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Hip muscle size and density are associated with trochanteric fractures of elderly women

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Hip muscle size and density are associated with trochanteric fractures of elderly women

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Hip muscle size and density are associated with trochanteric fractures of elderly women

Abstract

Purpose We aimed to investigate the differences in hip muscle area and density between older patients with femoral neck (FNF) and trochanteric fractures (TRF).

Design Cross-sectional study.

Setting and Participants University hospital; A total of 554 older women patients were enrolled, including 314 FNF (77.02 ± 7.15 years) and 240 TRF (79.70 ± 6.91 years) for the comparisons.

Methods The area and density of the gluteus medius and minimus muscle (G.Med/MinM) and the gluteus maximus muscle (G.MaxM) were measured by CT. Total hip (TH) areal bone mineral density (aBMD) and femoral neck aBMD (FNaBMD) were measured by quantitative CT. A cutoff of 80 years was used to stratify the cohort and to further explore the age-specific relationship.

Results For the total subjects, all these muscle parameters were higher in the FNF group than in the TRF group ($p< 0.001$). The muscle parameters except for the G.Med/MinM density were significantly correlated with hip fracture typing after adjustment for age, BMI, and THaBMD. In the age ≧ 80 group, no statistically significant correlation was found between all hip muscle parameters and fracture types. In contrast, in the age<80 group, interestingly, after adjustment of age, BMI, and THaBMD, the associations between G.MaxM density, G.MaxM area, G.Med/MinM density, and G.Med/MinM area and fracture type were all statistically

significant.

Conclusions Our results indicate that in older women, especially under 80 years of age, gluteus muscle parameters are related to trochanteric fractures.

[Key words] Osteoporosis; Muscle density; Muscle area; Femoral neck fracture; Trochanteric fractures.

Strengths and limitations of this study

- This is the first study to use a cutoff of 80 to stratify the age and further explore the age-specific relationship between area and density of gluteus with hip fracture type.
- The subjects imaged more than 48 hours after hip fracture were excluded from our study, which makes our measurements of bone and muscle parameters more reliable.
- Several factors for binary logistic regression were calibrated in this study, including BMD, which is an important factor that had been overlooked in previous relevant studies.
- This study was cross-sectional-designed, and subsequent longitudinal cohort studies are warranted further to investigate the relationship between gluteal muscles and fracture types.

Hip muscle size and density are associated with trochanteric fractures of elderly women

1. Introduction

Hip fracture in elderly adults is one of the most severe consequences of osteoporosis, with high morbidity, mortality, and disability rates[1-3]. Hip fracture consists of two main types, femoral neck fracture (FNF) and trochanteric fracture (TRF), which require different treatments and yield different clinical outcomes[4]. For example, the FNF was associated with a higher incidence of femoral head necrosis and nonunion than the TRF, while the TRF may bring higher mortality risks[5 6]. Therefore, it is critical to explore the potential differences between these two different fracture types. Previous reports identified some factors, i.e., bone structures and spatial distributions, and bone mineral density (BMD) at the femur, to be associated with fracture types[7-9]. However, evidence is still insufficient to draw a robust conclusion regarding the disparities between the two types.

Along with the aging process, the age-related loss of muscle compositions and functions directly leads to a dramatic decrease in older adults' ability to balance and, thus, an increased risk of falls. However, to the best of our knowledge, only two studies explored differences in muscle parameters between the two types of hip fragility fractures, but both of these studies did not measure hip bone mineral density, so BMD was not corrected for the comparison, while BMD reduction has been identified in many studies as an important cause of hip fractures[10 11]. Thus, further exploring the association between muscle biomarkers and hip fracture types becomes warranted.

In this cross-sectional study, by using a cohort of older hip fracture women with hip CT scans immediately after injury, we aimed to investigate the differences in hip muscle area and density between older patients with femoral neck and trochanteric fractures. We hypothesized that gluteal muscle density and area based on CT measurements might be involved in classifying hip fractures in the elderly.

2. Materials and methods

2.1. Study design and participants

From January 2012 to December 2019, 1134 consecutive elderly patients (over 65 years old) with diagnosed hip fractures were recruited for this study (Figure 1). In this institution, CT scans are routinely performed for subjects with suspected or confirmed hip fractures in the Emergency Department. According to the CT image, the fractures were categorized into FNF or TRF by an experienced musculoskeletal radiologist. A one-page questionnaire inquiring about demographic data (e.g., age, gender, height, and weight), details of the fall (when, where, and how), fracture history, and medical history was completed by the patients or their relatives after the CT examination.

The inclusion and exclusion criteria for hip fracture patients were similar to those described by *Wang et al.* [12]. In short, the inclusion criteria were women, hip fractures caused by low-energy injuries, and the patient's hip CT scan was performed within 48 hours. Patients with a history of hip fractures or other reasons that prevented them from standing or walking were excluded.

This cross-sectional study was approved by the Institutional Review Board of XXX Hospital and was conducted in accordance with the principles of the Declaration of Helsinki. Informed consent was obtained from each patient.

2.2. Computed tomography acquisition and quantitative CT (QCT) analysis

The Toshiba Aquilion spiral CT scanner (Toshiba Medical Systems Division, Tokyo, Japan) was used to perform CT scans of all study participants. The subject was scanned in a supine position, with a solid calibration body model (Mindways Software Inc., Austin, TX, USA) located just below the hips. Scans range from the top of the acetabular to 3 cm or longer below the lesser trochanter to cover the proximal femur. Scan parameters were 120 kVp, 125 mAs, 50 cm field of view, 512 × 512 matrix, 1 mm reconstructed slice thickness, and a standard reconstruction kernel with filtered back-projection. After the CT scan, the corresponding image was automatically uploaded to the Mindways QCT workstation.

CT X-ray absorptiometry technique (CTXA v 4.2.3, Mindways Inc., Austin, TX) is a QCTPro scan analysis module for the hip that generates a 2D image from 3D CT images of the proximal femur. The measurement procedure was described in detail previously[13 14]. In brief, it divides it into three regions of interest (ROIs), the femoral neck (FN), trochanter (TR), and intertrochanter (IT), that are equivalent to the standard ROIs widely used to interpret DXA hip scans. Thus, it is possible to calculate DXA-equivalent areal bone mineral density (aBMD, g/cm^2) results for each ROI as well as the combination of all three to give a measurement equivalent to the total hip (TH) ROI. The aBMD of the femoral neck (FN) and total hip (TH) were calculated from the hip CT scans using the CTXA. The hip BMD on the healthy side was measured for all the patients.

2.3. Muscle Cross-sectional area and density assessments

OsiriX software (Lite Version 12.0.2, Pixmeo, Geneva, Switzerland) was used for analysis. The muscle measurement procedure and precision have been reported previously[15].Two investigators who had received training from an expert radiologist in CT muscle imaging before the analysis performed all muscle measurements, and then the corresponding averages were yielded.

Figure 2 showed that cross-sectional area and density were measured of the gluteus maximus (G.MaxM) at the level of the greater trochanter and the gluteus medius and minimus muscle (G.Med/MinM) at the level of the third sacral (S3).

2.4. Statistical analysis

Data are presented as means and standard deviations for parametric data, while categorical variables are described using frequencies and numerical distributions. The Chi-squared test was used to assess the differences between the two groups for categorical variables and the Student's t-test for continuous variables. We used a cutoff of 80 to stratify the age and further explore the age-specific relationship between muscle parameters and fracture type. Logistic regression models were used with and without adjustments for age, BMI, and THaBMD. In addition, we applied generalized additive models to identify further the dose-response relationship between the densities and areas of the muscle and probabilities of TRF with and without adjustment for covariates mentioned above. All the analyses were performed with the statistical software package R 4.1.1 (http://www.R-project.org, The R Foundation). A two-tailed test was performed, and p<0.05 was considered statistically significant.

3. Results

3.1. Characteristics of subjects

Figure 1 illustrates the recruitment of study participants. 580 cases of the 1134 low trauma hip fracture patients were excluded. It is worth mentioning that 215 subjects imaged more than 48 hours after hip fracture were excluded due to prolonged immobilization. A total of 554 hip fracture subjects were eligible for further analysis, including 314 FNF cases and 240 TRF cases. Table 1 shows the distribution of relevant demographic data for these subjects. The FNF group was significantly younger and taller and had higher gluteus muscle area and density and higher aBMD in TH and FN regions. We then stratified the participants into two subgroups using a cutoff of 80 in age (Table 1).

3.2. Associations of muscle size and density variables with trochanteric fractures

All measurements of the area and density except for G.Med/MinM density were found to be significantly associated with TRF after adjusting for age and BMI (Table 2). What's more, these associations were still significant after further adjusting for THaBMD (Table 2, Figure 3). G.Med/MinM density (adj.OR 0.98,0.95~1,01) was on the border associated with TRF after adjustments for age, BMI, and THaBMD.

3.3. Relationship between muscle variables and age

Furthermore, we found a much stronger relationship between gluteus and TRF in the younger group (age <80) than that in the older group (age >80) (Table 2). After adjustment, all the performances of gluteus muscles were still statistically significant in the younger group (age <80) (G.Med/MinM area, 0.96 (0.92~0.99); G.Med/MinM density, 0.95 (0.91~0.98); G.MaxM area, 0.95 (0.91~0.99); G.MaxM density, 0.95(0.92~0.98)) (*P* <0.01, Table 2, Figure 3).

4. Discussion

In this cross-sectional study, we exploited CT images to obtain data on the density and area of hip muscles in acute low-energy hip fracture women, and our study showed that in older women, especially under 80 years of age, the area and density of the gluteus muscles were significantly associated with trochanteric fractures. After further adjustment for THaBMD, the associations were reduced but remained significant for most muscle parameters.

Regarding the differences between the two fracture subtypes (FNF and TRF) of hip fracture, a review by Mautalen et al. reported that women with TRF are older, thinner, and shorter, and the two fracture subtypes may also have different ethnic and geographic patterns[16]. In our study, the TRF groups were consistently older and shorter. In a case-control study, Yu et al. applied statistical multiparameter mapping to investigate spatial differences in proximal femur density and cortical bone characteristics between the two main types of hip fractures, and the results show that there were different spatial distributions of trabecular volumetric BMD between the two types of hip fractures[7]. However, few studies have explored whether there are differences in muscle parameters between the two types of hip fractures.

Muscle density measured by CT as mean attenuation of skeletal muscle in Hounsfield units (HU) has already been widely used in research studies[17-20] to assess muscle quality, because a low tissue HU (low muscle density) may be a marker of lipid or fluid infiltration in skeletal muscles that can be accompanied by functional changes[21]. Wang L et al. showed that muscle density performs better than aBMD from hip CTXA and muscle size in discrimination of hip fracture[12]. In 2008, Lang et al. reported that subjects with hip fractures showed trends towards lower hip muscle CSA and lower lean tissue muscle HU (reflecting greater fatty infiltration of the musculature) than controls[22]. Then in 2010, Lang et al. reported that decreased thigh muscle HU is associated with an increased risk of hip fracture[23]. All these studies indicated that muscle density plays a vital role in assessing physical function or fracture risk[24].

We hypothesized that gluteal muscle density and area may be involved in classifying hip fractures in the elderly. The gluteus maximus is located in the shallow layer of the gluteal muscle, its main movement is the hip extension and external rotation, and its upper area also acts as a hip abductor muscle[25 26]. The anterior upper part of the gluteal median muscle is located under the skin, and the posterior lower part is located on the deep side of the gluteus maximus, and its primary role is to abduct the hip joint (the anterior muscle bundle rotates the hip joint, and the posterior muscle bundle rotates the hip joint out)[26 27]. The gluteus minimus muscles are located on the deep side of the gluteus medius muscle and act the same way as the gluteal median muscle, so this study analyzed these two muscles as a whole. Erinç et al. reported that the gluteal median muscle and gluteus minimus muscle areas in the FNF group are higher than those in the TRF group, but there was no significant difference in the atrophy scores between subjects with TRF versus FNF[10]. Our study showed that the TRF group had a smaller area of G.Med/MinM than the FNF group in women older than 65 years, which is consistent with the above study's findings. Moreover, the difference was still statistically significant after adjusting for age, BMI, and THaBMD. Furthermore, G.MaxM density and size were also associated with the risk of TRF in women older than 65 years independently of hip aBMD. Similarly, Wang L et al. [15] showed that the G.MaxM density was significantly associated with physical performance in older women, with or without adjustment for age, height, and weight. This study revealed the important role of the G.MaxM muscle.

Interestingly, after we grouped patients by age 80, the difference in muscle parameters between the two fracture types in the over 80 years old group was no longer statistically significant after adjustment of covariates. However, in the 65-80 age group, muscle parameters, especially G.MaxM, were more strongly related to TRF. The explanations for the age effect on muscle parameters with the risk of TRF were unclear. Hip fracture women aged over 80 years seem to be especially frail with low bone mineral density, low cortical thickness, and low muscle quality, thus, we speculated that the incidence of hip fracture type might be a random event.

5.Strengths and limitations

To our knowledge, this is the first study to use a cutoff of 80 to stratify the age and further explore the age-specific relationship between G.MaxM and G.Med/MinM area and density with hip fracture type. Secondly, the subjects imaged more than 48 hours after hip fracture were excluded from our study, making our bone and muscle measurements more reliable. Moreover, several factors for binary logistic regression were calibrated in this study, including BMD, an essential factor that had been overlooked in previous relevant studies.

This study has two major limitations. Firstly, this study was cross-sectional-designed, and subsequent longitudinal cohort studies are warranted further to investigate the relationship between gluteal muscles and fracture types. Secondly, in the measurement, we chose to measure the healthy side to replace the data on the fracture side, which may be biased. However, we should take into account that fracture, bleeding, edema, etc., on the fracture side may affect the accuracy of muscle parameter measurements. Meanwhile, Cheng et al.[28] reflected the excellent symmetry of the hip joint on both sides and maybe it can be further improved if there is better technology in the future.

6. Conclusions

In conclusion, we found that in older women especially under 80, gluteus muscle parameters are related to trochanteric fractures. It is well known that age-related loss of muscle mass increases the risk of hip fractures. Therefore, maintaining muscle mass and function, as well as reducing fat infiltration in the muscles, may help prevent trochanteric fractures in older women.

Abbreviations

FNF	femoral neck fractures
TRF	trochanteric fractures

G.Med/MinM	gluteus medius and minimus muscle
G.MaxM	gluteus maximus muscle
THaBMD	total hip areal bone mineral density
FNaBMD	femoral neck areal bone mineral density
BLR	binary logistic regression
BMD	bone mineral density
BMI	body mass index
QCT	quantitative computed tomography
CTXA	CT X-ray absorptiometry technique
HU	Hounsfield units

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Author Contributions

Pengju Huang: Methodology, Writing - Original Draft, Writing- Reviewing;

Yufeng Ge: Methodology, Writing- Reviewing and Editing;

Yandong Liu: Writing- Reviewing and Editing, Investigation, Validation;

Jian Geng : Writing- Reviewing and Editing, Validation;

Wei Zhang: Investigation, Validation;

Wei Liang: Investigation, Validation;

Aihong Yu: Conceptualization, Methodology, Writing- Reviewing and Editing;

Xinbao Wu: Conceptualization, Methodology, Writing- Reviewing and Editing;

Ling Wang: Conceptualization, Methodology, Writing- Reviewing and Editing, Supervision;

Xiaoguang Cheng: Conceptualization, Methodology, Writing- Reviewing and Editing.

All authors reviewed the manuscript and approved the final version.

Conflicts of Interest

All authors states that there is no conflict of interest.

Availability of data

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

The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Institutional Review Board of Beijing Jishuitan Hospital (No.201512-02)**.** Informed consent was obtained from all subjects involved in the study.

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Table 1 Characteristics of subjects who sustained femoral neck or trochanteric fractures grouped by age

	Total (n = 554)			Age <80			Age ≥80		
	FN (n = 314)	TR (n = 240)	p	FN (n = 201)	TR (n = 110)	p	FN (n = 113)	TR (n = 130)	p
age, year	77.02 ± 7.15	79.70 ± 6.91	< 0.001	72.69 ± 4.48	73.60 ± 4.07	0.077	8[illegible]3 ± 3.69	84.86 ± 4.01	0.797
height, cm	159.15 ± 5.76	157.09 ± 5.84	< 0.001	159.92 ± 5.90	158.69 ± 5.47	0.074	1[illegible]7.7[illegible] ± 5.27	155.73 ± 5.83	0.005
weight, kg	58.04 ± 10.53	57.97 ± 11.25	0.944	59.65 ± 10.17	61.04 ± 10.48	0.256	5[illegible]6 ± 10.60	55.38 ± 11.27	0.880
BMI, kg/m^2	22.84 ± 3.51	23.43 ± 4.09	0.066	23.26 ± 3.33	24.21 ± 3.83	0.024	2[illegible]8 ± 3.69	22.78 ± 4.21	0.175
THaBMD, g/cm^2	0.57 ± 0.11	0.52 ± 0.11	< 0.001	0.59 ± 0.11	0.57 ± 0.10	0.036	0[illegible]4 ± 0.10	0.49 ± 0.10	< 0.001
FNaBMD, g/cm^2	0.50 ± 0.10	0.47 ± 0.10	< 0.001	0.51 ± 0.10	0.49 ± 0.09	0.092	0[illegible] ± 0.09	0.45 ± 0.09	0.076
G.Med/MinM area, cm^2	29.92 ± 7.17	27.24 ± 6.61	< 0.001	31.34 ± 6.94	28.83 ± 6.99	0.003	2[illegible].40 ± 6.88	25.88 ± 5.98	0.067
G.Med/MinM density, HU	33.40 ± 6.72	31.04 ± 6.81	< 0.001	34.92 ± 6.50	31.97 ± 6.72	< 0.001	3[illegible].68 ± 6.26	30.24 ± 6.82	0.603
G.MaxM area, cm^2	31.01 ± 6.81	28.40 ± 6.44	< 0.001	32.57 ± 6.66	30.48 ± 6.86	0.009	2[illegible].24 ± 6.21	26.63 ± 5.50	0.034
G.MaxM density, HU	25.71 ± 7.41	22.52 ±7.34	< 0.001	27.11 ± 7.36	23.62 ± 7.57	< 0.001	2[illegible].24 ± 6.86	21.58 ± 7.04	0.064

All the quantitative variables were expressed as mean ± SD (standard deviation).

TH: total hip; FN: femoral neck fracture; TR: trochanteric fracture;aBMD: areal bone mineral density; BMI: body mass index; G.Med/MinM: gluteus medius and minimus muscle; G.MaxM: gluteus maximus.

Table.2 Odds ratios for discrimination of hip fracture type per 1 SD of variables

		crude. OR (95CI)	adj.OR (95CI)*	adj.OR (95CI)#
Total (n=554)	G.Med/MinM area	0.94 (0.92~0.97)	0.95 (0.93~0.98)	0.97 (0.94~0.99)
	G.Med/MinM density	0.95 (0.93~0.97)	0.96 (0.94~0.99)	0.98 (0.95~1.01)
	G.MaxM area	0.94 (0.92~0.97)	0.94 (0.91~0.97)	0.95 (0.92~0.99)
	G.MaxM density	0.94 (0.92~0.97)	0.96 (0.93~0.98)	0.97 (0.95~1.00)
Age <80	G.Med/MinM area	0.95 (0.91~0.98)	0.95 (0.91~0.98)	0.95 (0.92~0.99)
	G.Med/MinM density	0.93 (0.90~0.97)	0.94 (0.90~0.97)	0.95 (0.91~0.98)
	G.MaxM area	0.95 (0.92~0.99)	0.94 (0.90~0.98)	0.94 (0.91~0.98)
	G.MaxM density	0.94 (0.91~0.97)	0.95 (0.91~0.98)	0.95 (0.92~0.99)
Age ≥80	G.Med/MinM area	0.96 (0.93~1.00)	0.96 (0.92~1.00)	0.99 (0.94~1.04)
	G.Med/MinM density	0.99 (0.95~1.03)	0.99 (0.95~1.03)	1.02 (0.98~1.07)
	G.MaxM area	0.95 (0.91~1.00)	0.94 (0.89~0.98)	0.97 (0.92~1.02)
	G.MaxM density	0.97 (0.93~1.00)	0.97 (0.93~1.01)	1.00 (0.96~1.04)

SD, standard deviation; OR, odds ratio; CI, confidence interval; G.Med/MinM: gluteus medius and minimus muscle; G.MaxM: gluteus maximus.

* adjustment for age and body mass index.

adjustment for age, body mass index, and total hip areal bone mineral density.

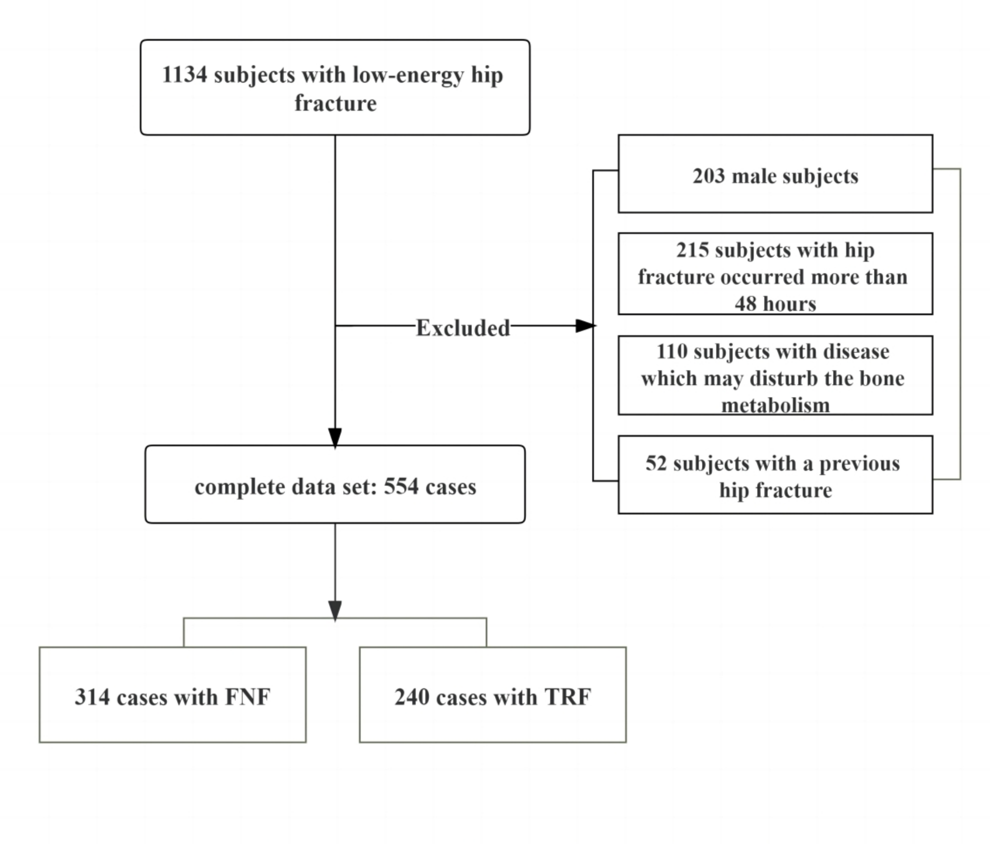
Fig. 1. Schematic flow diagram illustrating the stepwise exclusion of subjects with hip injuries. FNF, femoral neck fractures; TRF, trochanteric fractures.

Fig. 2. Measurement of cross-sectional area and mean CT values of the gluteus maximus at the level of the greater trochanter of the femur(2a); Measurement of the gluteus medius and minimus muscle at the 3rd sacral (S3) level(2b); Muscle region is represented by the area highlighted in red.

Fig. 3. The relationship of the density and area of Gluteus muscles with the risk of trochanteric fractures. (3a-d) *These lines refer to the relationship after adjustment for age and body mass index.

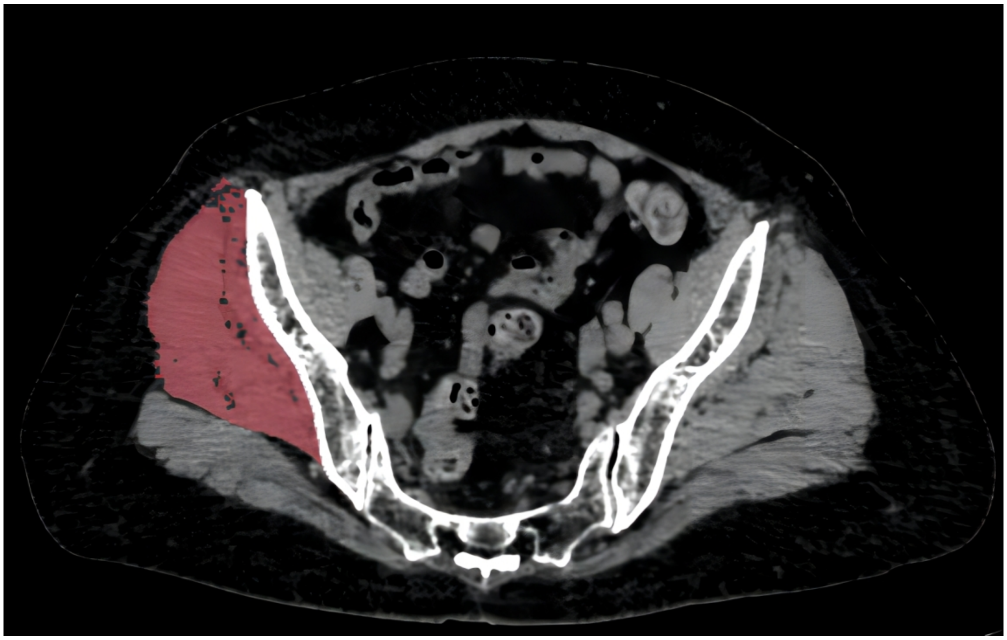
Supplementary Fig. 1. The relationship of the area of Gluteus muscles with the risk of trochanteric fractures

Supplementary Fig. 2. The relationship of the density of Gluteus muscles with the risk of trochanteric fractures



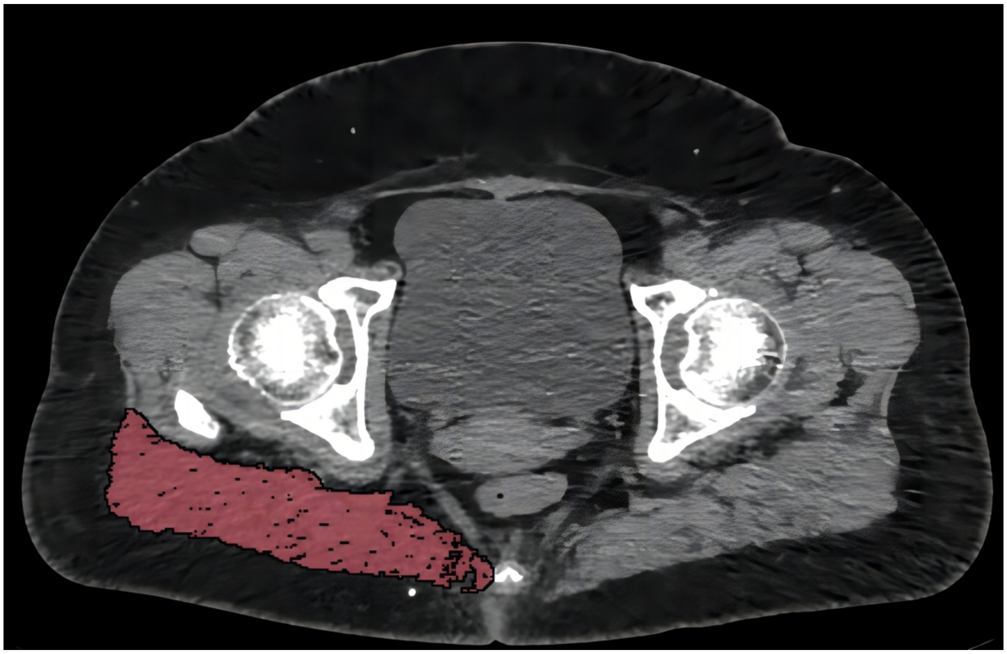
Schematic flow diagram illustrating the stepwise exclusion of subjects with hip injuries. FNF, femoral neck fractures; TRF, trochanteric fractures.

846x720mm (120 x 120 DPI)



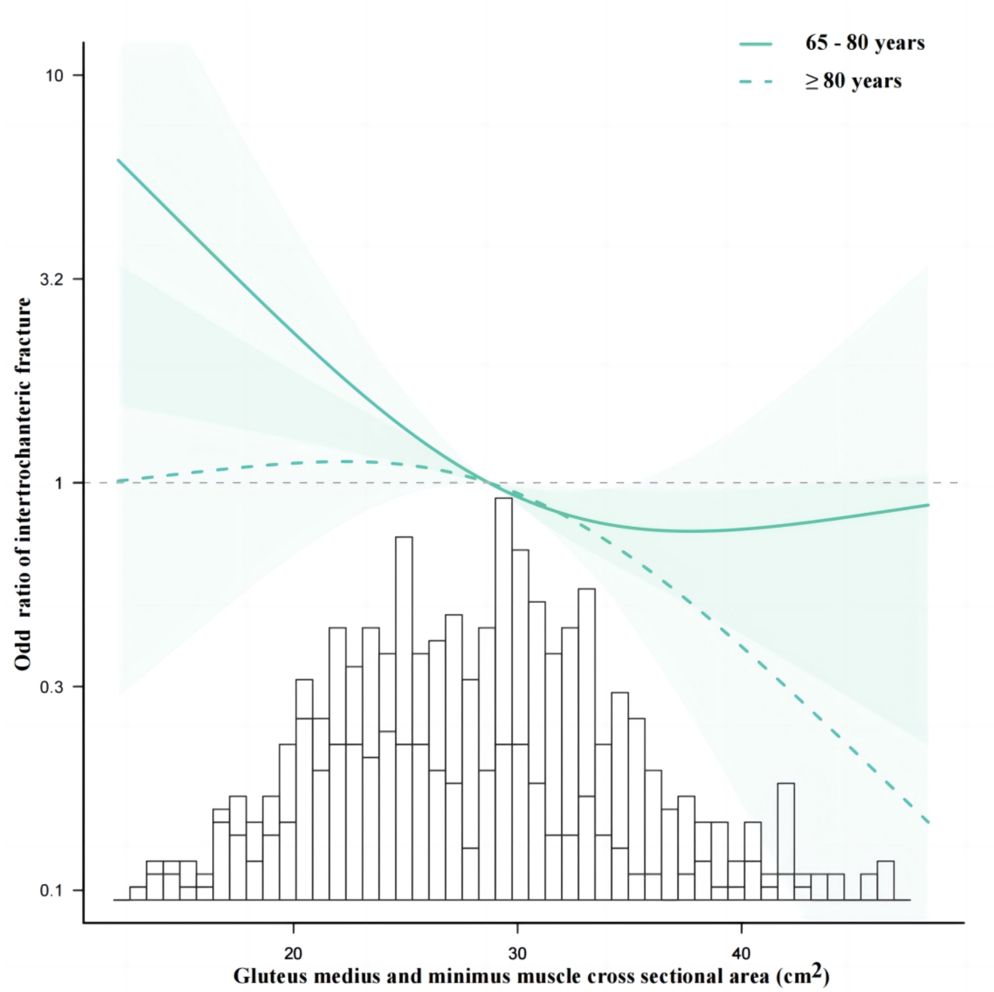
Measurement of cross-sectional area and mean CT values of the gluteus maximus at the level of the greater trochanter of the femur(2a)

356x226mm (120 x 120 DPI)



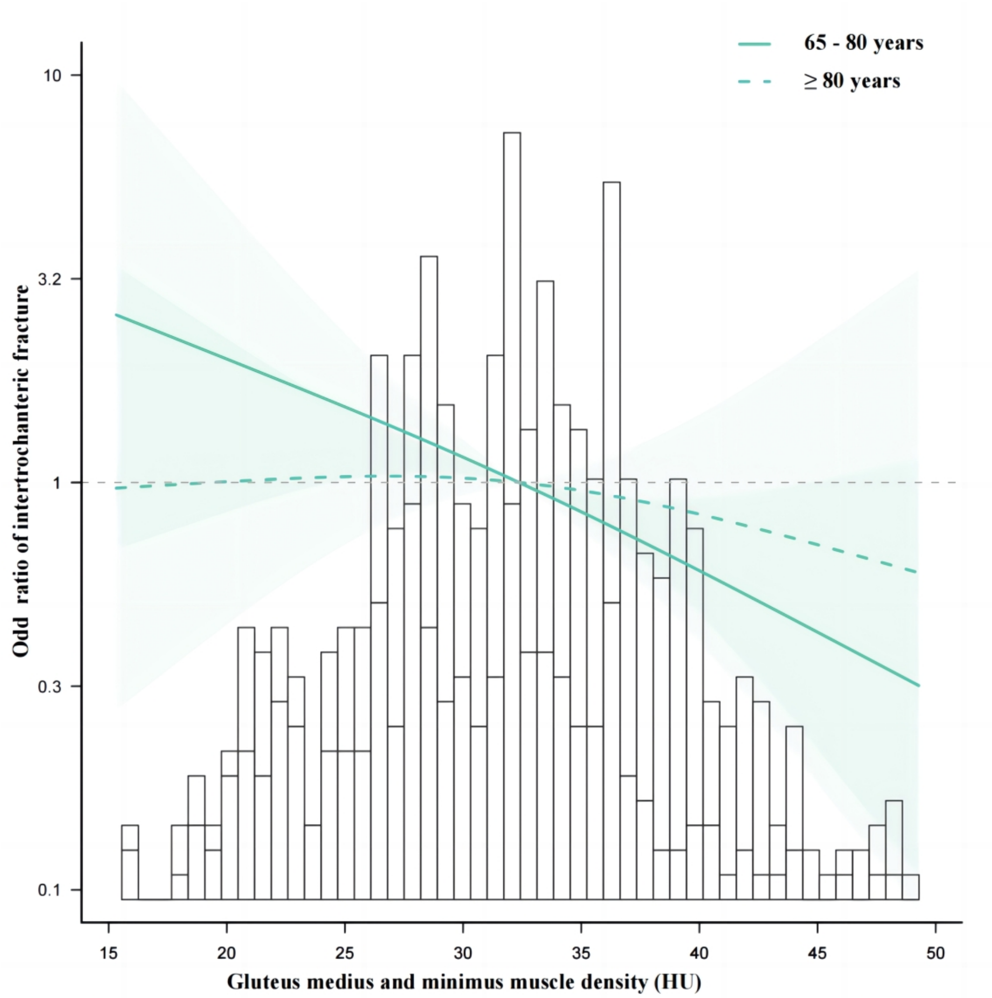
Measurement of the gluteus medius and minimus muscle at the 3rd sacral (S3) level(2b).
Muscle region is represented by the area highlighted in red.

443x287mm (120 x 120 DPI)



The relationship of the density and area of Gluteus muscles with the risk of trochanteric fractures. (3a-d)
*These lines refer to the relationship after adjustment for age and body mass index.

677x677mm (120 x 120 DPI)



The relationship of the density and area of Gluteus muscles with the risk of trochanteric fractures. (3a-d)
*These lines refer to the relationship after adjustment for age and body mass index.

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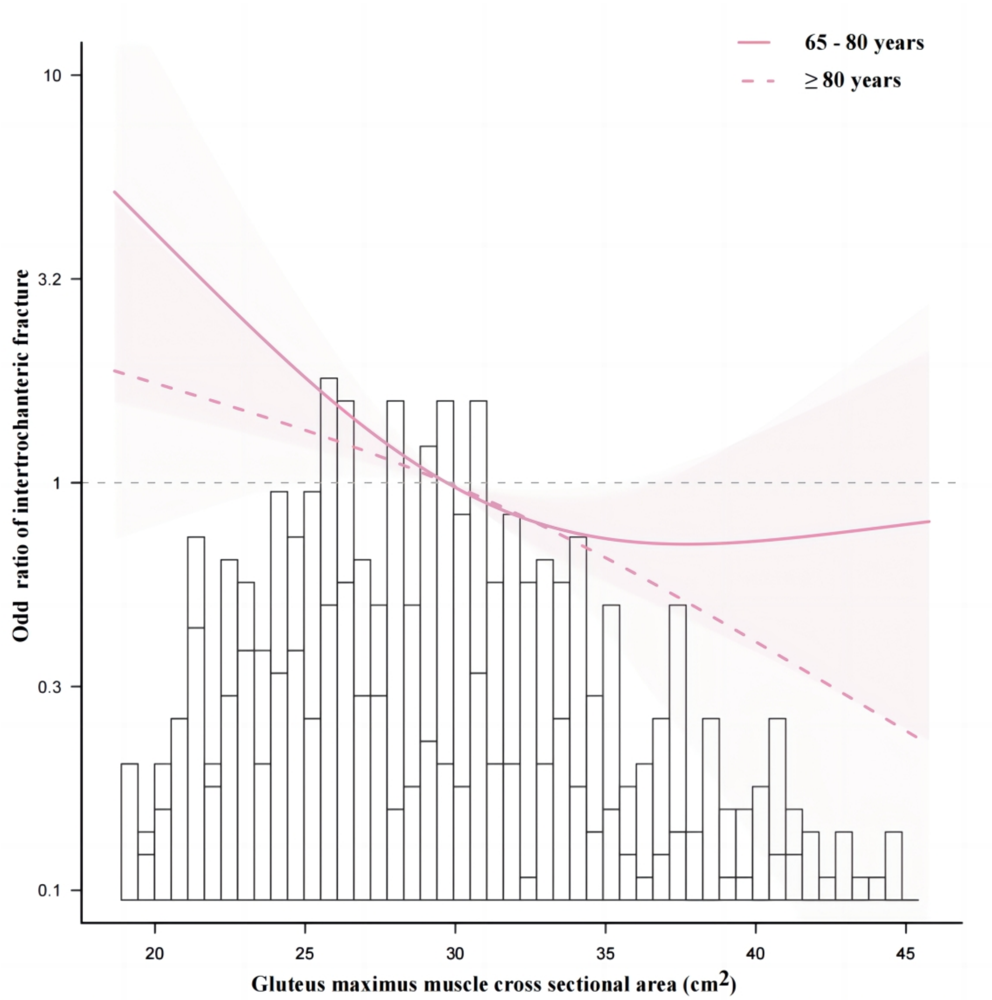

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*These lines refer to the relationship after adjustment for age and body mass index.

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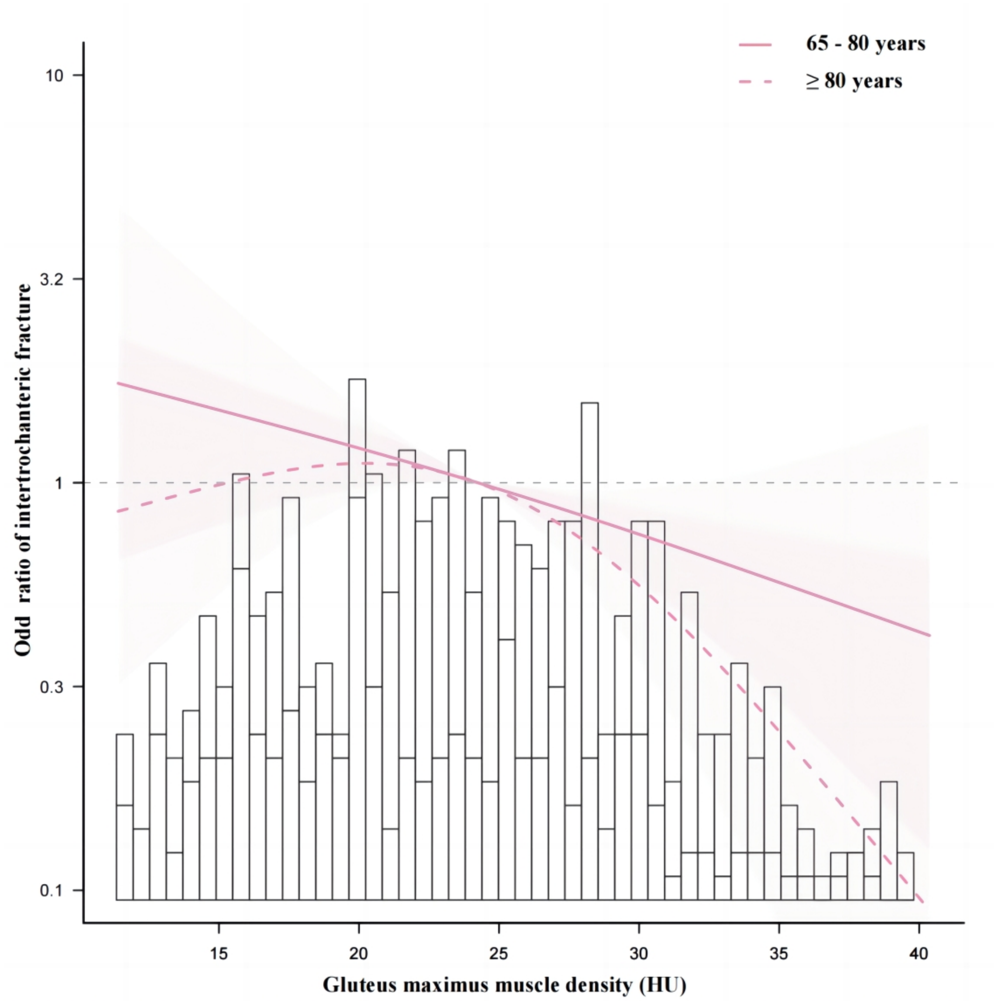

The relationship of the density and area of Gluteus muscles with the risk of trochanteric fractures. (3a-d)
*These lines refer to the relationship after adjustment for age and body mass index.

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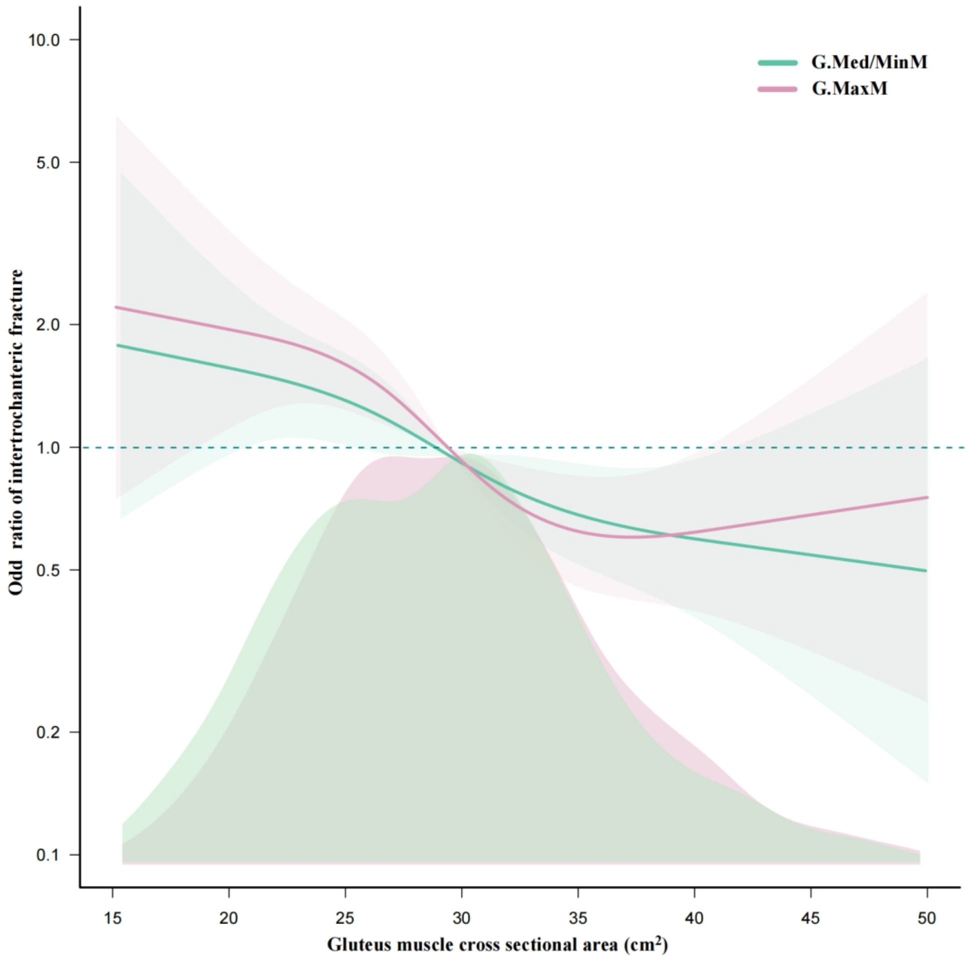

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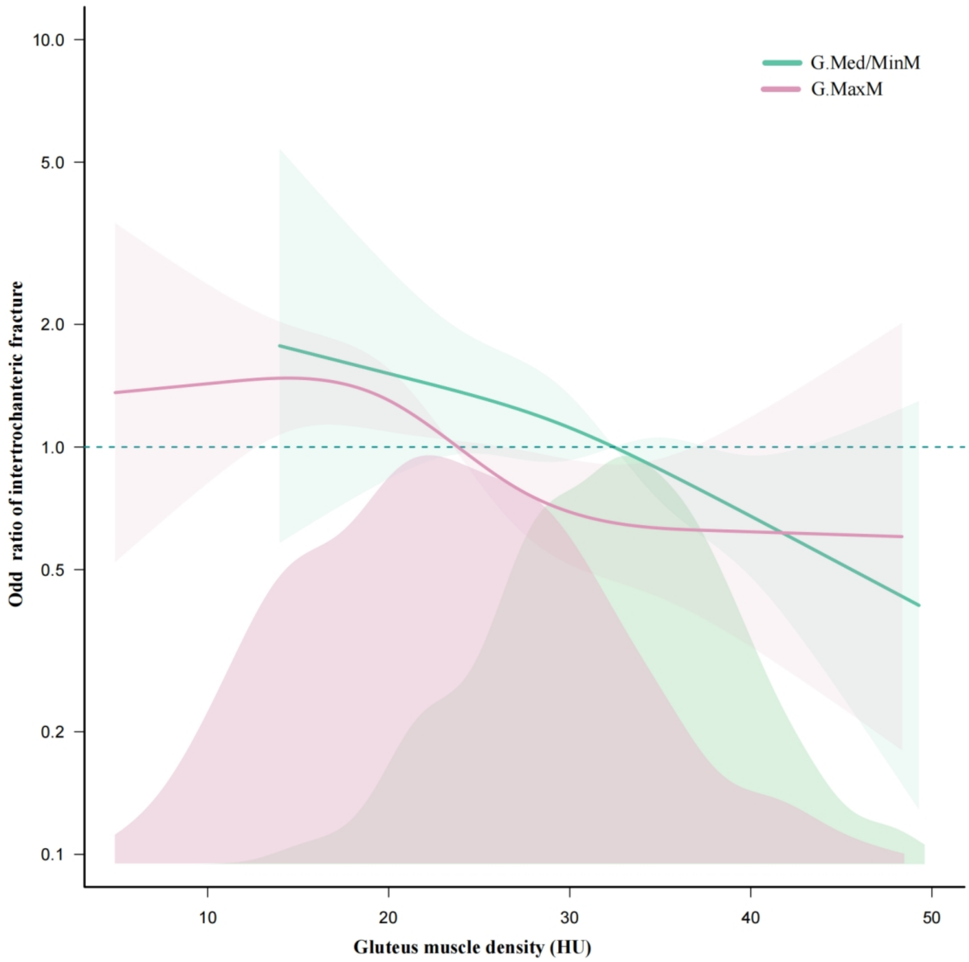

254x254mm (160 x 160 DPI)

Reporting checklist for cross sectional study.

Based on the STROBE cross sectional guidelines.

Instructions to authors

Complete this checklist by entering the page numbers from your manuscript where readers will find each of the items listed below.

Your article may not currently address all the items on the checklist. Please modify your text to include the missing information. If you are certain that an item does not apply, please write "n/a" and provide a short explanation.

Upload your completed checklist as an extra file when you submit to a journal.

In your methods section, say that you used the STROBE cross sectionalreporting guidelines, and cite them as:

von Elm E, Altman DG, Egger M, Pocock SJ, Gotzsche PC, Vandenbroucke JP. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) Statement: guidelines for reporting observational studies.

		Reporting Item	Page Number
Title and abstract			
Title	#1a	Indicate the study’s design with a commonly used term in the title or the abstract	1
Abstract	#1b	Provide in the abstract an informative and balanced summary of what was done and what was found	1,2
Introduction			
Background / rationale	#2	Explain the scientific background and rationale for the investigation being reported	3
Objectives	#3	State specific objectives, including any prespecified hypotheses	4
Methods			

Study design	[#4]	Present key elements of study design early in the paper	4
Setting	[#5]	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	4
Eligibility criteria	[#6a]	Give the eligibility criteria, and the sources and methods of selection of participants.	4,5
	[#7]	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	5,6
Data sources / measurement	[#8]	For each variable of interest give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group. Give information separately for for exposed and unexposed groups if applicable.	6
Bias	[#9]	Describe any efforts to address potential sources of bias	6
Study size	[#10]	Explain how the study size was arrived at	n/a
Quantitative variables	[#11]	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen, and why	6
Statistical methods	[#12a]	Describe all statistical methods, including those used to control for confounding	6,7
Statistical methods	[#12b]	Describe any methods used to examine subgroups and interactions	6
Statistical methods	[#12c]	Explain how missing data were addressed	n/a
Statistical methods	[#12d]	If applicable, describe analytical methods taking account of sampling strategy	n/a
Statistical methods	[#12e]	Describe any sensitivity analyses	n/a
Results			
Participants	[#13a]	Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed	7

		eligible, included in the study, completing follow-up, and analysed. Give information separately for for exposed and unexposed groups if applicable.	
Participants	#13b	Give reasons for non-participation at each stage	7
Participants	#13c	Consider use of a flow diagram	7
Descriptive data	#14a	Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders. Give information separately for exposed and unexposed groups if applicable.	7
Descriptive data	#14b	Indicate number of participants with missing data for each variable of interest	n/a
Outcome data	#15	Report numbers of outcome events or summary measures. Give information separately for exposed and unexposed groups if applicable.	n/a
Main results	#16a	Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	7,8
Main results	#16b	Report category boundaries when continuous variables were categorized	7,8
Main results	#16c	If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	n/a
Other analyses	#17	Report other analyses done—e.g., analyses of subgroups and interactions, and sensitivity analyses	7,8
Discussion			
Key results	#18	Summarise key results with reference to study objectives	8
Limitations	#19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias.	11
Interpretation	#20	Give a cautious overall interpretation considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence.	8,9,10

Generalisability	#21	Discuss the generalisability (external validity) of the study results	8,9,10
Other Information			
Funding	#22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	12

None This checklist can be completed online using https://www.goodreports.org/, a tool made by the EQUATOR Network in collaboration with Penelope.ai

Association between Trochanteric Fractures and Gluteal Muscle Size, Density in Older Women: A Cross-Sectional Study

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Association between Trochanteric Fractures and Gluteal Muscle Size, Density in Older Women: A Cross-Sectional Study

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** Xiaoguang Cheng is the senior author.

Word count: 2268

Table: 2

Figure: 3

Abstract

Purpose This study aimed to investigate differences in hip muscle area and density between older women with femoral neck fractures (FNF) and trochanteric fractures (TRF).

Design Cross-sectional study.

Setting and Participants The study was conducted at a university hospital. A total of 554 older women patients were enrolled, comprising 314 with FNF (mean age 77.02 ± 7.15 years) and 240 with TRF (mean age 79.70 ± 6.91 years), for comparative analysis.

Methods CT scans were used to measure the area and density of the gluteus medius and minimus muscles (G.Med/MinM) and the gluteus maximus muscle (G.MaxM). Areal bone mineral density (aBMD) of the total hip (TH) and femoral neck (FNaBMD) were quantified using quantitative CT. The cohort was stratified by age (cutoff 80 years) to explore age-specific associations.

Results Among all subjects, the FNF group exhibited significantly higher muscle parameters compared to the TRF group ($p < 0.001$). With adjustments made for age, BMI, and THaBMD, all muscle parameters, except G.Med/MinM density, showed significant correlations with hip fracture type. In the age ≥ 80 group, no statistically significant correlations were observed between hip muscle parameters and TRF. Conversely, in the age < 80 group, adjusting for age, BMI, and THaBMD revealed significant associations between decreased muscle density and area of both G.MaxM and G.Med/MinM with TRF.

Conclusions Our findings suggest that in older women, particularly those under 80 years of age, gluteus muscle parameters are associated with TRFs, independently of BMD.

[Key words] Osteoporosis; Muscle density; Muscle area; Femoral neck fracture; Trochanteric fractures.

Strengths and limitations of this study

- Detailed analysis using an age cutoff of 80 to examine gluteal muscle characteristics in relation to hip fracture classification.
- Exclusion of late imaging cases (>48 hours post-fracture) to ensure the reliability of muscle and bone parameter measurements.
- Adjustment of a binary logistic regression model to incorporate BMD, addressing a previous research gap.
- The cross-sectional design restricts the ability to establish causality between muscle parameters and hip fracture types.
- Findings may not be generalizable to older men experiencing fragility fractures.

Association between Trochanteric Fractures and Gluteal Muscle Size, Density in Older Women: A Cross-Sectional Study

1. Introduction

Hip fractures in older adults represent a significant consequence of osteoporosis, characterized by high morbidity, mortality, and disability rates.[1-3] These fractures manifest as two primary types: femoral neck fractures (FNF) and trochanteric fractures (TRF), each necessitating distinct treatments and associated with varying clinical outcomes.[4] For instance, FNFs are linked to higher incidences of femoral head necrosis and nonunion compared to TRFs, while TRFs may carry greater mortality risks.[5 6] Therefore, understanding the differences between these fracture types is crucial. Previous studies have identified factors such as bone structure, spatial distribution, and femoral bone mineral density (BMD) as associated with fracture types.[7-9] However, conclusive evidence regarding disparities between FNFs and TRFs remains insufficient.

With advancing age, the progressive loss of muscle composition and function significantly impairs balance in older adults, thereby increasing the risk of falls. Despite this, only a limited number of studies have explored differences in muscle parameters between these two types of hip fractures. Importantly, these studies did not account for hip BMD in their comparisons, despite BMD reduction being widely recognized as a key contributor to hip fractures [10 11]. Therefore, further investigation into the relationship between muscle properties and hip fracture types is warranted.

In this cross-sectional study, using a cohort of older women with hip fractures who underwent hip CT scans immediately after injury, we aimed to examine differences in hip muscle area and density between patients with femoral neck and trochanteric fractures. We hypothesized that CT-based measurements of gluteal muscle density and area could contribute to the classification of hip fracture types in older women, independent of BMD considerations.

2. Materials and methods

2.1. Study design and participants

From January 2012 to December 2019, a total of 1134 consecutive patients aged over 65 years with diagnosed hip fractures were enrolled in this study (Figure 1). At our institution, CT scans are standard practice for individuals presenting with suspected or confirmed hip fractures in the Emergency Department. Fractures were categorized as either FNF or TRF based on CT images interpreted by an experienced musculoskeletal radiologist. Following the CT examination, patients or their relatives completed a one-page questionnaire capturing demographic data (e.g., age, gender, height, weight), details of the fall (timing, location, mechanism), fracture history, and medical background.

Inclusion criteria for hip fracture patients mirrored those outlined by Wang et al. [12], specifically women who sustained hip fractures due to low-energy injuries and underwent hip CT scans within 48 hours. Exclusion criteria encompassed individuals with prior hip fractures, conditions preventing standing or walking, and metabolic or inflammatory diseases affecting muscle quality and bone density.

This cross-sectional study received approval from the Institutional Review Board of XXX Hospital and adhered to the principles set forth in the Declaration of Helsinki. Informed consent was obtained from all participants. The study followed STROBE guidelines for reporting observational studies.

2.2. Computed tomography acquisition and quantitative CT (QCT) analysis

CT scans of both hips for all study participants were performed using the Toshiba Aquilion spiral CT scanner (Toshiba Medical Systems Division, Tokyo, Japan). Subjects were scanned in a supine position, with a solid calibration body model (Mindways Software Inc., Austin, TX, USA) positioned just below the hips. Scans encompassed from the top of the acetabulum to 3 cm or more below the lesser trochanter, covering the proximal femur. Scan parameters included 120 kVp, 125 mAs, 50 cm field of view, 512 × 512 matrix, 1 mm reconstructed slice thickness, and a standard reconstruction kernel with filtered back-projection. Following the CT scan, images were automatically uploaded to the Mindways QCT workstation.

CT X-ray absorptiometry technique (CTXA v 4.2.3, Mindways Inc., Austin, TX) is a QCTPro scan analysis module for the hip that generates a 2D image from 3D CT images of the proximal femur. The measurement procedure has been previously described in detail [13 14]. In summary, it divides the proximal femur into three regions of interest (ROIs): the femoral neck (FN), trochanter (TR), and intertrochanter (IT), which correspond to standard ROIs commonly used in DXA hip scans. This allows for the calculation of areal bone mineral density (aBMD, g/cm^2) results for each ROI, as well as a combined measurement of all three, equivalent to the total hip (TH) ROI.

The aBMD of the femoral neck (FN) and total hip (TH) was calculated from the hip CT scans using CTXA. Hip BMD measurements were conducted on the healthy side for all patients.

2.3. Muscle Cross-sectional area and density assessments

OsiriX software (Lite Version 12.0.2, Pixmeo, Geneva, Switzerland) was utilized for analysis. The muscle measurement procedure and precision have been previously documented [15]. Two investigators, trained by an expert radiologist in CT muscle imaging, conducted all muscle measurements, and their respective averages were obtained. The muscle measurement results demonstrated high intra-observer agreement (intra-class correlation coefficients, ICC: 0.932- 0.998, P<0.001) and inter-observer consistency (ICC: 0.913- 0.961, P<0.001), with investigators blinded to each other's analyses during the imaging analysis.

Figure 2 illustrates the measurement of cross-sectional area and density of the gluteus maximus (G.MaxM) at the level of the greater trochanter, and the gluteus medius and minimus muscles (G.Med/MinM) at the level of the third sacral vertebra (S3). Due to potential muscle edema and bleeding on the fractured side, which could influence the cross-sectional area and CT value measurements of the muscles, thus not accurately reflecting their pre-fracture state, muscle parameters were measured exclusively on the non-fractured side.

2.4. Statistical analysis

Data were presented as means and standard deviations for parametric variables, while categorical variables were described using frequencies and percentages. The Chi-squared test assessed differences between groups for categorical variables, and Student's t-test was used for continuous variables. Age was stratified using a cutoff of 80 to explore age-specific relationships between muscle parameters and fracture type. Logistic regression models were employed, both with and without adjustments for age, BMI, and THaBMD. Generalized additive models were also used to further explore dose-response relationships between muscle densities, areas, and probabilities of TRF, adjusting for the aforementioned covariates. All analyses were conducted using R 4.1.1 (The R Foundation, http://www.R-project.org). A two-tailed test was applied, and significance was set at $p < 0.05$.

2.5. Patient and public involvement

Patients and the public did not participate in the design or conduct of this study.

3. Results

3.1. Characteristics of subjects

Figure 1 illustrates the recruitment of study participants. Out of 1134 low trauma hip fracture patients, 580 cases were excluded. Notably, 215 subjects imaged more than 48 hours after hip fracture were excluded due to prolonged immobilization. A total of 554 hip fracture subjects were eligible for further analysis, comprising 314 FNF cases and 240 TRF cases. Table 1 presents the distribution of relevant demographic data for these subjects. The FNF group was significantly younger and taller, with higher gluteus muscle area and density, as well as higher aBMD in the TH and FN regions. Participants were then stratified into two subgroups using an age cutoff of 80, yielding largely similar results (Table 1).

3.2. Associations of muscle size and density variables with trochanteric fractures

All area and density measurements, except for G.Med/MinM density, were significantly associated with TRF after adjusting for age and BMI (Table 2). These associations remained significant after further adjustment for THaBMD (Table 2, Figure 3). G.Med/MinM density (adj. OR 0.98, 95% CI 0.95–1.01) showed a marginal association with TRF after adjustments for age, BMI, and THaBMD.

3.3. Relationship between muscle variables and age

Additionally, a stronger relationship between gluteus muscles and TRF was observed in the younger group (age <80) compared to the older group (age >80) (Table 2). After adjustment, all associations of gluteus muscles remained statistically significant in the younger group (age <80) (G.Med/MinM area, OR 0.96, 95% CI 0.92–0.99; G.Med/MinM density, OR 0.95, 95% CI 0.91–0.98; G.MaxM area, OR 0.95, 95% CI 0.91–0.99; G.MaxM density, OR 0.95, 95% CI 0.92–0.98) ($p < 0.01$, Table 2, Figure 3a-d).

4. Discussion

In this cross-sectional study, CT images were utilized to collect data on the density and area of hip muscles in acute low-energy hip fracture women. Our findings highlight that in older women, particularly those under 80 years of age, both the area and density of the gluteus muscles were significantly associated with trochanteric fractures. Even after adjusting for THaBMD, these associations persisted, albeit attenuated for most muscle parameters.

Muscle density, measured by CT as the mean attenuation of skeletal muscle in

Hounsfield units (HU), has been extensively employed in research [16-19] to assess muscle quality. Low tissue HU (indicating low muscle density) may signify lipid or fluid infiltration in skeletal muscles, potentially accompanied by functional changes [20]. Wang et al. demonstrated that muscle density outperforms aBMD derived from hip CTXA and muscle size in distinguishing between individuals with and without hip fractures [12]. In 2008, Lang et al. observed trends toward lower hip muscle CSA and reduced lean tissue muscle HU (indicative of greater fatty infiltration) in subjects with hip fractures compared to controls [21]. Subsequently, in 2010, Lang et al. reported that decreased thigh muscle HU is associated with an elevated risk of hip fracture [22]. These studies collectively underscore the critical role of muscle density in evaluating physical function and fracture risk [23].

We hypothesized that gluteal muscle density and area play a role in classifying hip fracture types in older women. The gluteus maximus, situated superficially in the gluteal muscle, primarily functions in hip extension and external rotation, with its upper part also contributing to hip abduction [24 25]. The anterior upper portion of the gluteus medius muscle lies beneath the skin, while its posterior lower part lies deep to the gluteus maximus. Its main function involves hip abduction, with the anterior bundle rotating the hip joint internally and the posterior bundle externally [25 26]. The gluteus minimus muscles, located deep to the gluteus medius muscle, function similarly to the gluteus medius in hip abduction. Therefore, this study analyzed these two muscles collectively. Erinç et al. reported that the areas of the gluteus medius and minimus muscles were higher in the FNF group compared to the TRF group, although there was no significant difference in atrophy scores between subjects with TRF versus FNF [10]. Our study found that women older than 65 years in the TRF group exhibited smaller G.Med/MinM areas than those in the FNF group, consistent with the findings of the aforementioned study. Importantly, this difference remained statistically significant after adjusting for age, BMI, and THaBMD. Furthermore, G.MaxM density and size were independently associated with the risk of TRF in women older than 65 years, regardless of hip aBMD. Similarly, Wang et al. demonstrated that G.MaxM density significantly correlates with physical performance in older women, even after adjusting for age, height, and weight [15]. This study underscores the significant role of the G.MaxM muscle in hip fracture risk assessment. Interestingly, after we grouped patients by age 80, the difference in muscle parameters between the two fracture types in the over 80 years old group was no longer statistically significant after adjustment of covariates. However, in the 65-80 age group, muscle parameters, especially G.MaxM, were more strongly related to TRF. The explanations for the age effect on muscle parameters with the risk of TRF were unclear. Hip fracture women aged over 80 years seem to be especially frail with low bone mineral density, low cortical thickness, and low muscle quality, thus, we speculated that the incidence of hip fracture type might be a random event.

5. Strengths and limitations

To our knowledge, this study is the first to utilize an age cutoff of 80 to stratify and investigate the age-specific relationship between G.MaxM and G.Med/MinM area and density with hip fracture type. Additionally, we rigorously excluded subjects imaged more than 48 hours after hip fracture, enhancing the reliability of our bone and muscle measurements. Prolonged immobility or reduced activity following a fracture can exacerbate muscle atrophy, rendering muscle area or CT values measured post-48 hours less reflective of the muscle state at or before the fracture. Furthermore, our study calibrated several factors in binary logistic regression, including BMD, an essential factor that had been overlooked in previous relevant studies.

This study possesses several notable limitations. Firstly, its cross-sectional design warrants future longitudinal cohort studies to further explore the relationship between gluteal muscles and fracture types over time. Secondly, our decision to measure the healthy side instead of the fractured side introduces potential bias. However, this approach was taken to mitigate the impact of factors like fracture, bleeding, and edema on muscle parameter accuracy. Future advancements in technology, as suggested by Cheng et al. [27], may offer improved symmetry assessment of the hip joint sides. Lastly, our study is inherently limited by its exclusive focus on older female patients with fractures, which limits generalizability to older males. This gender-specific focus was driven by a predominance of female cases in our dataset. Given known sex differences in muscle characteristics, combining datasets into a unified cohort for analysis was deemed inappropriate, necessitating our concentration on the larger female patient sample. Future research should strive to address this limitation by recruiting a more balanced cohort encompassing both genders, thereby broadening the applicability and robustness of findings concerning skeletal muscle health in older patients following fractures.

6. Conclusions

In conclusion, our study demonstrates that in older women, particularly those under 80 years of age, gluteus muscle parameters are associated with trochanteric fractures. Age-related loss of muscle mass is a well-known risk factor for hip fractures. Therefore, preserving muscle mass and minimizing fat infiltration in muscles may be crucial in preventing trochanteric fractures in this demographic, especially those under 80 years old.

Abbreviations

FNF	femoral neck fractures
TRF	trochanteric fractures
G.Med/MinM	gluteus medius and minimus muscle
G.MaxM	gluteus maximus muscle
THaBMD	total hip areal bone mineral density
FNaBMD	femoral neck areal bone mineral density
BLR	binary logistic regression
BMD	bone mineral density
BMI	body mass index
QCT	quantitative computed tomography
CTXA	CT X-ray absorptiometry technique
HU	Hounsfield units

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Author Contributions

Pengju Huang: Methodology, Writing - Original Draft, Writing- Reviewing;

Yufeng Ge: Methodology, Writing- Reviewing and Editing;

Yandong Liu: Writing- Reviewing and Editing, Investigation, Validation;

Jian Geng: Writing- Reviewing and Editing, Validation;

Wei Zhang: Investigation, Validation;

Wei Liang: Investigation, Validation;

Aihong Yu: Conceptualization, Methodology, Writing- Reviewing and Editing;

Xinbao Wu: Conceptualization, Methodology, Writing- Reviewing and Editing;

Ling Wang: Conceptualization, Methodology, Writing- Reviewing and Editing, Supervision;

Xiaoguang Cheng: Conceptualization, Methodology, Writing- Reviewing and Editing.

All authors reviewed the manuscript and approved the final version, and Ling Wang is the guarantor.

Conflicts of Interest

All authors state that there is no conflict of interest.

Availability of data

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

Declarations

Ethics approval and consent to participate

The study was conducted in accordance with the guidelines of the Declaration of Helsinki and approved by the Institutional Review Board of Beijing Jishuitan Hospital (No. 201512-02). Informed consent was obtained from all subjects participating in the study.

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Table 1 Characteristics of subjects who sustained femoral neck or trochanteric fractures grouped by age

	Total (n = 554)			Age <80			Age ≥80		
	FN (n = 314)	TR (n = 240)	p	FN (n = 201)	TR (n = 110)	p	FN (n = 113)	TR (n = 130)	p
age, year	77.02 ± 7.15	79.70 ± 6.91	**< 0.001**	72.69 ± 4.48	73.60 ± 4.07	0.077	84.73 ± 3.69	84.86 ± 4.01	0.797
height, cm	159.15 ± 5.76	157.09 ± 5.84	**< 0.001**	159.92 ± 5.90	158.69 ± 5.47	0.074	157.78 ± 5.27	155.73 ± 5.83	**0.005**
weight, kg	58.04 ± 10.53	57.97 ± 11.25	0.944	59.65 ± 10.17	61.04 ± 10.48	0.256	55.16 ± 10.60	55.38 ± 11.27	0.880
BMI, kg/m^2	22.84 ± 3.51	23.43 ± 4.09	0.066	23.26 ± 3.33	24.21 ± 3.83	**0.024**	22.08 ± 3.69	22.78 ± 4.21	0.175
THaBMD, g/cm^2	0.57 ± 0.11	0.52 ± 0.11	**< 0.001**	0.59 ± 0.11	0.57 ± 0.10	**0.036**	0.54 ± 0.10	0.49 ± 0.10	**< 0.001**
FNaBMD, g/cm^2	0.50 ± 0.10	0.47 ± 0.10	**< 0.001**	0.51 ± 0.10	0.49 ± 0.09	0.092	0.47 ± 0.09	0.45 ± 0.09	0.076
G.Med/MinM area, cm^2	29.92 ± 7.17	27.24 ± 6.61	**< 0.001**	31.34 ± 6.94	28.83 ± 6.99	**0.003**	27.40 ± 6.88	25.88 ± 5.98	0.067
G.Med/MinM density, HU	33.40 ± 6.72	31.04 ± 6.81	**< 0.001**	34.92 ± 6.50	31.97 ± 6.72	**< 0.001**	30.68 ± 6.26	30.24 ± 6.82	0.603
G.MaxM area, cm^2	31.01 ± 6.81	28.40 ± 6.44	**< 0.001**	32.57 ± 6.66	30.48 ± 6.86	**0.009**	28.24 ± 6.21	26.63 ± 5.50	**0.034**
G.MaxM density, HU	25.71 ± 7.41	22.52 ±7.34	**< 0.001**	27.11 ± 7.36	23.62 ± 7.57	**< 0.001**	23.24 ± 6.86	21.58 ± 7.04	0.064

All the quantitative variables were expressed as mean ± SD (standard deviation).

TH: total hip; FN: femoral neck fracture; TR: trochanteric fracture;aBMD: areal bone mineral density; BMI: body mass index; G.Med/MinM: gluteus medius and minimus muscle; G.MaxM: gluteus maximus.

Table 2 Odds ratios of having a TRF per 1 SD of variables

		crude. OR (95CI)	adj.OR (95CI)*	adj.OR (95CI)#
Total (n=554)	G.Med/MinM area	**0.94 (0.92~0.97)**	**0.95 (0.93~0.98)**	**0.97 (0.94~0.99)**
	G.Med/MinM density	**0.95 (0.93~0.97)**	**0.96 (0.94~0.99)**	0.98 (0.95~1.01)
	G.MaxM area	**0.94 (0.92~0.97)**	**0.94 (0.91~0.97)**	**0.95 (0.92~0.99)**
	G.MaxM density	**0.94 (0.92~0.97)**	**0.96 (0.93~0.98)**	0.97 (0.95~1.00)
Age <80	G.Med/MinM area	**0.95 (0.91~0.98)**	**0.95 (0.91~0.98)**	**0.95 (0.92~0.99)**
	G.Med/MinM density	**0.93 (0.90~0.97)**	**0.94 (0.90~0.97)**	**0.95 (0.91~0.98)**
	G.MaxM area	**0.95 (0.92~0.99)**	**0.94 (0.90~0.98)**	**0.94 (0.91~0.98)**
	G.MaxM density	**0.94 (0.91~0.97)**	**0.95 (0.91~0.98)**	**0.95 (0.92~0.99)**
Age ≥80	G.Med/MinM area	0.96 (0.93~1.00)	0.96 (0.92~1.00)	0.99 (0.94~1.04)
	G.Med/MinM density	0.99 (0.95~1.03)	0.99 (0.95~1.03)	1.02 (0.98~1.07)
	G.MaxM area	0.95 (0.91~1.00)	**0.94 (0.89~0.98)**	0.97 (0.92~1.02)
	G.MaxM density	0.97 (0.93~1.00)	0.97 (0.93~1.01)	1.00 (0.96~1.04)

SD, standard deviation; OR, odds ratio; CI, confidence interval; G.Med/MinM: gluteus medius and minimus muscle; G.MaxM: gluteus maximus.

* adjustment for age and body mass index.

adjustment for age, body mass index, and total hip areal bone mineral density.

Fig. 1. Schematic flow diagram illustrating the stepwise exclusion of subjects with hip injuries. FNF, femoral neck fractures; TRF, trochanteric fractures.

Fig. 2. 2a: Measurement of the gluteus medius and minimus muscles at the 3rd sacral (S3) level. 2b: Measurement of cross-sectional area and mean CT values of the gluteus maximus at the level of the greater trochanter of the femur. Muscle regions are highlighted in red.

Fig. 3. The relationship of the density and area of Gluteus muscles with the risk of trochanteric fractures. 3a-d: These lines depict the relationships after adjusting for age and body mass index (BMI), corresponding to the adjusted odds ratios (adj. OR) presented in Table 2, Column 4, which also includes these covariates.

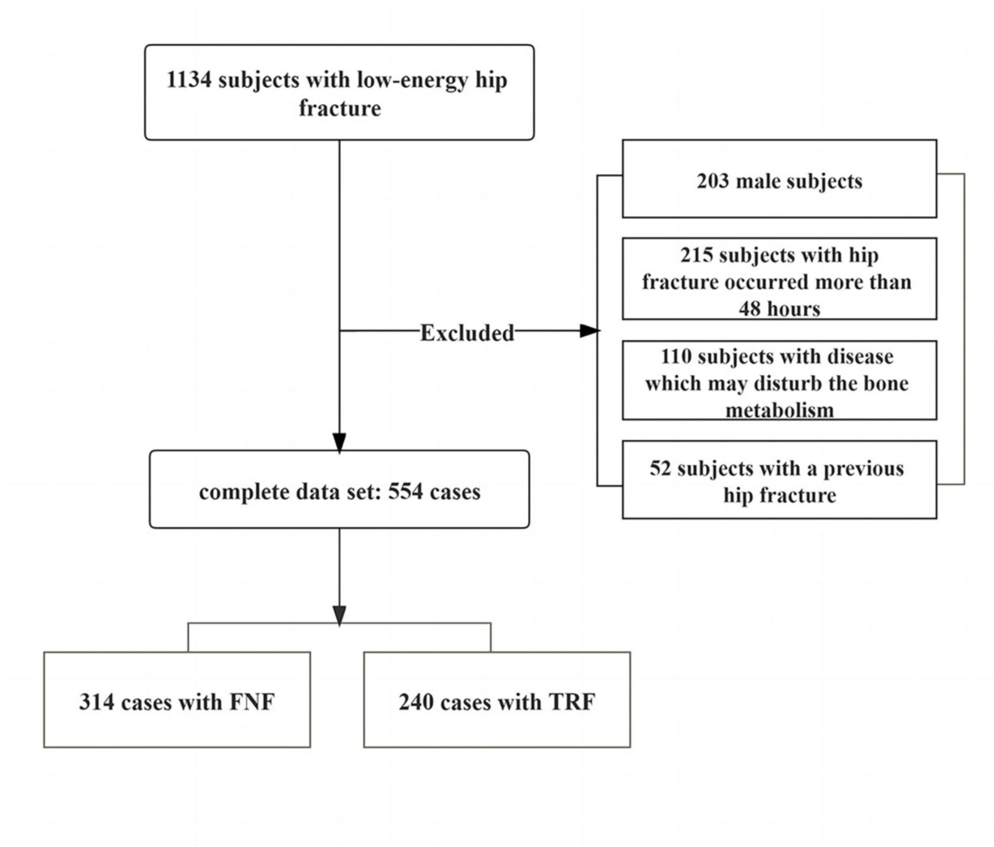
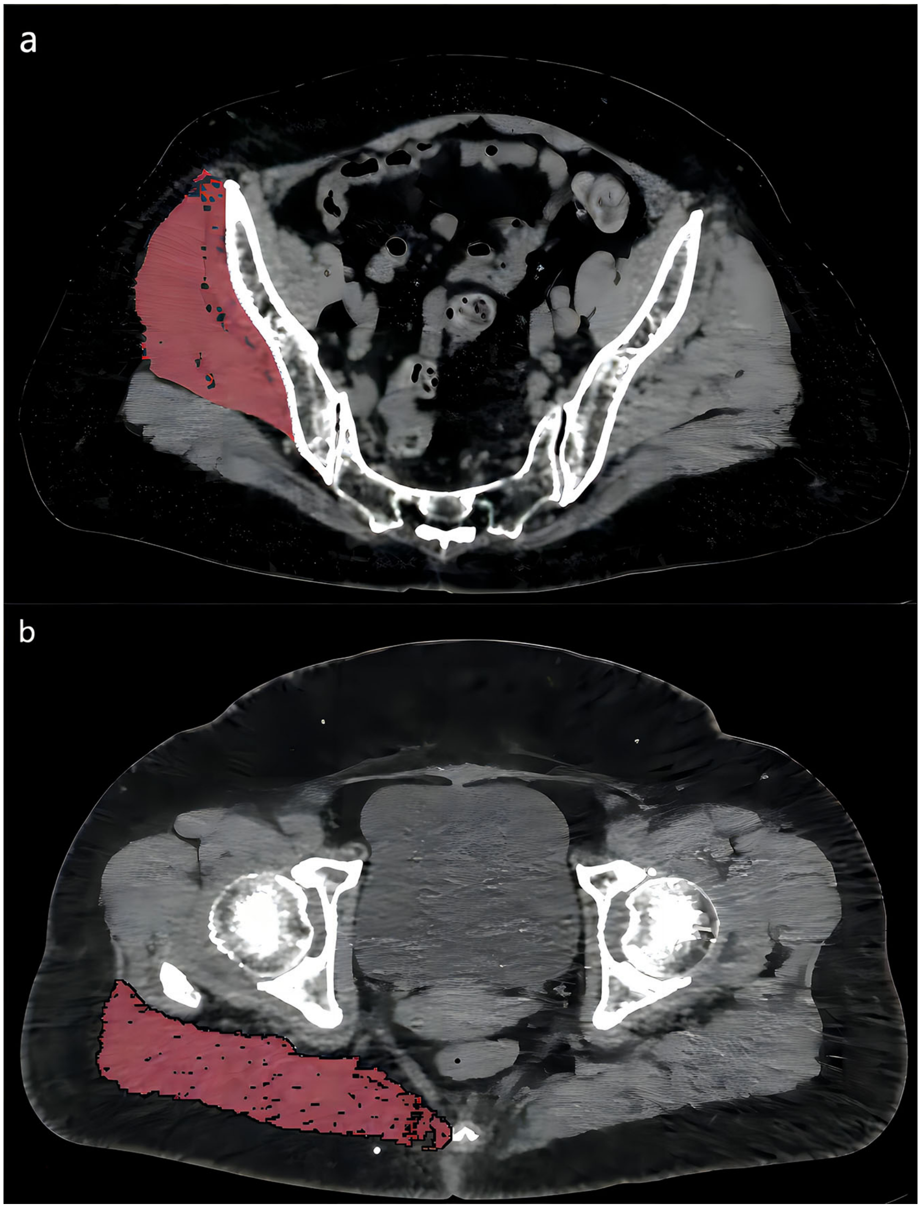


Fig. 1. Schematic flow diagram illustrating the stepwise exclusion of subjects with hip injuries. FNF, femoral neck fractures; TRF, trochanteric fractures.

173x147mm (300 x 300 DPI)



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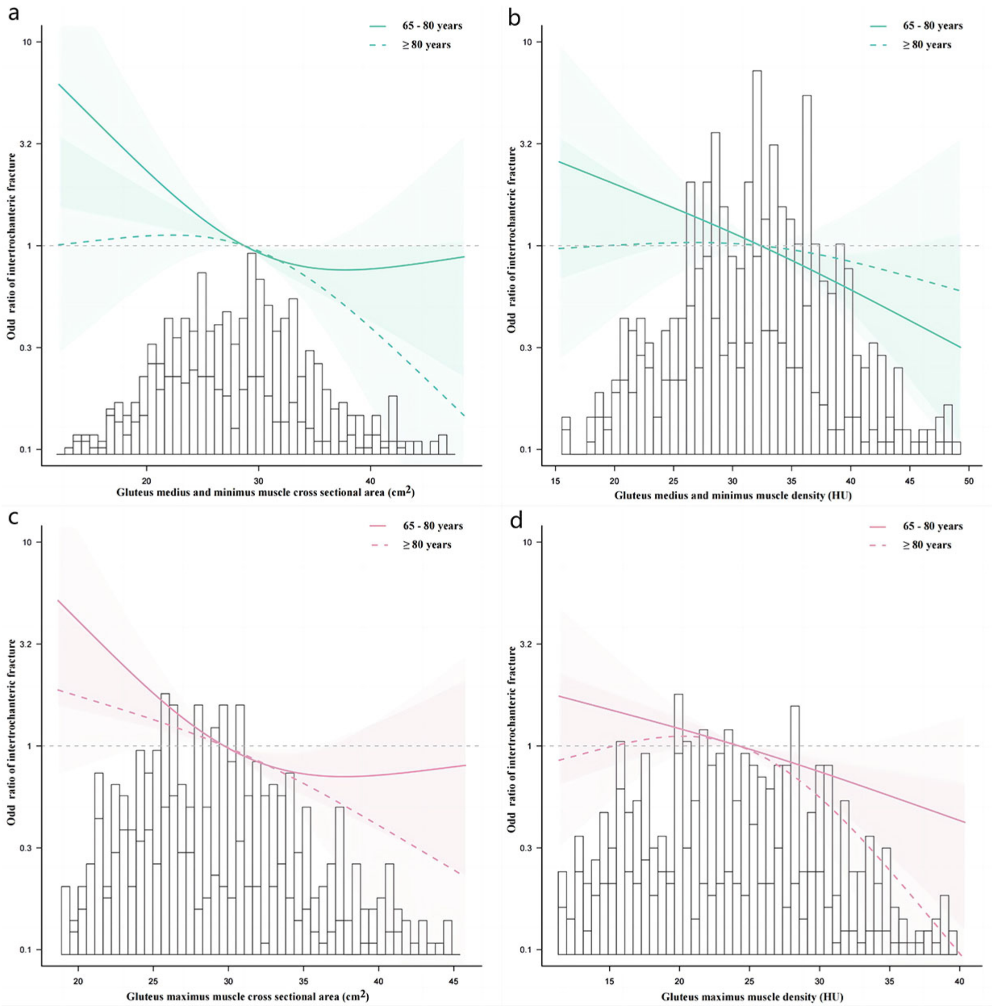
112x147mm (300 x 300 DPI)



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104x104mm (300 x 300 DPI)

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Instructions to authors

Complete this checklist by entering the page numbers from your manuscript where readers will find each of the items listed below.

Your article may not currently address all the items on the checklist. Please modify your text to include the missing information. If you are certain that an item does not apply, please write "n/a" and provide a short explanation.

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		Reporting Item	Page Number
Title and abstract			
Title	#1a	Indicate the study’s design with a commonly used term in the title or the abstract	1
Abstract	#1b	Provide in the abstract an informative and balanced summary of what was done and what was found	2,3
Introduction			
Background / rationale	#2	Explain the scientific background and rationale for the investigation being reported	4
Objectives	#3	State specific objectives, including any prespecified hypotheses	5
Methods			

Study design	#4	Present key elements of study design early in the paper	5
Setting	#5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	5
Eligibility criteria	#6a	Give the eligibility criteria, and the sources and methods of selection of participants.	5,6
	#7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	5,6
Data sources / measurement	#8	For each variable of interest give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group. Give information separately for for exposed and unexposed groups if applicable.	7
Bias	#9	Describe any efforts to address potential sources of bias	6,7
Study size	#10	Explain how the study size was arrived at	5
Quantitative variables	#11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen, and why	7,8
Statistical methods	#12a	Describe all statistical methods, including those used to control for confounding	7,8
Statistical methods	#12b	Describe any methods used to examine subgroups and interactions	7,8
Statistical methods	#12c	Explain how missing data were addressed	n/a
Statistical methods	#12d	If applicable, describe analytical methods taking account of sampling strategy	n/a
Statistical methods	#12e	Describe any sensitivity analyses	n/a

Results

Participants	#13a	Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed	8

		eligible, included in the study, completing follow-up, and analysed. Give information separately for for exposed and unexposed groups if applicable.	
Participants	#13b	Give reasons for non-participation at each stage	8
Participants	#13c	Consider use of a flow diagram	8
Descriptive data	#14a	Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders. Give information separately for exposed and unexposed groups if applicable.	8
Descriptive data	#14b	Indicate number of participants with missing data for each variable of interest	n/a
Outcome data	#15	Report numbers of outcome events or summary measures. Give information separately for exposed and unexposed groups if applicable.	n/a
Main results	#16a	Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	8,9
Main results	#16b	Report category boundaries when continuous variables were categorized	8,9
Main results	#16c	If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	n/a
Other analyses	#17	Report other analyses done—e.g., analyses of subgroups and interactions, and sensitivity analyses	8,9
Discussion			
Key results	#18	Summarise key results with reference to study objectives	9
Limitations	#19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias.	12
Interpretation	#20	Give a cautious overall interpretation considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence.	10,11

Generalisability	#21	Discuss the generalisability (external validity) of the study results	10,11
Other Information			
Funding	#22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	14

None This checklist can be completed online using https://www.goodreports.org/, a tool made by the EQUATOR Network in collaboration with Penelope.ai

Association between Trochanteric Fractures and Gluteal Muscle Size, Density in Older Women: A Cross-Sectional Study at a University Hospital

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Association between Trochanteric Fractures and Gluteal Muscle Size, Density in Older Women: A Cross-Sectional Study at a University Hospital

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Abstract

Purpose This study aimed to investigate differences in hip muscle area and density between older women with femoral neck fractures (FNF) and trochanteric fractures (TRF).

Design Cross-sectional study.

Setting and Participants The study was conducted at a university hospital. A total of 554 older women patients were enrolled, comprising 314 with FNF (mean age 77.02 ± 7.15 years) and 240 with TRF (mean age 79.70 ± 6.91 years), for comparative analysis.

Methods CT scans were used to measure the area and density of the gluteus medius and minimus muscles (G.Med/MinM) and the gluteus maximus muscle (G.MaxM). Areal bone mineral density (aBMD) of the total hip (TH) and femoral neck (FNaBMD) were quantified using quantitative CT. The cohort was stratified by age (cutoff 80 years) to explore age-specific associations.

Results Among all subjects, the FNF group exhibited significantly higher muscle parameters compared to the TRF group ($p < 0.001$). With adjustments made for age, BMI, and THaBMD, all muscle parameters, except G.Med/MinM density, showed significant correlations with TRF. In the age ≥ 80 group, no statistically significant correlations were observed between hip muscle parameters and TRF. Conversely, in the age < 80 group, adjusting for age, BMI, and THaBMD revealed significant associations between decreased muscle density and area of both G.MaxM and G.Med/MinM with TRF.

Conclusions Our findings suggest that in older women, particularly those under 80 years of age, gluteus muscle parameters are associated with TRFs, independently of BMD.

[Key words] Osteoporosis; Muscle density; Muscle area; Femoral neck fracture; Trochanteric fractures.

Strengths and limitations of this study

- Detailed analysis using an age cutoff of 80 to examine gluteal muscle characteristics in relation to hip fracture classification.
- Exclusion of late imaging cases (>48 hours post-fracture) to ensure the reliability of muscle and bone parameter measurements.
- Adjustment of a binary logistic regression model to incorporate BMD, addressing a previous research gap.
- The cross-sectional design restricts the ability to establish causality between muscle parameters and hip fracture types.
- Findings may not be generalizable to older men experiencing fragility fractures.

Association between Trochanteric Fractures and Gluteal Muscle Size, Density in Older Women: A Cross-Sectional Study at a University Hospital

1. Introduction

Hip fractures in older adults represent a significant consequence of osteoporosis, characterized by high morbidity, mortality, and disability rates.[1-3] These fractures manifest as two primary types: femoral neck fractures (FNF) and trochanteric fractures (TRF), each necessitating distinct treatments and associated with varying clinical outcomes.[4] For instance, FNFs are linked to higher incidences of femoral head necrosis and nonunion compared to TRFs, while TRFs may carry greater mortality risks.[5 6] Therefore, understanding the differences between these fracture types is crucial. Previous studies have identified factors such as bone structure, spatial distribution, and femoral bone mineral density (BMD) as associated with fracture types.[7-9] However, conclusive evidence regarding disparities between FNFs and TRFs remains insufficient.

With advancing age, the progressive loss of muscle composition and function significantly impairs balance in older adults, thereby increasing the risk of falls. Despite this, only a limited number of studies have explored differences in muscle parameters between these two types of hip fractures. Importantly, these studies did not account for hip BMD in their comparisons, despite BMD reduction being widely recognized as a key contributor to hip fractures [10 11]. Therefore, further investigation into the relationship between muscle properties and hip fracture types is warranted.

In this cross-sectional study, using a cohort of older women with hip fractures who underwent hip CT scans immediately after injury, we aimed to examine differences in hip muscle area and density between patients with femoral neck and trochanteric fractures. We hypothesized that CT-based measurements of gluteal muscle density and area could contribute to the classification of hip fracture types in older women, independent of BMD considerations.

2. Materials and methods

2.1. Study design and participants

From January 2012 to December 2019, a total of 1134 consecutive patients aged over 65 years with diagnosed hip fractures were enrolled in this study (Figure 1). At our institution, CT scans are standard practice for individuals presenting with suspected or confirmed hip fractures in the Emergency Department. Fractures were categorized as either FNF or TRF based on CT images interpreted by an experienced musculoskeletal radiologist. Following the CT examination, patients or their relatives completed a one-page questionnaire capturing demographic data (e.g., age, gender, height, weight), details of the fall (timing, location, mechanism), fracture history, and medical background.

Inclusion criteria for hip fracture patients mirrored those outlined by Wang et al. [12], specifically women who sustained hip fractures due to low-energy injuries and underwent hip CT scans within 48 hours. 48 hours was chosen as the cutoff to minimize influence of disuse atrophy on the measures of muscle size, and this project focused on women as there were not enough men in the sample to do a meaningful between sex comparison to account for muscle and bone density differences between the sexes. Exclusion criteria encompassed individuals with prior hip fractures, conditions preventing standing or walking, and metabolic or inflammatory diseases affecting muscle quality and bone density.

This cross-sectional study received approval from the Institutional Review Board of XXX Hospital and adhered to the principles set forth in the Declaration of Helsinki. Informed consent was obtained from all participants. The study followed STROBE guidelines for reporting observational studies.

2.2. Computed tomography acquisition and quantitative CT (QCT) analysis

CT scans of both hips for all study participants were performed using the Toshiba Aquilion spiral CT scanner (Toshiba Medical Systems Division, Tokyo, Japan). Subjects were scanned in a supine position, with a solid calibration body model (Mindways Software Inc., Austin, TX, USA) positioned just below the hips. Scans encompassed from the top of the acetabulum to 3 cm or more below the lesser trochanter, covering the proximal femur. Scan parameters included 120 kVp, 125 mAs, 50 cm field of view, 512 × 512 matrix, 1 mm reconstructed slice thickness, and a standard reconstruction kernel with filtered back-projection. Following the CT scan, images were automatically uploaded to the Mindways QCT workstation.

CT X-ray absorptiometry technique (CTXA v 4.2.3, Mindways Inc., Austin, TX) is a QCTPro scan analysis module for the hip that generates a 2D image from 3D CT images of the proximal femur. The measurement procedure has been previously described in detail [13 14]. In summary, it divides the proximal femur into three regions of interest (ROIs): the femoral neck (FN), trochanter (TR), and intertrochanter (IT), which correspond to standard ROIs commonly used in DXA hip scans. This allows for the calculation of areal bone mineral density (aBMD, g/cm^2) results for each ROI, as well as a combined measurement of all three, equivalent to the total hip (TH) ROI. The aBMD of the femoral neck (FN) and total hip (TH) was calculated from the hip CT scans using CTXA. Hip BMD measurements were conducted on the healthy side for all patients.

2.3. Muscle Cross-sectional area and density assessments

OsiriX software (Lite Version 12.0.2, Pixmeo, Geneva, Switzerland) was utilized for analysis. The muscle measurement procedure and precision have been previously documented [15]. Two investigators, trained by an expert radiologist in CT muscle imaging, conducted all muscle measurements, and their respective averages were obtained. The muscle measurement results demonstrated high intra-observer agreement (intra-class correlation coefficients, ICC: 0.932- 0.998, P<0.001) and inter-observer consistency (ICC: 0.913- 0.961, P<0.001), with investigators blinded to each other's analyses during the imaging analysis.

Figure 2 illustrates the measurement of cross-sectional area and density of the gluteus maximus (G.MaxM) at the level of the greater trochanter, and the gluteus medius and minimus muscles (G.Med/MinM) at the level of the third sacral vertebra (S3). Due to potential muscle edema and bleeding on the fractured side, which could influence the cross-sectional area and CT value measurements of the muscles, thus not accurately reflecting their pre-fracture state, muscle parameters were measured exclusively on the non-fractured side.

2.4. Statistical analysis

Data were presented as means and standard deviations for parametric variables, while categorical variables were described using frequencies and percentages. The Chi-squared test assessed differences between groups for categorical variables, and Student's t-test was used for continuous variables. Age was stratified using a cutoff of 80, the mean and median age of the sample, to explore age-specific relationships between muscle parameters and fracture type. Logistic regression models were employed, both with and without adjustments for age, BMI, and THaBMD. Generalized additive models were also used to further explore dose-response relationships between muscle densities, areas, and probabilities of TRF, adjusting for the aforementioned covariates. All analyses were conducted using R 4.1.1 (The R Foundation, http://www.R-project.org). A two-tailed test was applied, and significance was set at $p < 0.05$.

2.5. Patient and public involvement

Patients and the public did not participate in the design or conduct of this study.

3. Results

3.1. Characteristics of subjects

Figure 1 illustrates the recruitment of study participants. Out of 1134 low trauma hip fracture patients, 580 cases were excluded. Notably, 215 subjects imaged more than 48 hours after hip fracture were excluded due to prolonged immobilization. A total of 554 hip fracture subjects were eligible for further analysis, comprising 314 FNF cases and 240 TRF cases. Table 1 presents the distribution of relevant demographic data for these subjects. The FNF group was significantly younger and taller, with higher gluteus muscle area and density, as well as higher aBMD in the TH and FN regions. Participants were then stratified into two subgroups using an age cutoff of 80, yielding largely similar results (Table 1).

3.2. Associations of muscle size and density variables with trochanteric fractures

All area and density measurements, except for G.Med/MinM density, were significantly associated with TRF after adjusting for age and BMI (Table 2, Column 4). These associations remained significant after further adjustment for THaBMD (Table 2, Column 5). G.Med/MinM density (adj. OR 0.98, 95% CI 0.95–1.01) showed a marginal association with TRF after adjustments for age, BMI, and THaBMD.

3.3. Relationship between muscle variables and age

Additionally, a stronger relationship between gluteus muscles and TRF was observed in the younger group (age <80) compared to the older group (age >80) (Table 2). After adjustment, all associations of gluteus muscles remained statistically significant in the younger group (age <80) (G.Med/MinM area, OR 0.96, 95% CI 0.92–0.99; G.Med/MinM density, OR 0.95, 95% CI 0.91–0.98; G.MaxM area, OR 0.94, 95% CI 0.91–0.98; G.MaxM density, OR 0.95, 95% CI 0.92–0.99) ($p < 0.01$, Table 2). Figure 3a-d visualizes the relationship between muscle parameters and the risk of TRF. It shows a clear decreasing trend in the risk of TRF as the area or density of the gluteal muscles (both G.maxM and G.Med/MinM) increases. However, it should be noted that with increasing values on the x-axis, the number of samples for individuals over

80 years old decreases significantly. Therefore, the trends described in this figure should be interpreted with caution.

4. Discussion

In this cross-sectional study, CT images were utilized to collect data on the density and area of hip muscles in acute low-energy hip fracture women. Our findings highlight that in older women, particularly those under 80 years of age, both the area and density of the gluteus muscles were significantly associated with trochanteric fractures. Even after adjusting for THaBMD, these associations persisted, albeit attenuated for most muscle parameters.

Muscle density, measured by CT as the mean attenuation of skeletal muscle in Hounsfield units (HU), has been extensively employed in research [16-19] to assess muscle quality. Low tissue HU (indicating low muscle density) may signify lipid or fluid infiltration in skeletal muscles, potentially accompanied by functional changes [20]. Wang et al. demonstrated that muscle density outperforms aBMD derived from hip CTXA and muscle size in distinguishing between individuals with and without hip fractures [12]. In 2008, Lang et al. observed trends toward lower hip muscle CSA and reduced lean tissue muscle HU (indicative of greater fatty infiltration) in subjects with hip fractures compared to controls [21]. Subsequently, in 2010, Lang et al. reported that decreased thigh muscle HU is associated with an elevated risk of hip fracture [22]. These studies collectively underscore the critical role of muscle density in evaluating physical function and fracture risk [23].

We hypothesized that gluteal muscle density and area play a role in classifying hip fracture types in older women. The gluteus maximus, situated superficially in the gluteal muscle, primarily functions in hip extension and external rotation, with its upper part also contributing to hip abduction [24 25]. The anterior upper portion of the gluteus medius muscle lies beneath the skin, while its posterior lower part lies deep to the gluteus maximus. Its main function involves hip abduction, with the anterior bundle rotating the hip joint internally and the posterior bundle externally [25 26]. The gluteus minimus muscles, located deep to the gluteus medius muscle, function similarly to the gluteus medius in hip abduction. Therefore, this study analyzed these two muscles collectively. Erinç et al. reported that the areas of the gluteus medius and minimus muscles were higher in the FNF group compared to the TRF group, although there was no significant difference in atrophy scores between subjects with TRF versus FNF [10]. Our study found that women older than 65 years in the TRF group exhibited smaller G.Med/MinM areas than those in the FNF group, consistent with the findings of the aforementioned study. Importantly, this difference remained statistically significant after adjusting for age, BMI, and THaBMD. Furthermore, G.MaxM density and size were independently associated with the risk of TRF in women older than 65 years, regardless of hip aBMD. Similarly, Wang et al. demonstrated that G.MaxM density significantly correlates with physical performance in older women, even after adjusting for age, height, and weight [15]. This study underscores the significant role of the G.MaxM muscle in hip fracture risk assessment. Interestingly, after we grouped patients by age 80, the difference in muscle parameters between the two fracture types in the over 80 years old group was no longer statistically significant after adjustment of covariates. However, in the 65-80 age group, muscle parameters, especially G.MaxM, were more strongly related to TRF. The explanations for the age effect on muscle parameters with the risk of TRF were unclear. Hip fracture women aged over 80 years seem to be especially frail with low bone mineral density, low cortical thickness, and low muscle quality, thus, we speculated that the incidence of hip fracture type might be a random event.

5. Strengths and limitations

To our knowledge, this study is the first to utilize an age cutoff of 80 to stratify and investigate the age-specific relationship between G.MaxM and G.Med/MinM area and density with hip fracture type. Additionally, we rigorously excluded subjects imaged more than 48 hours after hip fracture, enhancing the reliability of our bone and muscle measurements. Prolonged immobility or reduced activity following a fracture can exacerbate muscle atrophy, rendering muscle area or CT values measured post-48 hours less reflective of the muscle state at or before the fracture. Furthermore, our study calibrated several factors in binary logistic regression, including BMD, an essential factor that had been overlooked in previous relevant studies.

This study possesses several notable limitations. Firstly, its cross-sectional design warrants future longitudinal cohort studies to further explore the relationship between gluteal muscles and fracture types over time. Secondly, our decision to measure the healthy side instead of the fractured side introduces potential bias. However, this approach was taken to mitigate the impact of factors like fracture, bleeding, and edema on muscle parameter accuracy. Future advancements in technology, as suggested by Cheng et al. [27], may offer improved symmetry assessment of the hip joint sides. Lastly, our study is inherently limited by its exclusive focus on older female patients with fractures, which limits generalizability to older males. This gender-specific focus was driven by a predominance of female cases in our dataset. Given known sex differences in muscle characteristics, combining datasets into a unified cohort for analysis was deemed inappropriate, necessitating our concentration on the larger female patient sample. Future research should strive to address this limitation by recruiting a more balanced cohort encompassing both genders, thereby broadening the applicability and robustness of findings concerning skeletal muscle health in older patients following fractures.

6. Conclusions

In conclusion, our study demonstrates that in older women, particularly those under 80 years of age, gluteus muscle parameters are associated with trochanteric fractures. Age-related loss of muscle mass is a well-known risk factor for hip fractures. Therefore, preserving muscle mass and minimizing fat infiltration in muscles may be crucial in preventing trochanteric fractures in this demographic, especially those under 80 years old.

Abbreviations

FNF	femoral neck fractures
TRF	trochanteric fractures
G.Med/MinM	gluteus medius and minimus muscle
G.MaxM	gluteus maximus muscle

THaBMD	total hip areal bone mineral density
FNaBMD	femoral neck areal bone mineral density
BLR	binary logistic regression
BMD	bone mineral density
BMI	body mass index
QCT	quantitative computed tomography
CTXA	CT X-ray absorptiometry technique
HU	Hounsfield units

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Author Contributions

Pengju Huang: Methodology, Writing - Original Draft, Writing- Reviewing;

Yufeng Ge: Methodology, Writing- Reviewing and Editing;

Yandong Liu: Writing- Reviewing and Editing, Investigation, Validation;

Jian Geng: Writing- Reviewing and Editing, Validation;

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Aihong Yu: Conceptualization, Methodology, Writing- Reviewing and Editing;

Xinbao Wu: Conceptualization, Methodology, Writing- Reviewing and Editing;

Ling Wang: Conceptualization, Methodology, Writing- Reviewing and Editing, Supervision;

Xiaoguang Cheng: Conceptualization, Methodology, Writing- Reviewing and Editing.

All authors reviewed the manuscript and approved the final version, and Ling Wang is the guarantor.

Conflicts of Interest

All authors state that there is no conflict of interest.

Availability of data

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

Declarations

Ethics approval and consent to participate

The study was conducted in accordance with the guidelines of the Declaration of Helsinki and approved by the Institutional Review Board of Beijing Jishuitan Hospital (No. 201512-02). Informed consent was obtained from all subjects participating in the study.

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Table 1 Characteristics of subjects who sustained femoral neck or trochanteric fractures grouped by age

	Total (n = 554)			Age <80			Age ≥80		
	FN (n = 314)	TR (n = 240)	p	FN (n = 201)	TR (n = 110)	p	FN (n = 113)	TR (n = 130)	p
age, year	77.02 ± 7.15	79.70 ± 6.91	**< 0.001**	72.69 ± 4.48	73.60 ± 4.07	0.077	8[illegible]3 ± 3.69	84.86 ± 4.01	0.797
height, cm	159.15 ± 5.76	157.09 ± 5.84	**< 0.001**	159.92 ± 5.90	158.69 ± 5.47	0.074	1[illegible]7.7[illegible] ± 5.27	155.73 ± 5.83	**0.005**
weight, kg	58.04 ± 10.53	57.97 ± 11.25	0.944	59.65 ± 10.17	61.04 ± 10.48	0.256	5[illegible].16 ± 10.60	55.38 ± 11.27	0.880
BMI, kg/m²	22.84 ± 3.51	23.43 ± 4.09	0.066	23.26 ± 3.33	24.21 ± 3.83	**0.024**	2[illegible]8 ± 3.69	22.78 ± 4.21	0.175
THaBMD, g/cm²	0.57 ± 0.11	0.52 ± 0.11	**< 0.001**	0.59 ± 0.11	0.57 ± 0.10	**0.036**	0[illegible]4 ± 0.10	0.49 ± 0.10	**< 0.001**
FNaBMD, g/cm²	0.50 ± 0.10	0.47 ± 0.10	**< 0.001**	0.51 ± 0.10	0.49 ± 0.09	0.092	0[illegible]4 ± 0.09	0.45 ± 0.09	0.076
G.Med/MinM area, cm²	29.92 ± 7.17	27.24 ± 6.61	**< 0.001**	31.34 ± 6.94	28.83 ± 6.99	**0.003**	2[illegible].40 ± 6.88	25.88 ± 5.98	0.067
G.Med/MinM density, HU	33.40 ± 6.72	31.04 ± 6.81	**< 0.001**	34.92 ± 6.50	31.97 ± 6.72	**< 0.001**	3[illegible].68 ± 6.26	30.24 ± 6.82	0.603
G.MaxM area, cm²	31.01 ± 6.81	28.40 ± 6.44	**< 0.001**	32.57 ± 6.66	30.48 ± 6.86	**0.009**	2[illegible].24 ± 6.21	26.63 ± 5.50	**0.034**
G.MaxM density, HU	25.71 ± 7.41	22.52 ±7.34	**< 0.001**	27.11 ± 7.36	23.62 ± 7.57	**< 0.001**	2[illegible].24 ± 6.86	21.58 ± 7.04	0.064

All the quantitative variables were expressed as mean ± SD (standard deviation).

TH: total hip; FN: femoral neck fracture; TR: trochanteric fracture;aBMD: areal bone mineral density; BMI: body mass index; G.Med/MinM: gluteus medius and minimus muscle; G.MaxM: gluteus maximus.

Table 2 Odds ratios of having a TRF per 1 SD of variables

		crude. OR (95CI)	adj.OR (95CI)*	adj.OR (95CI)#
Total (n=554)	G.Med/MinM area	**0.94 (0.92~0.97)**	**0.95 (0.93~0.98)**	**0.97 (0.94~0.99)**
	G.Med/MinM density	**0.95 (0.93~0.97)**	**0.96 (0.94~0.99)**	0.98 (0.95~1.01)
	G.MaxM area	**0.94 (0.92~0.97)**	**0.94 (0.91~0.97)**	**0.95 (0.92~0.99)**
	G.MaxM density	**0.94 (0.92~0.97)**	**0.96 (0.93~0.98)**	**0.97 (0.95~1.00)** ##
Age <80	G.Med/MinM area	**0.95 (0.91~0.98)**	**0.95 (0.91~0.98)**	**0.95 (0.92~0.99)**
	G.Med/MinM density	**0.93 (0.90~0.97)**	**0.94 (0.90~0.97)**	**0.95 (0.91~0.98)**
	G.MaxM area	**0.95 (0.92~0.99)**	**0.94 (0.90~0.98)**	**0.94 (0.91~0.98)**
	G.MaxM density	**0.94 (0.91~0.97)**	**0.95 (0.91~0.98)**	**0.95 (0.92~0.99)**
Age ≥80	G.Med/MinM area	0.96 (0.93~1.00)	0.96 (0.92~1.00)	0.99 (0.94~1.04)
	G.Med/MinM density	0.99 (0.95~1.03)	0.99 (0.95~1.03)	1.02 (0.98~1.07)
	G.MaxM area	0.95 (0.91~1.00)	**0.94 (0.89~0.98)**	0.97 (0.92~1.02)
	G.MaxM density	0.97 (0.93~1.00)	0.97 (0.93~1.01)	1.00 (0.96~1.04)

SD, standard deviation; OR, odds ratio; CI, confidence interval; G.Med/MinM: gluteus medius and minimus muscle; G.MaxM: gluteus maximus.

* adjustment for age and body mass index.

adjustment for age, body mass index, and total hip areal bone mineral density.

P value=0.038

Fig. 1. Schematic flow diagram illustrating the stepwise exclusion of subjects with hip injuries. FNF, femoral neck fractures; TRF, trochanteric fractures.

Fig. 2. 2a: Measurement of the gluteus medius and minimus muscles at the 3rd sacral (S3) level. 2b: Measurement of cross-sectional area and mean CT values of the gluteus maximus at the level of the greater trochanter of the femur. Muscle regions are highlighted in red.

Fig. 3. Relationship between the density and area of the gluteal muscles and the risk of trochanteric fractures (TRF).

*Adjusted for age and body mass index (BMI);

Bar chart includes a dividing line above which represents the sample size of two subgroups.

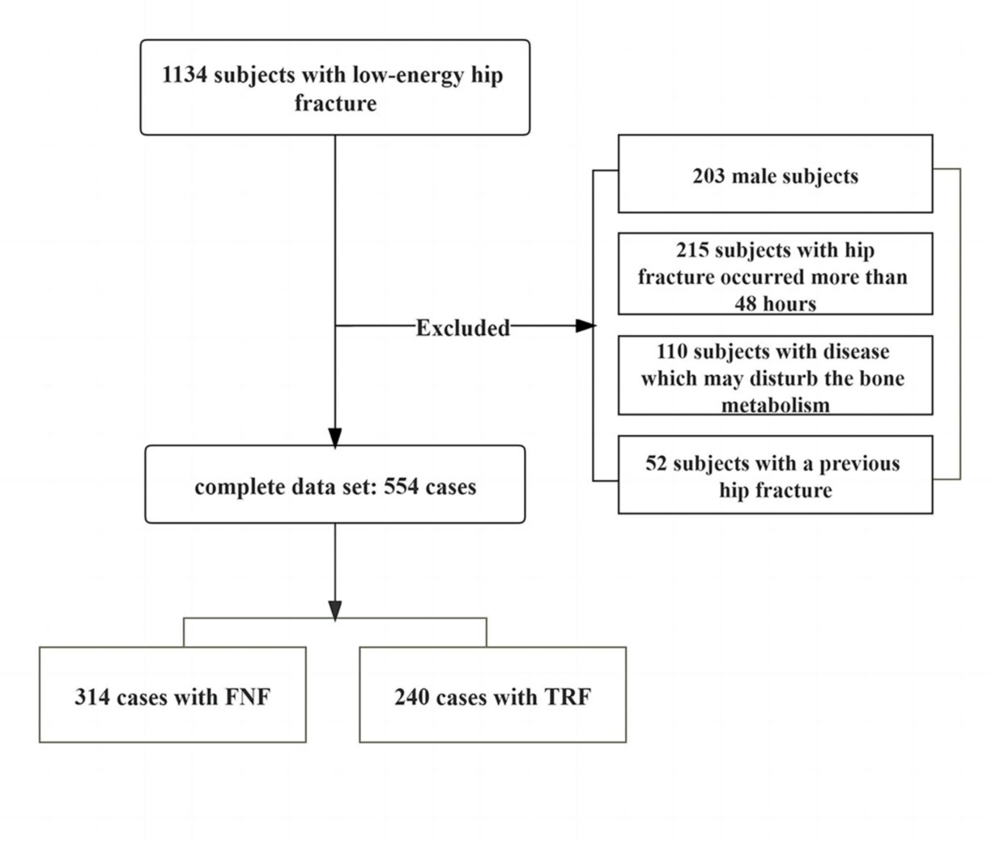

Fig. 1. Schematic flow diagram illustrating the stepwise exclusion of subjects with hip injuries. FNF, femoral neck fractures; TRF, trochanteric fractures.

173x147mm (300 x 300 DPI)

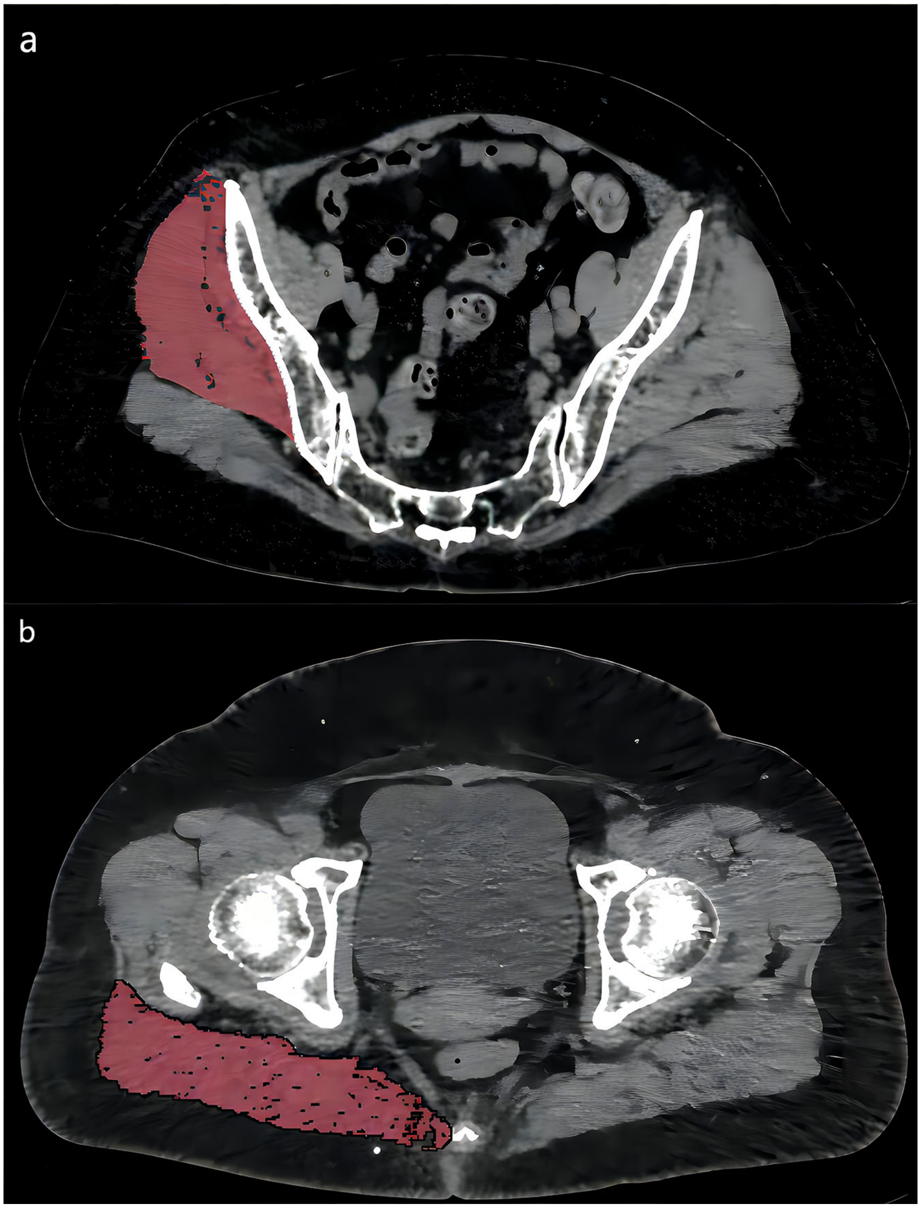

Fig. 2. 2a: Measurement of the gluteus medius and minimus muscles at the 3rd sacral (S3) level. 2b: Measurement of cross-sectional area and mean CT values of the gluteus maximus at the level of the greater trochanter of the femur. Muscle regions are highlighted in red.

112x147mm (300 x 300 DPI)

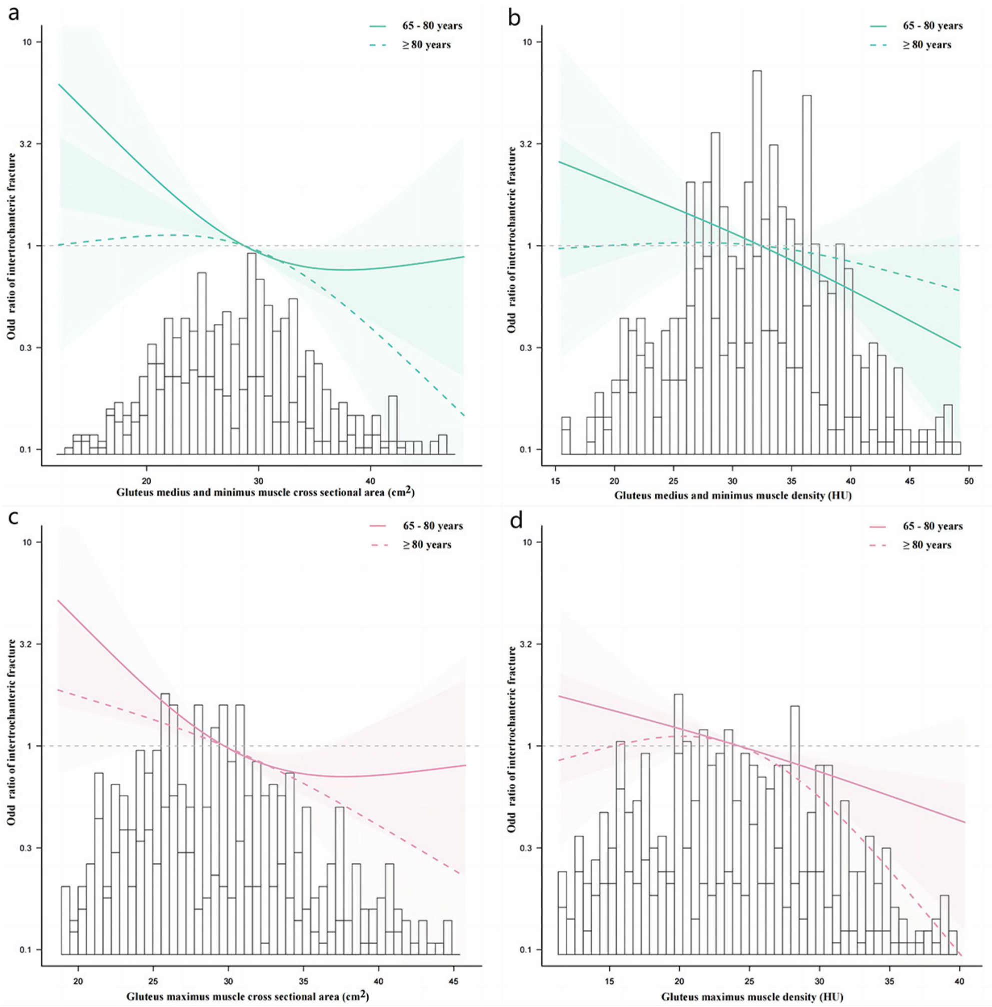

Fig. 3. Relationship between the density and area of the gluteal muscles and the risk of trochanteric fractures (TRF).
*Adjusted for age and body mass index (BMI);
Bar chart includes a dividing line above which represents the sample size of two subgroups.

104x104mm (300 x 300 DPI)

Reporting checklist for cross sectional study.

Based on the STROBE cross sectional guidelines.

Instructions to authors

Complete this checklist by entering the page numbers from your manuscript where readers will find each of the items listed below.

Your article may not currently address all the items on the checklist. Please modify your text to include the missing information. If you are certain that an item does not apply, please write "n/a" and provide a short explanation.

Upload your completed checklist as an extra file when you submit to a journal.

In your methods section, say that you used the STROBE cross sectionalreporting guidelines, and cite them as:

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		Reporting Item	Page Number
Title and abstract			
Title	#1a	Indicate the study's design with a commonly used term in the title or the abstract	1
Abstract	#1b	Provide in the abstract an informative and balanced summary of what was done and what was found	2,3
Introduction			
Background / rationale	#2	Explain the scientific background and rationale for the investigation being reported	4
Objectives	#3	State specific objectives, including any prespecified hypotheses	5
Methods			

Study design	#4	Present key elements of study design early in the paper	5
Setting	#5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	5
Eligibility criteria	#6a	Give the eligibility criteria, and the sources and methods of selection of participants.	5,6
	#7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	5,6
Data sources / measurement	#8	For each variable of interest give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group. Give information separately for for exposed and unexposed groups if applicable.	7
Bias	#9	Describe any efforts to address potential sources of bias	6,7
Study size	#10	Explain how the study size was arrived at	5
Quantitative variables	#11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen, and why	7,8
Statistical methods	#12a	Describe all statistical methods, including those used to control for confounding	7,8
Statistical methods	#12b	Describe any methods used to examine subgroups and interactions	7,8
Statistical methods	#12c	Explain how missing data were addressed	n/a
Statistical methods	#12d	If applicable, describe analytical methods taking account of sampling strategy	n/a
Statistical methods	#12e	Describe any sensitivity analyses	n/a
Results			
Participants	#13a	Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed	8

		eligible, included in the study, completing follow-up, and analysed. Give information separately for for exposed and unexposed groups if applicable.	
Participants	#13b	Give reasons for non-participation at each stage	8
Participants	#13c	Consider use of a flow diagram	8
Descriptive data	#14a	Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders. Give information separately for exposed and unexposed groups if applicable.	8
Descriptive data	#14b	Indicate number of participants with missing data for each variable of interest	n/a
Outcome data	#15	Report numbers of outcome events or summary measures. Give information separately for exposed and unexposed groups if applicable.	n/a
Main results	#16a	Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	8,9
Main results	#16b	Report category boundaries when continuous variables were categorized	8,9
Main results	#16c	If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	n/a
Other analyses	#17	Report other analyses done—e.g., analyses of subgroups and interactions, and sensitivity analyses	8,9
Discussion			
Key results	#18	Summarise key results with reference to study objectives	9
Limitations	#19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias.	12
Interpretation	#20	Give a cautious overall interpretation considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence.	10,11

Generalisability	#21	Discuss the generalisability (external validity) of the study results	10,11
Other Information			
Funding	#22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	14