patient data, including sex, age at surgery, body mass index (BMI), and preoperative walking status, were compared. Additionally, preoperative CT scans assessed the cross-sectional areas and CT values of the gluteus medius, gluteus maximus, and rectus femoris muscles on the unaffected side. These measurements were compared between the two groups.

Results No significant differences were observed between the groups regarding sex, age, BMI, or preoperative walking status. The CT values of the gluteus medius and gluteus maximus were significantly lower in the non-walking group compared with the walking group (gluteus medius: 39.3 ± 7.5 Hounsfield units (HU) vs. 28.6 ± 6.9 HU; $P < 0.01$; gluteus maximus: 33.0 ± 8.1 HU vs. 23.3 ± 10.7 HU; $P < 0.01$), whereas no significant differences were found for the rectus femoris. Cross-sectional areas of all muscles did not show significant differences between the two groups. Receiver operating characteristic curve analysis revealed that the gluteus medius had an area under the curve (AUC) of 0.86, with a sensitivity of 0.78 and specificity of 0.82, using a cut-off of 33.1 HU. The gluteus maximus had an AUC of 0.77, with a sensitivity of 0.63 and specificity of 0.77, using a cut-off of 31.6 HU.

Conclusions Preoperative CT values of the gluteus medius and gluteus maximus were lower in the non-walking group, suggesting that these muscles influence postoperative walking ability. Preoperative CT evaluation of these muscles can be a useful predictor of postoperative walking outcomes.

Keywords Femoral neck fracture, gluteus medius, gluteus maximus, Computed tomography, Walking ability

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Background

With the aging population, the global incidence of proximal femoral fractures was estimated at 1.6 million annually in 2000 and is expected to rise to 6.3 million annually by 2050 [1]. Many patients with proximal femoral fractures already exhibit a reduction in skeletal muscle mass before injury [2]. This reduction is associated with an increased risk of falls and is recognized as one of the key risk factors for proximal femoral fractures [3]. Moreover, pre-injury muscle loss can negatively impact postoperative activities of daily living (ADL) and increase mortality rates [4]. Therefore, evaluating peri-hip muscles at the time of hospitalization in patients with proximal femoral fractures is crucial for predicting postoperative ADL decline and preventing secondary fractures.

Computed tomography (CT) enables quantitative evaluation of skeletal muscle mass around the hip. Beyond muscle mass, CT can also assess fatty degeneration by measuring Hounsfield units (HU). HU values correspond to tissue density: air is − 1,000 HU, fat is − 100 HU, water is 0 HU, muscle ranges from 30–50 HU, and bone from 400–1,000 HU. As muscle degeneration progresses, HU values decrease, making it a useful metric for assessing muscle quality and degeneration [5]. Previous studies have used muscle cross-sectional areas and HU values from CT scans of paraspinal and thigh muscles to evaluate physical function and sarcopenia [6]. Previous studies have also reported that the cross-sectional area of thigh muscles and their HU values are associated with knee extension strength. Additionally, lower HU values, indicative of fatty degeneration in the muscles, are associated with reduced physical function, muscle weakness, and a higher risk of falls [6, 7]. However, studies examining the relationship between peri-hip muscles and proximal femoral fractures are limited [6–10]. Some research suggests that hip flexors, such as the iliopsoas and rectus femoris, experience a reduction in HU values postoperatively following surgery for proximal femoral fractures [10]. Moreover, the muscle cross-sectional areas of the gluteus medius and paraspinal muscles have been found to correlate with postoperative walking ability [9].

Despite these findings, it remains unclear whether preoperative peri-hip muscles affect postoperative walking function. No studies have evaluated the preoperative CT values of peri-hip muscles before proximal femoral fracture surgery. Thus, we hypothesized that evaluating both the muscle cross-sectional areas and CT values of peri-hip muscles using preoperative CT could help predict postoperative walking function. The aim of this study was to evaluate: (1) whether differences in the muscle cross-sectional areas of preoperative peri-hip muscles exist between patients who can walk postoperatively and those who cannot, and (2) whether differences in preoperative CT values of peri-hip muscles can predict postoperative walking ability. We hypothesized that in patients who are unable to walk after surgery, the peri-hip muscles exhibit preoperative atrophy and fatty degeneration, resulting in reduced muscle cross-sectional area and CT values.

Methods

Experimental design

We retrospectively identified 166 patients who underwent bipolar hemiarthroplasty (BHA) for femoral neck fractures at our hospital between January 2018 and July 2021. Of these, 58 patients with femoral neck fractures who met the exclusion criteria were classified into two groups: the independent walking and non-walking groups (Fig. 1). Preoperative CT was used to measure the cross-sectional area and CT values of the peri-hip muscles gluteus medius, gluteus maximus, and rectus femoris on the unaffected. These measurements were compared between the two groups.

Patients

We studied the hips of 58 patients (12 male, 46 female) aged 70 years and older who underwent BHA for femoral neck fractures at our hospital between January 2018 and July 2021. All patients had at least six months of postoperative follow-up. At the six-month follow-up, the patients were divided into two groups: the independent walking group (41 patients; 10 males, 31 females) and the non-walking group (17 patients; 2 males, 15 females). Comparisons were then made between the groups.

Inclusion criteria were: (1) patients who underwent BHA for femoral neck fractures and had at least six months of postoperative follow-up. Exclusion criteria included: (1) femoral neck fracture on the contralateral side; (2) lack of preoperative CT imaging; (3) non-walking status in ADL before the injury; (4) BHA performed due to nonunion or osteonecrosis of the femoral head following bone fixation. This study was conducted retrospectively with approval from the hospital's clinical research committee and conflict of interest committee (23R106). Informed consent was waived due to the retrospective nature of the study.

Endpoints

Patient data, including sex, age at surgery, body mass index (BMI), and preoperative walking status, were compared. Additionally, preoperative CT was used to measure the CT values and cross-sectional areas of the gluteus medius, gluteus maximus, and rectus femoris on the unaffected side. All data were obtained from medical records.

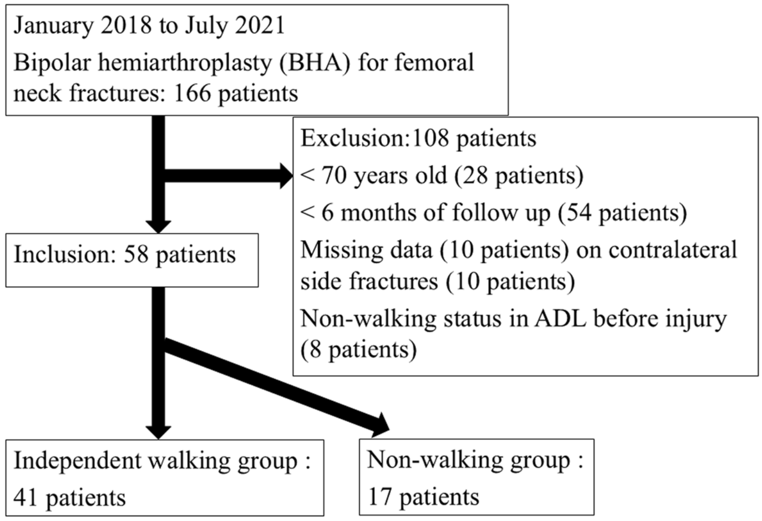

Fig. 1 Flow chart of the patient's inclusion and criteria

Walking function

Walking ability was evaluated preoperatively and six months postoperatively, with ADL categorized into five levels: (1) independent, (2) one cane, (3) walker, (4) stepping with support, and (5) wheelchair or bedridden. Non-walking status was defined as category 5 (wheelchair or bedridden). ADL data were retrieved from medical records.

Surgery

Fifty-eight patients underwent surgery performed by five orthopedic surgeons under the supervision of a hip surgeon. Both groups underwent BHA in the lateral position via a posterior lateral approach. The short external rotator muscles and posterior joint capsule were detached, and the femoral head was removed. A cementless stem was placed in all cases. After implantation, the short external rotator muscles and posterior joint capsule were sutured and repaired to the greater trochanter. Postoperative rehabilitation began the following day, with full-weight walking training initiated.

CT evaluations

CT scans (Canon Medical System, Otawara, Japan) were performed upon hospitalization using a standard protocol (120 kV tube voltage, 0.5 mm slice thickness, 0.5 s scan time) with patients in the supine position. The scanning range extended from the anterior superior iliac spine to the lesser trochanter. All CT analyses were conducted using axial section images. In this study, similar to previously reported cases, measurement levels were evaluated on preoperative CT axial section images of the unaffected side. The gluteus medius muscle was assessed at the level of the anterior superior iliac spine, the gluteus maximus muscle at the level of the top of the greater trochanter, and the rectus femoris muscle at the level of the lesser trochanter [11–13]. The evaluation was performed on the unaffected side, as the affected side would likely be affected by hematoma and muscle contusion at the fracture site. CT analysis of the unaffected side was performed on axial section images: at the level of the anterior superior iliac spine for the gluteus medius, the greater trochanter for the gluteus maximus, and the lesser trochanter for the rectus femoris. Muscle borders were manually marked using the region of interest tool in Digital Imaging and Communications in Medicine format (512×512 pixels) to measure the cross-sectional area and CT values (Fig. 2).

Statistical analysis

Statistical analysis was conducted using SPSS Statistics (version 26; IBM Corp., Armonk, NY, USA). The Mann–Whitney U test was used to evaluate age at surgery, BMI, and the cross-sectional areas and CT values of the gluteus medius, gluteus maximus, and rectus femoris. Fisher's exact test (Chi-square test) was used to assess preoperative sex difference and walking status. Intra-rater and inter-rater reliability were evaluated by having two raters independently measure each patient twice. The reliability of the muscle cross-sectional areas and CT values was assessed using intraclass correlation coefficients (ICC). Receiver operating characteristic (ROC) curve analysis was conducted to assess the cross-sectional areas and CT values of the gluteus medius, gluteus maximus, and rectus femoris. The Youden index was used to determine optimal cut-off values. The Mann–Whitney U test was

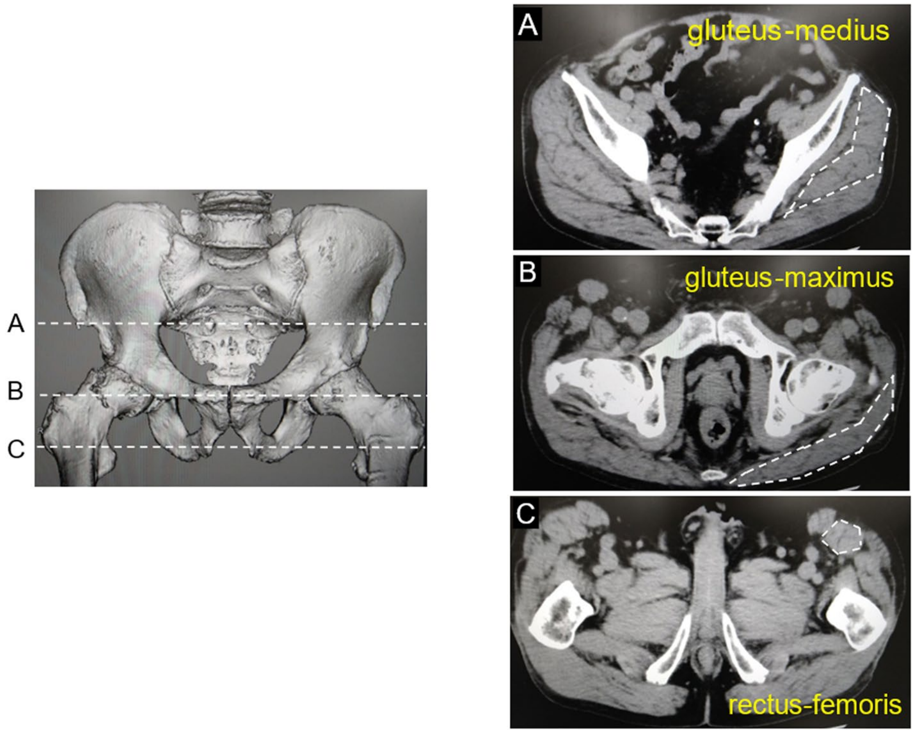

Fig. 2 Analysis of muscle cross-sectional area and CT values. **A** The gluteus medius was measured at the level of the anterior superior iliac spine. **B** The gluteus maximus was measured at the level of the greater trochanter. **C** The rectus femoris was measured at the level of the lesser trochanter

used to compare the CT values of the gluteus medius, gluteus maximus, and rectus femoris by sex. A significance level of $P<0.05$ was set for all tests.

Results

The average age at surgery for the 41 patients in the independent walking group (10 males, 31 females) was 82.6 ± 7 years, whereas the average age for the 17 patients in the non-walking group (2 males, 15 females) was 84.1 ± 4.1 years. There were no significant differences between the two groups in terms of sex, age at surgery, or BMI (Table 1). Preoperative walking status was classified as follows: (1) independent, (2) one cane, (3) walker, and (4) stepping with support. No significant difference was observed between the two groups (Table 1). The preoperative CT values for the gluteus medius and gluteus maximus were significantly lower in the non-walking group compared to the independent walking group (gluteus medius: 39.3 ± 7.5 HU vs. 28.6 ± 6.9 HU; $P<0.01$; gluteus maximus: 33.0 ± 8.1 HU vs. 23.3 ± 10.7 HU; $P<0.01$) (Table 2). There were no significant differences in the CT values of the rectus femoris (Table 2) or muscle cross-sectional areas of the gluteus medius, gluteus maximus, and rectus femoris between the two groups (Table 3).

In the ROC curve analysis, the CT value of the gluteus medius had an area under the curve (AUC) of 0.86, with a sensitivity of 0.78 and a specificity of 0.82; the cut-off value using the Youden index was 33.1 HU. For the gluteus maximus, the CT value had an AUC of 0.77, with a sensitivity of 0.63 and a specificity of 0.77, with a cut-off value of 31.6 HU. No significant difference was noted for the rectus femoris (Fig. 3). ROC curve analysis of the muscle cross-sectional areas of all three muscles showed no significant differences (Fig. 4). Intra-rater and inter-rater reliability were assessed using ICC, with

Table 1 Comparison of patient demographics between the independent walking and non-walking groups

Patient demographics	**Independent group ($n=41$)**	**Non-walking group ($n=17$)**	***P*-value**
Sex (nHips)	Males: 10	Males: 2	0.48
	Females: 31	Females: 15	
Age at surgery (years)	82.6 ± 7.0	84.1 ± 4.1	0.47
BMI (kg/m^2)	19..8 ± 3.1	19.5 ± 4.3	0.45
Preoperative walking status			
Independent (%)	31(75.6)	12(70.6)	0.85
One cane (%)	6(14.6)	2(11.8)	
Walker (%)	1(2.4)	1(5.9)	
Stepping with support (%)	3(7.3)	2(11.8)	

Table 2 Comparison of CT values of the gluteus medius, gluteus ma imus, and rectus femoris between the independent walking and the non-walking groups

CT endpoints	Independent group (*n* = 41)	Non-walking group (*n* = 17)	*P*-value
Gluteus medius CT value (HU)	39.3 ± 7.5	28.6 ± 6.9	< 0.001
Gluteus ma imus CT value (HU)	33.0 ± 8.1	23.3 ± 10.7	0.001
Rectus femoris CT value (HU)	50.0 ± 5.2	49.4 ± 4.3	0.818

values above 0.9 for each parameter, indicating high reliability. The intra-rater reliability for the muscle cross-sectional area was 0.993 (95% confidence interval (CI): 0.99–0.995), whereas the inter-rater reliability was 0.993 (95% CI: 0.992–0.995). The intra-rater reliability for the CT values was 0.992 (95% CI: 0.991–0.995), whereas the inter-rater reliability was 0.963 (95% CI: 0.953–0.971). In this study, the CT values of the gluteus medius, gluteus maximus, and rectus femoris were compared between 12 men and 46 women out of 58 patients, with no significant differences found between the sexes.

Discussion

In this study, comparing the independent walking group and the non-walking group revealed that while the cross-sectional areas of the gluteus medius and gluteus maximus did not differ significantly, the CT values were lower in the non-walking group. The rectus femoris showed no significant differences in either cross-sectional area or CT values.

Patients with proximal femoral fractures are known to experience a decline in walking function postoperatively, which is also associated with increased mortality rates [9]. Postoperative mortality rates have been reported at approximately 4% at 1 month postoperatively and approximately 10–23% at 1 year after surgery [9, 14]. Thus, regaining walking function is critical to prevent postoperative mortality and deterioration of overall health. However, studies have shown that only approximately 50% of patients regain walking ability 1 year after surgery [1, 15]. Additionally, among patients with a decline in ADL following proximal femoral fracture surgery, only around 40% are able to return home [1, 15]. Preoperative walking ability and the nutritional status of patients are known to be predictive factors for postoperative outcomes [16].

Skeletal muscle mass begins to decline rapidly after the age of 60 years [17], and aging leads to both quantitative and qualitative reductions in muscle mass, which affects ADL [18]. Furthermore, decreased muscle mass and fatty infiltration are thought to contribute to physical frailty [19]. Our study suggests that preoperative fatty degeneration of the gluteus medius and gluteus maximus on the unaffected side may influence postoperative walking function.

Among the muscles surrounding the hip, the gluteus medius and gluteus maximus are critical for pelvic stability during the stance phase of walking [10]. A decrease in the strength of these muscles can affect gait patterns, leading to abnormal signs such as Trendelenburg's sign [20]. It is known that fat accumulation in muscles increases with aging, especially in individuals over 50, and the gluteal muscles are more susceptible to fatty degeneration compared to other muscles [6]. This atrophy and fatty degeneration in the gluteus medius may lead to decreased abductor function, which in turn can increase the risk of falls [20, 21]. Studies have demonstrated that fatty degeneration of the gluteus medius and minimus, as classified by Goutallier [22], is more pronounced in patients with proximal femoral fractures than in healthy individuals [8].

A potential cause of gluteus medius atrophy could be the rubbing and compressive degeneration that occurs as the tendon crosses the greater trochanter [8]. Age-related changes in the gluteus maximus also increase the risk of gait disturbances, falls, and fractures [6]. Strengthening skeletal muscles, especially the gluteus medius and gluteus maximus, is thought to be effective in reducing the risk of proximal femoral fractures and falls [10, 23]. However, there is currently limited research identifying specific muscles that should be targeted for strengthening during rehabilitation in patients with proximal femoral fractures [10]. This study

Table 3 Comparison of muscle cross-sectional areas of the gluteus medius, gluteus maximus, and rectus femoris between the independent walking and non-walking groups

CT endpoints	Independent group (*n* = 41)	Non-walking group (*n* = 17)	*P*-value
Gluteus medius cross sectional area (mm^2)	2074.2 ± 449.4	1923.4 ± 366.1	0.33
Gluteus maximus cross sectional area (mm^2)	2323.6 ± 600.5	2167.3 ± 487.6	0.57
Rectus femoris cross sectional area (mm^2)	346.0 ± 110.5	314.1 ± 84.0	0.34

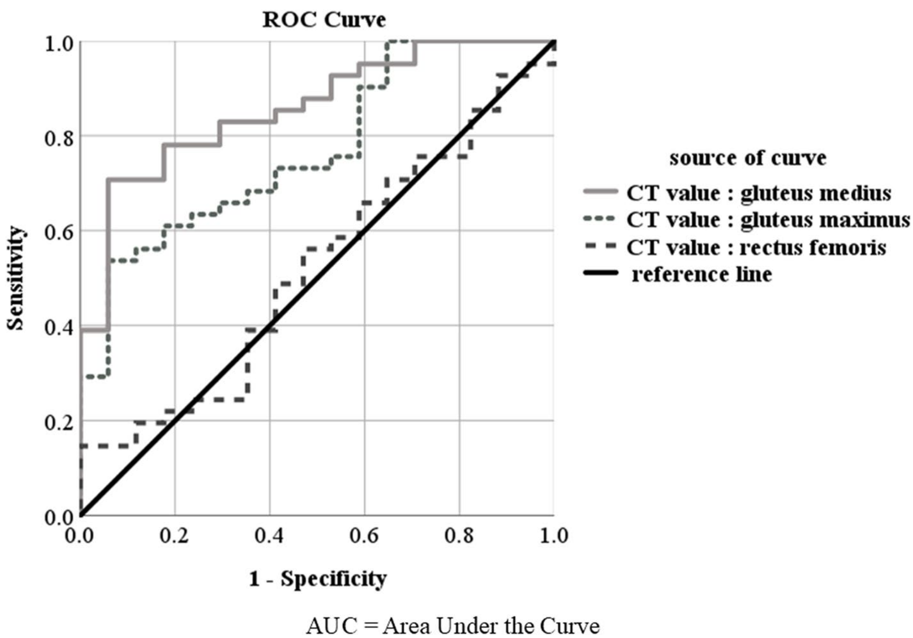

Fig. 3 ROC curve analysis of CT values for the gluteus medius, gluteus maximus, and rectus femoris. The CT value for the gluteus medius had an AUC of 0.86, a sensitivity of 0.78, and a specificity of 0.82, with a cutoff value of 33.1 HU ($P < 0.01$). The CT value for the gluteus maximus had an AUC of 0.77, a sensitivity of 0.63, and a specificity of 0.77, with a cutoff value of 31.6 HU ($P < 0.01$). The CT value for the rectus femoris had an AUC of 0.52, a sensitivity of 0.56, and a specificity of 0.53 ($P = 0.82$)

showed that fatty degeneration of the gluteus medius and gluteus maximus muscles may impair postoperative walking function. Therefore, it is crucial to actively incorporate rehabilitation of these muscles early in the postoperative period.

Several studies have investigated the muscle mass of peri-hip muscles using CT [11, 12, 24–26]. Most research has focused on patients undergoing total hip arthroplasty for osteoarthritis, exploring changes in muscle cross-sectional area and degeneration before and after

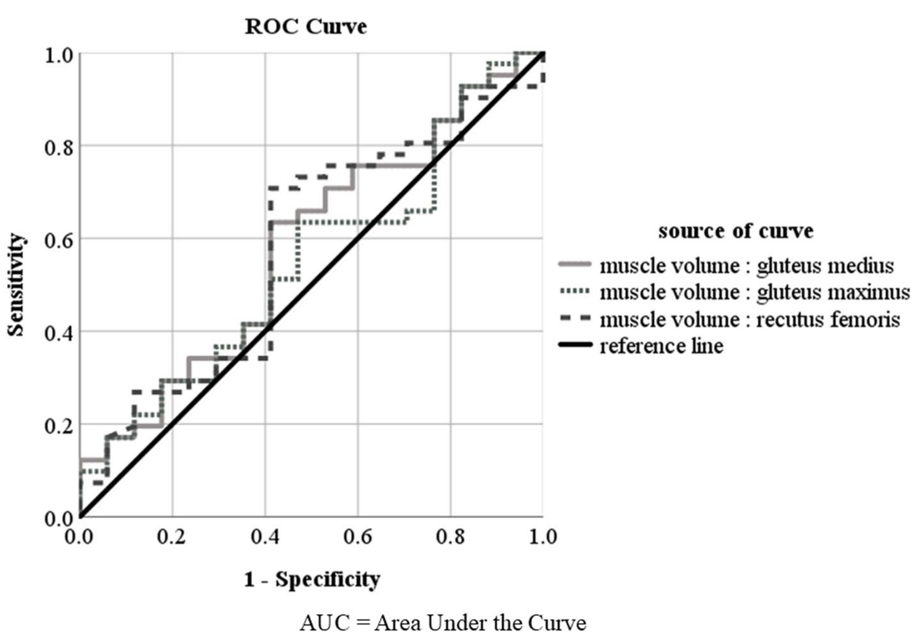

Fig. 4 ROC curve analysis of muscle cross-sectional areas for the gluteus medius, gluteus maximus, and rectus femoris. The cross-sectional area of the gluteus medius had an AUC of 0.58, a sensitivity of 0.63, and a specificity of 0.53 ($P = 0.33$). The cross-sectional area of the gluteus maximus had an AUC of 0.55, a sensitivity of 0.63, and a specificity of 0.53 ($P = 0.57$). The cross-sectional area of the rectus femoris had an AUC of 0.58, a sensitivity of 0.71, and a specificity of 0.59 ($P = 0.34$)

surgery [11, 12, 24–26]. Additionally, studies have shown that the HU values of the iliopsoas and rectus femoris muscles decrease after surgery for proximal femoral fractures [10]. Previous research has correlated the preoperative cross-sectional area of the gluteus medius and paraspinal muscles with postoperative walking status in patients with femoral neck fractures [9]. Uemura and Ukai measured the gluteus medius at the level of the anterior superior iliac spine and the gluteus maximus at the greater trochanter [11, 12]. Ogawa et al. compared the 2D and 3D CT evaluations of muscular atrophy and fatty degeneration in the muscles around the hip. They reported a strong correlation between the 2D and 3D CT measurements of muscular atrophy in 64% of the muscles assessed, particularly for the gluteus medius at the level of the anterior superior iliac spine and the gluteus maximus at the greater trochanter [26]. As this was a retrospective study, the CT scan range was limited to the proximal hip, which may have affected the ability to adequately measure the muscle cross-sectional area of the rectus femoris. Future studies should consider including CT scans extending to the mid-thigh region to better assess this muscle's role in postoperative outcomes.

In this study, we evaluated muscle mass using CT images taken upon admission for patients with femoral neck fractures, without additional examinations. Sudo et al. assessed the cross-sectional areas of the gluteus maximus, gluteus medius, paraspinal muscles, and iliopsoas using CT of the affected side and reported that the cross-sectional areas of the gluteus medius and paraspinal muscles could potentially predict postoperative walking status [9]. In contrast, unlike Sudo et al., our study evaluated the cross-sectional areas and computed CT values of the unaffected side, which may account for differences in the results compared to their report. This choice might explain some of the differences noted in results from other studies that assessed the affected side, where factors such as hematoma and muscle contusion around the fracture site could have influenced the results.

In a study similar to this one, Noda et al. reported that the gluteus maximus CT value was significantly different from the gluteus maximus CT value, with a cut-off value for the gluteus medius CT value was of 30.9 HU [27]. In this study, the CT values of the gluteus medius and gluteus maximus were also significantly different; however, the AUC for the gluteus medius CT value was higher than that for the gluteus maximus CT value. Since the cut-off value for the gluteus medius CT value is the same as that reported by Noda et al., it is possible that the gluteus medius CT value is a more important prognostic factor for walking function than the gluteus maximus CT value. However, the number of cases in this study was small, and further research is needed.

This study has some limitations. First, as a retrospective study, there are inherent constraints in the study design. Second, the follow-up period of six months may not be sufficient for long-term assessments, and future studies should include larger sample sizes and extended follow-up periods to confirm these findings. Third, our assessment was limited to CT imaging, lacking muscle strength measurements, which could provide a more comprehensive evaluation. Fourth, the study did not assess postoperative balance and walking ability, which are critical factors in determining functional outcomes. Future research should incorporate assessments of walking speed and balance during postoperative rehabilitation to better predict walking function. Finally, given that the rectus femoris was evaluated only in the proximal thigh region, its role in postoperative outcomes may have been underestimated. Future prospective studies should include CT imaging that extends to the mid-thigh region to provide a more accurate assessment of the rectus femoris. Sixth, proximal femoral fractures are more common in female patients than male patients [28], and male patients were underrepresented in this study. Although no significant sex differences in patient background were observed between the two groups, the small sample size prevented a full ROC curve analysis of the muscle cross-sectional area and CT values by sex. Future studies should assess a larger number of cases and evaluate these parameters by sex.

In summary, this study suggests that lower preoperative CT values of the gluteus medius and gluteus maximus are associated with poor postoperative walking function. Preoperative evaluation of these muscles using CT can be a valuable tool for predicting postoperative outcomes in patients undergoing BHA for femoral neck fractures.

Conclusions

We classified patients with femoral neck fractures who underwent BHA into two groups: independent walkers and non-walkers. Preoperative CT of the unaffected side showed that the CT values of the gluteus medius and gluteus maximus were lower in the non-walking group, suggesting these muscles may influence postoperative walking ability. Evaluating the gluteus medius and gluteus maximus preoperatively using CT may serve as a useful tool for predicting postoperative walking function.

Abbreviations

HU	Hounsfield units
CT	Computed tomography
BMI	Body mass index
ROC	Receiver operating characteristic
AUC	Area under the curve
ADL	Activities of daily living
BHA	Bipolar hemiarthroplasty
ICC	Intraclass correlation coefficients
CI	Confidence interval

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Not applicable.

Authors' contributions
T.U. conceptualized and designed this study; K.Y. and M.O. acquired and analyzed the data; K.Y. and T.U. drafted the article; M.W. critically revised the important intellectual content of the manuscript; All authors approved the final version to be published.

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Data availability
The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
All procedures were performed in accordance with the guidelines of the Declaration of Helsinki and approved by the Institutional Review Board of Tokai University Hospital (approval number: 23R106). The ethics committee of the University of Tokai waived the need for informed consent.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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