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Gender similarities and differences in skeletal muscle and body composition: an MRI study of recreational cyclists

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ABSTRACT

Objectives This study aims to quantitatively evaluate whether there are muscle mass differences between male and female recreational cyclists and compare muscle quality and body composition in the pelvis region between two well-matched groups of fit and healthy male and female adults.

Methods This cross-sectional study involved 45 female and 42 male recreational cyclists. The inclusion criteria for both groups were to have cycled more than 7000 km in the last year, have an absence of injuries and other health problems, have no contraindication to MRI, and be 30–65 years old. Our main outcome measures were fat fraction, as a measure of intramuscular fat (IMF) content, and volume of the gluteal muscles measured using Dixon MRI. The gluteal subcutaneous adipose tissue (SAT) volume was evaluated as a secondary measure.

Results We found that there were no gender differences in the IMF content of gluteus maximus (GMAX, p=0.42), gluteus medius (GMED, p=0.69) and gluteus minimus (GMIN, p=0.06) muscles, despite women having more gluteal SAT (p<0.01). Men had larger gluteal muscles than women (p<0.01), but no differences were found when muscle volume was normalised by body weight (GMAX, p=0.54; GMED, p=0.14; GMIN, p=0.19).

Conclusions Our study shows that despite the recognised hormonal differences between men and women, there is gender equivalence in the muscle mass and quality of the gluteal muscles when matched for exercise and body weight. This new MRI study provides key information to better understand gender similarities and differences in skeletal muscle and body composition.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Men have higher muscle mass than women in absolute terms and relative to body mass.
⇒ Women have a higher percentage of body fat than men of the same body mass index, but less is known regarding gender differences in intramuscular fat (IMF).
⇒ The gender gap in cycling performance seems to have reached a plateau and may be simply due to differences in VO_2max and musculoskeletal factors.

WHAT THIS STUDY ADDS

⇒ There are no gender differences in the IMF content and muscle mass of the gluteal muscles when matched for exercise and body weight, even though women have more gluteal subcutaneous adipose tissue.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ By emphasising the importance of exercise and body weight in understanding muscle characteristics independently of gender, this study contributes to a more informed and equitable approach to health, sports science and disease prevention.
⇒ These findings challenge existing assumptions about gender-based differences in muscle mass and quality. Researchers in exercise physiology and musculoskeletal science may now consider the importance of exercise levels and body weight when studying gender-related muscle characteristics.

INTRODUCTION

There is renewed interest in understanding gender differences and similarities in skeletal muscle (SM) and body composition.[1–5] On the one hand, SM is now known to be important in many physiological and disease processes.[6–12] On the other hand, sports performance differences between male and female athletes have attracted new attention in recent years because of the inclusion of transgender athletes in female competitions.[13]

There are known gender differences in SM and body composition.[2] Men have higher muscle mass than women in absolute terms and relative to body mass, and this difference is greater in the upper body.[14 15] Women have a higher percentage of body fat than men of the same body mass index (BMI) and tend to accumulate more subcutaneous adipose tissue (SAT) around the hip, while men around the trunk and abdomen.[16] Less is known regarding gender differences in intramuscular fat (IMF). Using Dixon MRI and computational tools, we have previously shown that the IMF of gluteus maximus

Table 1 Demographics of the two study groups. Mean±SD values are reported

Subjects	Female n=45	Male n=42
Age (years)	41.9±10.1	43.8±10.2
Weight (kg)	61.4±5.5	77.0±8.2
Height (cm)	166.1±7.1	180.1±6.8
BMI (kg/m^2)	22.3±2.1	23.7±2.5

BMI, body mass index.

(GMAX) is associated with different levels of physical activity and that women had higher levels of IMF in the gluteal muscles.[17 18]

In this work, we focus on gender differences in recreational cyclists, as cycling is one of the sports that has gained more popularity as a means to stay fit and active among middle-aged adults.[19–21] Although traditionally dominated by men, nowadays, this trend has changed, and women have closed the gap in participation and performance.[22–25] The performance gap seems to have reached a plateau, and the gender differences are now probably due to biological reasons,[26] in particular VO_2max[27 28] and musculoskeletal factors. Consequently, it is important to understand if there are gender differences in muscle mass and composition between equally trained cyclists.

The aim of this study is twofold: to quantitatively evaluate if there are muscle mass differences between male and female recreational cyclists; and to compare muscle quality and body composition in the pelvis region between two well-matched groups of fit and healthy male and female adults, which is relevant to study public health and SM related diseases. To achieve this, we recruited well-trained recreational cyclists who underwent Dixon MRI and computed the IMF content, muscle mass, lean muscle mass of the gluteal muscles and the SAT volume of the pelvis.

METHODS

Study design

This cross-sectional study involved a group of female and male recreational cyclists who underwent MRI. The inclusion criteria for both groups were to have cycled more than 7000 km in the last year, have an absence of injuries and other health problems, have no contraindication to MRI and be 30–65 years old.

We recruited 87 subjects, 45 women and 42 men, from cycling clubs in London, UK, which complied with the inclusion criteria. The demographic data for each group are presented in table 1. The volunteers underwent MRI

Table 2 Median (IQR) fat fraction, muscle volume, NV and NLV values for GMAX, GMED and GMIN, for each gender. Median (IQR) values of V_{SAT} and NV_{SAT} are also included. P values correspond to Kruskal-Wallis tests for gender differences

	Men	Women	P value
Fat fraction (%)			
GMAX	14.5 (11.7–15.6)	14.8 (12.2–17.1)	p=0.42
GMED	11.4 (10.5–12.9)	11.3 (10.3–13.7)	p=0.69
GMIN	14.7 (13.3–17.1)	16.3 (14.9–17.8)	p=0.06
Volume (cm^3)			
GMAX	770.3 (704.7–884.0)	620.6 (568.8–686.8)	p<0.01
GMED	394.4 (363.1–433.8)	300.1 (274.3–338.4)	p<0.01
GMIN	110.4 (101.9–118.1)	85.1 (79.6–92.8)	p<0.01
NV (cm^3/kg)			
GMAX	10.3 (9.6–11.6)	10.2 (9.5–10.9)	p=0.54
GMED	5.1 (4.8–5.5)	4.9 (4.6–5.3)	p=0.14
GMIN	1.5 (1.4–1.6)	1.4 (1.3–1.5)	p=0.19
NLV (cm^3/kg)			
GMAX	8.7 (8.1–10.3)	8.7 (7.9–9.5)	p=0.36
GMED	4.5 (4.2–4.9)	4.3 (3.9–4.7)	p=0.17
GMIN	1.2 (1.2–1.4)	1.2 (1.1–1.3)	p=0.09
V_{SAT}(cm^3)	2216.3 (1909.3–2774.4)	2908.9 (2481.4–3998.7)	p<0.01
NV_{SAT}(cm^3/kg)	28.8 (24.7–34.4)	50.7 (42.5–61.7)	p<0.01

GMAX, gluteus maximus; GMIN, gluteus minimus; NLV, normalised lean volume; NV, normalised volume; NV_{SAT}, SAT normalised volume; V_{SAT}, SAT volume.

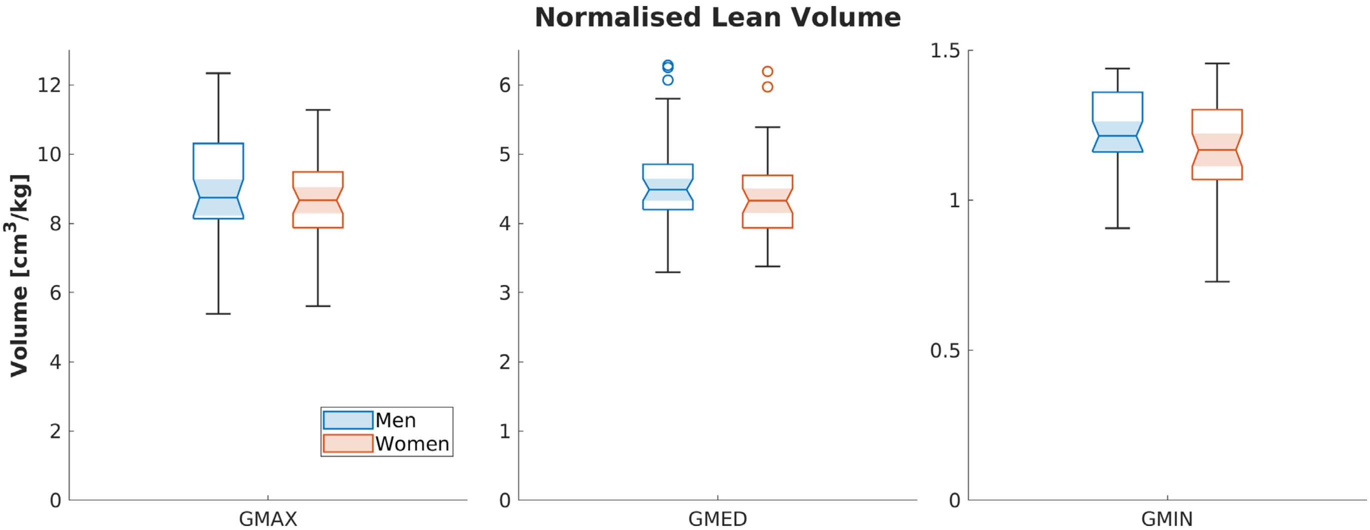

Figure 1 Boxplots of lean muscle volume normalised by body mass for GMAX, GMED and GMIN for each gender. On each box, the central mark is the median, and the edges of the box are the 25th and 75th centiles. Outliers are plotted individually with circles. CMAX, gluteus maximus; GMED, gluteus medius; GMIN, gluteus minimus.

and completed a structured questionnaire regarding their physical activity levels and lifestyle on the scanning day. Body mass (weight) and standing height were measured before each volunteer entered the MRI room. All subjects provided written informed consent.

MRI acquisition

All subjects underwent a standardised MRI protocol. The MRIs were acquired on a 3T scanner (Siemens Magneton Vida, Erlangen, Germany) using a body coil. The scanning protocol consisted of axial PD TSE (proton density turbo spin echo) Dixon and axial T1-weighted images with a field of view (FOV) that covered from 2 cm below the lesser trochanter (LT) to the top of the L1 vertebra of the lumbar spine. The PD TSE Dixon sequence had the following parameters: slice thickness 2.6 mm, spacing between slices 2.6 mm, repetition time 5590 ms, echo time 51 ms, number of excitations 1, number of echoes 14, flip angle 150°. The voxel size was $0.55 \times 0.55 \times 2.6\,mm^3$.

Measurements of muscle size and IMF

We quantitatively measured muscle volume, Dixon fat fraction (FF) as a measure of IMF content and lean muscle volume (LV) of the three main gluteal muscles: GMAX, gluteus medius (GMED) and gluteus minimus (GMIN). The volume measurements were normalised by body mass. The measurements were made using an inhouse segmentation tool[29 30] that labels each gluteal muscle and computes the FF, muscle volume and LV. The tool is based in a multiatlas segmentation method and has shown good accuracy for this type of cross-sectional study in previous works.[17 18 31] To ensure the quality of the labels, they were verified by an experienced user and manually corrected when suboptimal segmentations were observed. All the MRI scans were cropped at the tip of the LT to avoid volume differences due to FOV mismatches. Therefore, the GMAX analysis is only performed from the origin to the LT, while the other muscles are completely covered.

Measurement of the SAT

We measured the amount of SAT in the pelvis region by labelling the SAT on the Dixon MRI and computing its volume (V_{SAT}) and normalised volume (NV_{SAT}) by body mass. The labelling was performed with an automated algorithm that classifies each voxel into three different classes[32] and then subtracts a convex hull of the non-fat mask from the fat label for each slice to generate the final SAT label. Finally, the SAT mask was split into two masks, anterior and posterior to the ASIS (anterior superior iliac spine), to measure the gluteal and abdominal SAT volume, respectively.

Muscle shape and fat distribution

We computed axial profiles of each muscle by measuring the cross-sectional areas (CSAs) for each slice[18] which provides information on the muscle mass distribution. These profiles were also normalised by body mass (normCSA). Profiles of FF and SAT were also included, which show the IMF distribution of each muscle and the SAT distribution along the pelvis, respectively. Additionally, we measured the shape factor of each muscle, defined as the ratio between the mean CSA and the maximum CSA.

Statistical analyses

We computed each measured metric's non-parametrical descriptive statistics (median and IQR). We evaluated if there were gender differences in V_{SAT} and in muscle FF, volume, lean volume and shape factors using a Kruskal-Wallis test for non-normally distributed samples (normality had been previously tested with a Kolmogorov-Smirnov test).

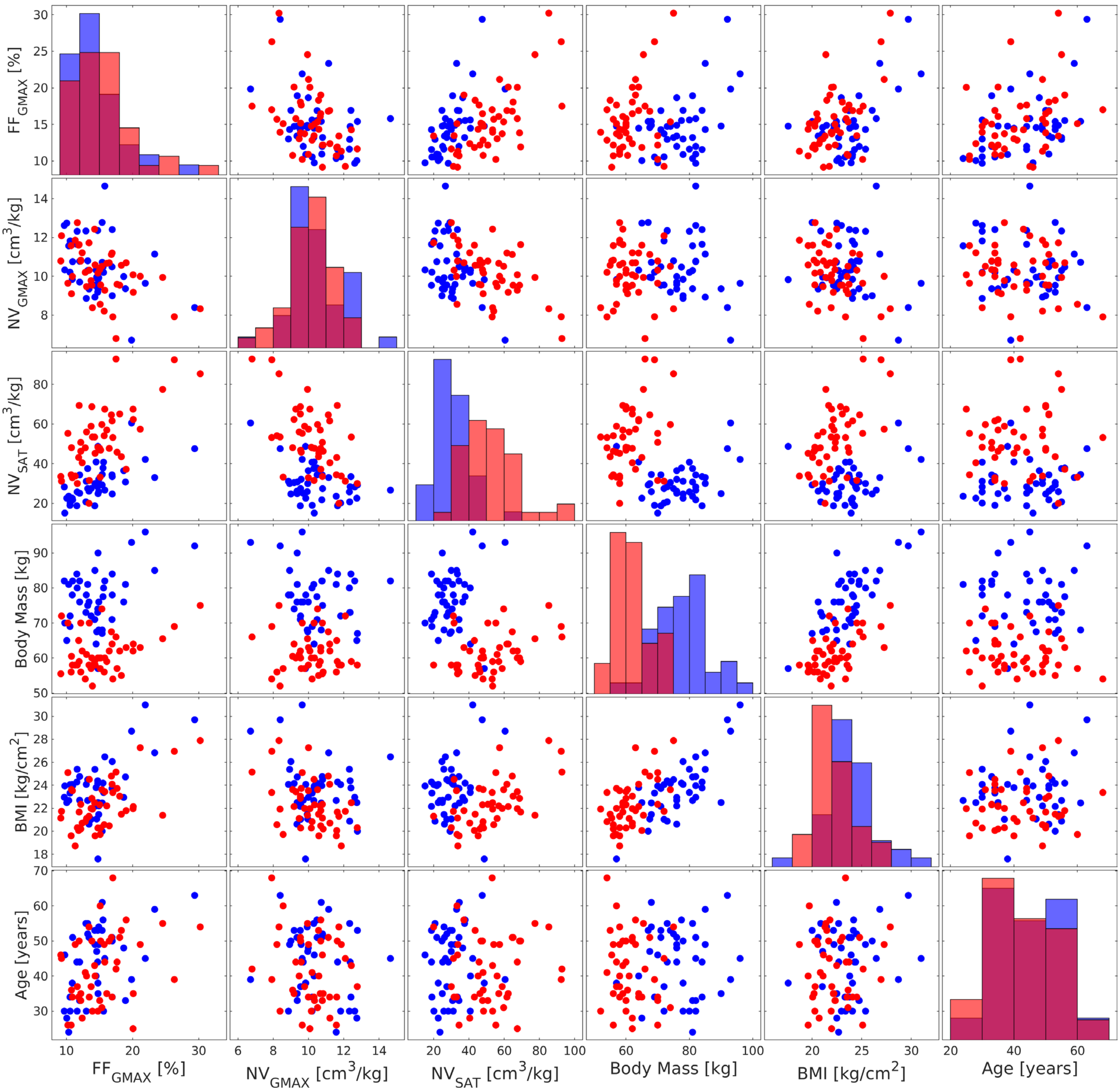

Figure 2 Exploratory data analysis of the main analysed variables and demographics variables. The blue dots correspond to men, and the red dots correspond to women. On the diagonals, histograms for each variable and gender are plotted. BMI, body mass index; FF, fat fraction; GMAX, gluteus maximus; NV, normalised volume; NV_{SAT}, SAT normalised volume;

We used a statistical significance level (α) of 0.05 for all the tests.

RESULTS

The female cyclists had a slightly lower BMI (median 22.0 kg/m^2; p<0.01) than the men (median 23.7 kg/m^2). There were no differences in cycling experience between the male and female recreational cyclists: men had a median of 11.5 years of training experience while women had 9.0 years (p=0.08); the median maximum distance ride in a single race or training was 220 km and 192 km, respectively (p=0.42); and there were no differences in the total number of races done per cyclists (p=0.62).

Volume and FF of the gluteal muscles

We found no significant differences between genders in muscle FF, normalised volume (NV) and normalised lean volume (NLV). Men had larger muscles than women (p<0.01), but no differences were found when muscle volume was normalised by body mass (GMAX, p=0.54; GMED, p=0.14; GMIN, p=0.19). There were also no gender differences for FF (GMAX, p=0.42; GMED,

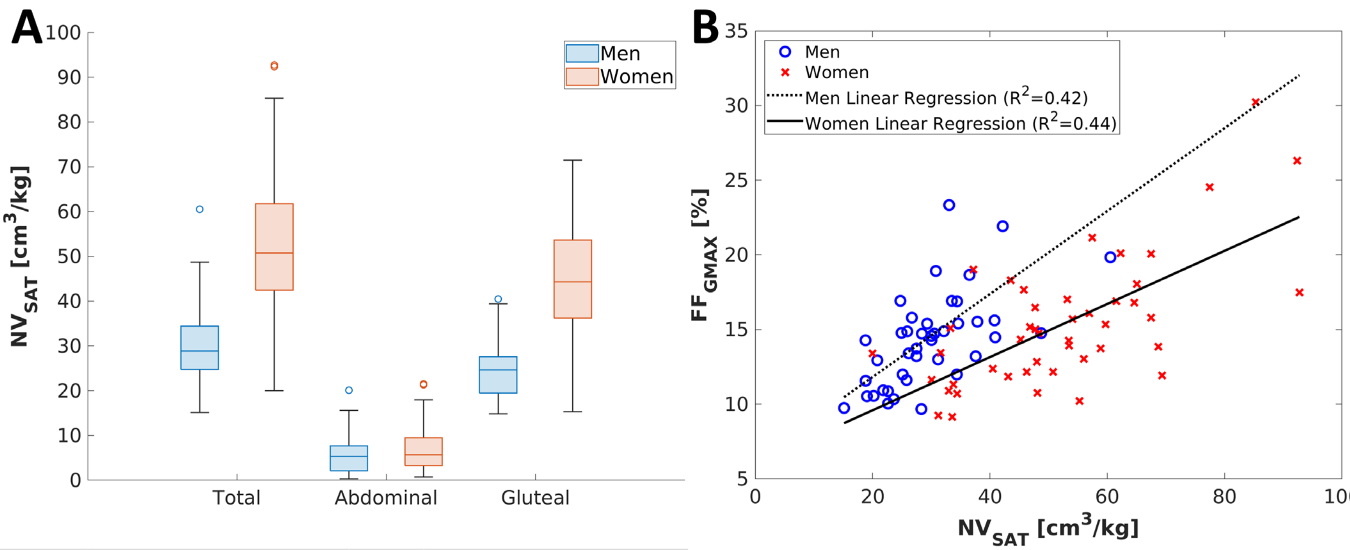

Figure 3 (A) Boxplots of the total NV_{SAT} for the male and female groups, and then divided into the abdominal and gluteal regions. (B) GMAX FF plotted against NV_{SAT} for men (circles) and women (crosses). Regression lines are plotted with dotted and solid lines for men and women. FF, fat fraction; GMAX, gluteus maximus; NV_{SAT}, SAT normalised volume.

p=0.69; GMIN, p=0.06). Table 2 shows the median (IQR) values of FF, volume, NV and NLV for each group. In figure 1, we show boxplots of the NLV representing both muscle mass and composition for GMAX, GMED and GMIN. Figure 2, shows an exploratory analysis of the

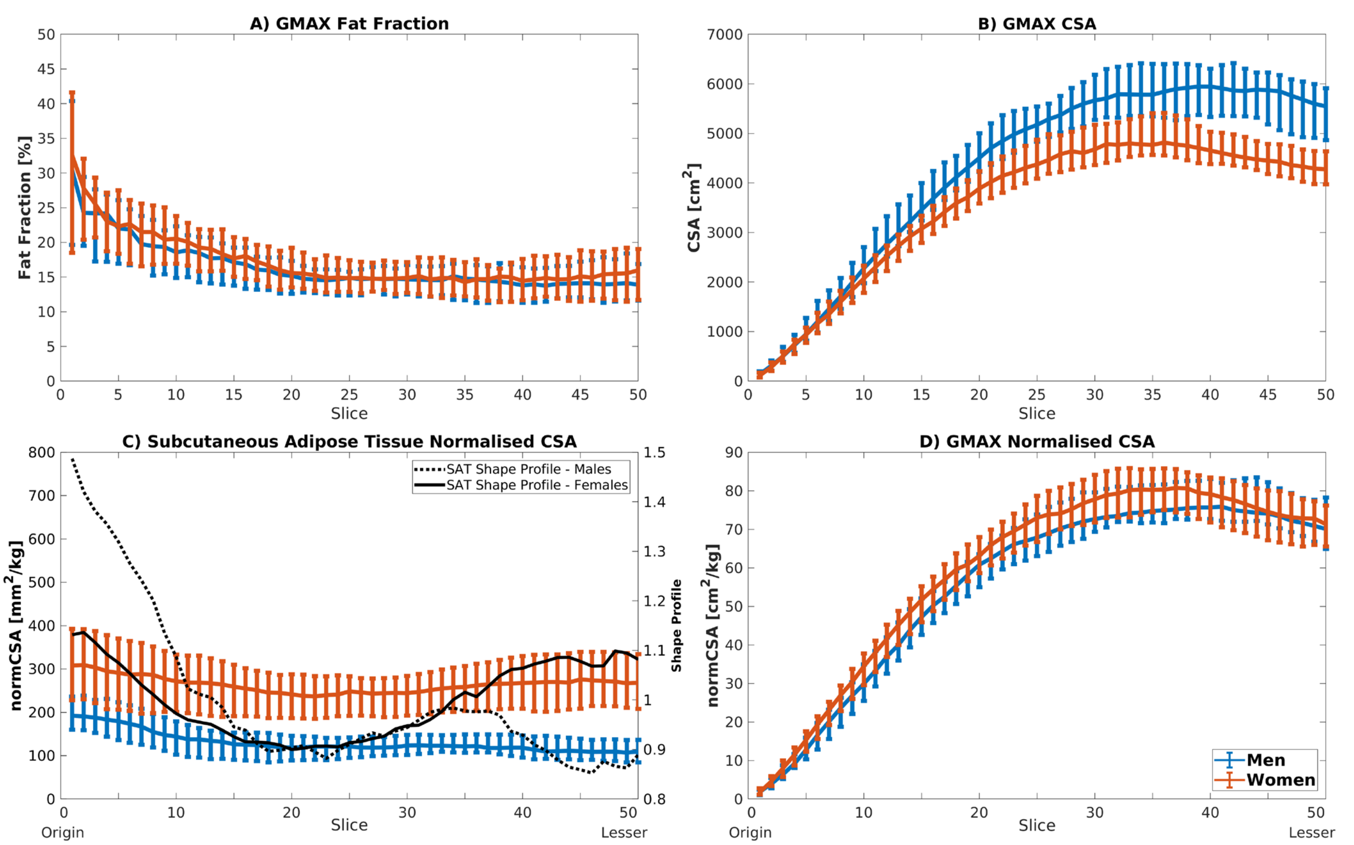

Figure 4 Axial profiles with median values and IQR error bars for GMAX fat fraction (A), GMAX CSAs (B), normalised SAT CSAs (C) and GMAX normalised CSAs (D) for the male (blue) and female (red) cyclists' groups. In C, a purple dashed line is shown and using the left y-axis, the relative percentage difference between the two groups is shown for each slice. The profiles go from the origin of GMAX (slice 1) to the level of the lesser trochanter (slice 50, the most inferior slice). CSA, cross-sectional area; GMAX, gluteus maximus; SAT, subcutaneous adipose tissue.

Table 3 Median (IQR) shape factor, muscle length, maximum CSA, and mean CSA for the gluteal muscles for the men and women groups

	Men	Women	P value
Shape Factor			
GMAX	0.60 (0.59–0.62)	0.63 (0.60–0.65)	p<0.01
GMED	0.51 (0.49–0.53)	0.52 (0.51–0.54)	p<0.01
GMIN	0.37 (0.35–0.38)	0.36 (0.35–0.38)	p=0.91
Muscle length (cm)			
GMAX	18.4 (17.7–19.0)	17.4 (16.6–17.9)	p<0.01
GMED	19.1 (18.5–19.8)	17.9 (16.9–18.5)	p<0.01
GMIN	12.7 (12.2–13.3)	11.7 (11.4–12.2)	p<0.01
Max CSA (cm^2)			
GMAX	61.4 (56.0–67.4)	50.2 (46.6–56.9)	p<0.01
GMED	36.7 (34.4–39.9)	30.1 (27.7–31.9)	p<0.01
GMIN	14.2 (13.3–15.2)	12.0 (11.0–12.7)	p<0.01
Mean CSA (cm^2)			
GMAX	36.8 (34.3–41.4)	31.7 (29.7–34.6)	p<0.01
GMED	18.7 (17.2–20.7)	15.7 (14.4–16.5)	p<0.01
GMIN	5.2 (4.8–5.6)	4.3 (4.1–4.7)	p<0.01

CSA, cross-sectional area; GMAX, gluteus maximus; GMED, gluteus medius; GMIN, gluteus minimus.

variables FF_{GMAX} and NV_{GMAX} in relation to the demographic variables.

Subcutaneous adipose tissue

The SAT volume around the pelvis was larger for women than men (p<0.01). The V_{SAT} and NV_{SAT} median (IQR) values can be found in table 2. The difference between groups was mainly due to differences in the SAT surrounding the gluteal muscles, as no differences were found in the abdominal region (figure 3A).

In figure 3B, we show a plot of the GMAX FF against the pelvis NV_{SAT}. GMAX FF was correlated with the NV_{SAT} for both genders (r=0.65 and r=0.66 for men and women, respectively). However, the relationship between the two variables was considerably different, with coefficients of 0.28 for men and 0.18 for women.

Fat distribution and muscle shape

Figure 4 shows the median (IQR) axial profiles of GMAX FF (figure 4A) and SAT normCSA (figure 4C) that correspond to the intramuscular and subcutaneous fat distribution along the axial axis, from the origin of GMAX to the insertion at the LT. The FF was not significantly different between genders, although women show a considerably larger SAT in this region. In figure 4C, the mean shape profile for each gender (dotted line for men and solid line for women) is shown with a different scale using the right axis. These profiles represent the average shape of the fat distribution independently of the magnitude of the CSAs. For women, the amount of SAT increases towards the LT, while this is not the case for men.

Regarding size and shape, figure 4B shows the CSAs of GMAX along the axial axis, where men have larger GMAX CSA than women. However, when normalising the CSA by body mass, the female cyclists show a slightly larger normCSA (figure 4D) due to a shorter muscle length in the axial direction (the profiles are normalised in length).

The median shape factors were 0.60, 0.51 and 0.37 for GMAX, GMED and GMIN for the men, while 0.63 (p<0.01), 0.52 (p<0.01) and 0.36 (p=0.91) for the women. Other metrics, such as muscle length in the axial direction and maximum and mean CSA, are presented in table 3.

DISCUSSION

In this study, we found no gender differences in the IMF content of the gluteal muscles, despite the broad differences in the amount of SAT around the pelvis. Male recreational cyclists had a larger gluteal muscle mass than similarly trained female cyclists, but these differences were negligible when normalising muscle mass by body weight. The two groups of men and women were recruited from cycling groups in London, UK, and were matched in age, cycling experience and amount of training during the year before they underwent MRI for this study.

We previously found that the female gender was a predictor of higher GMAX IMF when we studied these metrics in healthy subjects with different physical activity levels.[17] However, in this new study with a larger sample size and better fit between groups in training load and demographics, we did not find significant differences in the IMF of the gluteal muscles. Both genders had GMAX IMF values similar to those of our previous study's high physical activity men, composed mainly of recreational marathon runners. This would suggest that there are no gender differences in the IMF content of the gluteal muscles for trained and active adults.

The IMF of the gluteal muscles was correlated with the amount of SAT in the pelvis region, although the relationship between these two quantities was gender dependent. Despite women having lower BMI and similar IMF levels than men, they had a higher amount of SAT, located mainly around the glutes, in line with the gender-specific pattern of subcutaneous fat accumulation.[2 16] Regarding muscle mass and fat distribution, women had larger CSAs relative to body mass but with slightly shorter GMAX and GMED, translating into a different shape factor. There were no significant differences in the distribution of the IMF along the gluteal muscle.

Our results differ from Janssen *et al*,[14] who performed whole-body MRI in 468 men and women and found that men had significantly higher SM mass than women relative to body mass. However, these differences were milder in the lower body. It should be considered that our quantitative metrics are more accurate, obtained from Dixon MRI and segmentations of individual muscles. More research is needed to determine whether our results are due to comparing only well-trained cyclists, due to newer and more accurate methods, or if our results are limited to the gluteal muscles.

The larger muscle mass of the recreational male cyclists is consistent with what has been observed in elite cyclists.[33] Muscle mass is an important factor in cycling performance, as it is correlated with strength and power.[34–38] Studies comparing gender performance in elite races have found differences between 10% and 20%,[25 33] which can be explained by the higher VO_2max of men and the muscle factor. According to our results, the higher muscle mass of male cyclists is mainly due to body size.

Furthermore, most studies examining cycling performance, body composition and muscle mass have been centred around male athletes.[39] While further research is necessary to determine whether our findings can be extrapolated to the thigh and lower leg muscles, our results could provide valuable guidance for coaches and cyclists. Specifically, they may consider shifting their focus beyond conventional body composition metrics and start integrating more advanced measurements, such as IMF content, which appears to be more robust across genders.

A limitation of this work is that we only studied the gluteal muscles, which are only partially involved in cycling. GMAX is the only gluteal muscle heavily involved during the hip extension phase of pedalling cycle.[40] Another limitation is that we could only assess muscle mass and composition and could not distinguish fibre types, which are also relevant for performance. Women are known to have a higher amount of slower-twitch type-I fibres with higher oxidative capacity, which have performance benefits in terms of endurance and recovery;[5] while men have more fast-twitch fibres with a higher contractile velocity that results in more power and speed. Therefore, even if we did not find differences in the ratio of muscle mass to body mass and in the IMF content of the gluteal muscles, there may be differences in fibre composition between the two groups.

Conclusions

Our study shows that despite the recognised hormonal differences between men and women and the higher SAT of the latter, there was gender equivalence in the muscle mass and quality of the gluteal muscles when matched for exercise and body weight. These findings provide key information to better understand gender similarities and differences in the general population and athletes' SM and body composition.

Contributors MAB, JH, ADL, LMH and AJH designed the study, collected the data and analysed it. MAB wrote the manuscript. All authors reviewed the manuscript. AJH is the guarantor for the overall content of the study.

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Competing interests None declared.

Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Not applicable.

Ethics approval This study involves human participants and was approved by the UCL Research Ethics Committee (REC) (Number 13823/001). Participants gave informed consent to participate in the study before taking part.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data are available upon reasonable request.

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