The influence of gender on hip range of motion, hip muscle strength, gluteus medius thickness and M-mode ultrasound examination in asymptomatic university athletes: a cross-sectional study

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Abstract

Introduction: Physical activity is a proposed factor in the development of hip pathologies in males and females. The main objectives of this study were to investigate the influence of gender on isometric hip muscle strength, hip range of motion and gluteus medius thickness at rest, during contraction and onset activation.

Material and methods: A cross-sectional study was carried out. Hip range of motion, hip muscle strength and gluteus medius thickness at rest (B-mode ultrasound) and onset activation (M-mode ultrasound) were measured in thirty asymptomatic university athletes without a history of hip pain.

Results: A total of fifteen males (30 hips) and fifteen females (30 hips) with a mean age of 22 ±6.5 and 20 ±2.75 years were recruited. Females demonstrated greater hip range of motion in flexion, abduction and internal rotation in dominant and non-dominant legs ($p < 0.05$) but no differences were found in extension, adduction and external rotation ($p > 0.05$). Furthermore, females showed less isometric hip muscle strength in hip flexion, extension, abduction, adduction, internal and external rotation ($p < 0.05$) but not in strength ratios ($p > 0.05$). In addition, female exhibited lower gluteus medius thickness at muscle contraction, smaller differences in rest-contraction thickness, but no differences were observed for rest thickness or contraction velocity.

Conclusions: This study found that asymptomatic female athletes demonstrated greater hip flexion, abduction and internal rotation ROM, lower isometric hip muscle strength and different gluteus medius thickness and onset activation compared with asymptomatic male athletes.

Key words: hip, range of motion, muscle strength, ultrasound imaging, gluteus medius.

Introduction

Physical activity is a proposed factor in the development of hip pathologies such as femoroacetabular impingement syndrome (FAIs) [1], acute labral tears [2] or gluteus medius tendinopathy [3]. These conditions are common and may induce pain around the hip joint in the general and athletic populations [4]. Primary prevention can be useful and may allow early identification of those athletes at higher injury risk and enable training program modifications in order to minimize injury risk.

Hip muscle strength and hip range of motion (ROM) deficits have been described in people with hip pain [5, 6]. These physical impairments may result in abnormal movement patterns (e.g. step down or landing) and can stress hip joint structures [7]. To better understand why some athletes have hip pain, we need to improve our knowledge of normal hip muscle strength and ROM in both genders.

Additionally to hip physical function, the gluteus medius muscle is a key lateral hip muscle that contributes to pelvic stability and lower limb function [8], and it was associated with clinical disorders of the pelvis, hip and knee [3]. Muscle thickness or activation, measured by musculoskeletal ultrasound imaging (USI), is an important factor of force-generating capacity [9]. Grimaldi *et al.* [10] found that gluteus medius size, measured by magnetic resonance imaging, was smaller around the affected hip in subjects with hip joint pathology. However, gender differences in gluteus medius thickness or onset activation have not been described in an asymptomatic or symptomatic athletic population. In this context, USI has been described for the assessment of the muscle architecture and texture of several muscles and soft tissues in the lower limb [11]. In addition, in the last 10 years, the study of ultrasonography has increased exponentially, revealing this tool to be a valid, reliable, quick and safe approach for the assessment of muscle features [12].

Therefore, the objectives of this study were to investigate the influence of gender on hip isometric muscle strength, hip ROM and gluteus medius thickness at rest, during contraction and onset activation. We hypothesized that muscle strength, hip ROM and ultrasonography variables would show gender differences.

Material and methods

Study design

A cross-sectional study was carried out based on the Strengthening the Reporting of OBservational studies in Epidemiology (STROBE) statement [13], with the objective to compare the functional parameters of hip muscle strength, hip range of motion and femoral head ultrasonographic morphology between healthy amateur male and female athletes.

Ethical considerations

The Helsinki Declaration and all human experimentation rules [14] were considered, and previously the Ethics Committee of the Hospital Clínico San Carlos approved the research (21/257-E). All participants were previously informed before their inclusion in the study, and a written consent form was obtained from each participant.

Sample size calculation

The sample size calculation was performed with the G*Power 3.1.9.2 software (G*Power, University of Dusseldorf. Germany). A 2-tailed hypothesis, effect size of 0.75, α error probability of 0.05, power (1-β error probability) of 0.80 and an allocation ratio (N2/N1) of 1 were employed for sample size calculation. Thus, a sample of 60 hips was divided into 30 hips by group (dominant and non-dominant leg).

Participants

Thirty asymptomatic athletes (n = 30) were evaluated bilaterally in the hip joint and lower limb (n = 60), dividing the sample into a female group (n = 15) and male group (n = 15) from October 2021 to December 2021 at Universidad Europea de Madrid. The inclusion criteria for participation were (1) amateur athletes, (2) aged 18–35 years, (3) who have a training schedule of at least 2 days of training and competition during the weekend or who have a scheduled competition included in its planning depending on the discipline. The exclusion criteria were determined by the presence of musculoskeletal or lumbopelvic pathology at least in the previous years, neuromuscular, rheumatic, or neurological diseases and surgical interventions or fractures in the lower extremity.

Descriptive data

Athletes' gender, age (years), height (cm), weight (kg), BMI (kg/cm^2 according to the Quetelet index) [15], dominant leg (right or left), pelvic tilt angle and femoral alpha angle measure were collected as sociodemographic descriptive data (Table I).

Pelvic tilt angle

Pelvic tilt angle was measured using a bubble inclinometer and palpation meter (PALM; Performance Attainment Associations, St. Paul, MN, USA) consisting of two caliper arms. The bubble inclinometer is a semicircular arc with a range from 0° to 30° on either side of the midline. Each participant was positioned in a standing position with separation of 30 cm between the feet and they were instructed to look at a fixed point in front of them to control the postural sway. Subjects assumed an upright posture with weight evenly distributed and arms crossed over the chest while the investigator palpated the anterior superior iliac

Table I. Quantitative descriptive variables for female and male athletes

Descriptive variables	Total sample (n = 30)	Males athletes (n = 15)	Female athletes (n = 15)	*P*-value (n = 30)
Age [years]	20.50 ±5.0 (18–32.00)†	22.00 ±6.50 (18.00–32.00)†	20.00 ±2.75 (18.00–26.00)†	< 0.001‡
Weight [kg]	71.83 ±9.60 (52.00–88.00)*	77.44 ±5.38 (66.00–88.00)*	63.42 ±8.31 (52.00–80.00)*	0.156**
Height [m]	1.76 ±0.09 (1.59–1.98)*	1.82 ±6.36 (170–1.98)*	1.68 ±5.98 (1.59–1.78)*	0.787**
BMI [kg/m^2]	22.97 ±2.00 (17.92–26.28)*	23.41 ±1.43 (20.60–26.28)*	22.32 ±2.66 (17.92–25.32)*	0.242**
Alpha angle [°]:				
Dominant	71.57 ±9.22 (52.63–86.83)*	70.45 ±9.28 (52.63–84.96)*	73.25 ±9.26 (61.69–86.83)*	0.500**
Non-dominant	70.02 ±9.50 (51.50–85.82)*	69.31 ±10.34 (51.48–85.82)*	71.09 ±8.43 (57.05–82.18)*	0.452**
Pelvic tilt [°]:				
Dominant	6.57 ±3.57 (0.00–15.00)*	6.83 ±3.24 (1.00–13.00)*	6.17 ±4.13 (0.00–15.00)*	0.855**
Non-dominant	6.57 ±3.50 (0.00–15.00)*	6.61 ±2.85 (1.00–10.00)*	6.50 ±4.44 (0.00–15.00)*	0.680**

*Alpha-angle F.H. – alpha angle of the femoral head, BMI – body mass index. *Mean ± standard deviation and range (min.–max.). †Median ± interquartile range and range (min.–max.). **Student's t-test for independent samples was used according to parametric distributions (Shapiro-Wilk test showing a p-value ≥ 0.05). ‡Mann-Whitney U test was applied according to non-parametric distributions (Shapiro-Wilk test showing a p-value < 0.05). For all analyses, p < 0.05 (for a confidence interval of 95%) was considered as statistically significant (bold).*

spine and posterior superior iliac spine. The pelvic tilt angle in standing position was determined as the angle formed by a horizontal line drawn between the ASIS and the EIPS. Positive grades were used to describe the anterior pelvic tilt and negative grades for the posterior pelvic tilt. Three measurements were taken on each side to obtain an average of both sides (dominant and non-dominant side). The PALM has excellent intra-examiner reliability and good inter-examiner reliability [16].

Ultrasound imaging examination of femoral head and gluteus medius

USI of the femoral head alpha angle and gluteus medius muscle contraction was carried out bilaterally by the same examiner (FG) with experience in USI assessment of more than 5 years. The same ultrasonographic device (Logiq S7 Expert, GE Healthcare, Chicago, IL) was used to carry out the entire sonographic study, equipped with a linear probe (broad-spectrum linear matrix array probe ML6-15 H40452LY, field of view of 50 mm) with a frequency range of 4–15 MHz. A pre-fixed preset of 7 cm depth, 8 MHz frequency, 55 points gain, 69 points dynamic range and 1 focus located at 5 cm depth was established for hip morphology evaluation. Femoral head image acquisition was carried out with participants in the supine position with the hip held at 20° of internal rotation. For the initial location of the probe, the anterosuperior iliac spine and the umbilicus were used as references. From both points, the probe was placed at the point of crossing an imaginary line from these structures that would cross at the hip joint (Figure 1 A). From this position, the ultrasound probe was placed at the longitudinal course of the hip femoral neck in order to identify the acetabular edge, the femoral head and the femoral neck as bony reliefs, as well as the hip capsule, the iliopsoas and sartorius muscle as soft-tissue landmarks (Figure 1 B) [17, 18].

Ultrasound assessment of gluteus medius muscle activity was evaluated in the side-lying position with the lower leg flexed and the upper leg extended aligned with the trunk and cinched to the stretcher at knee level to induce a muscle contraction in abduction (Figures 2 A and D) [19]. Likewise, a pre-fixed preset of 7 cm depth, 8 MHz frequency, 62 points gain, 66 points dynamic range and 1 focus located at 3 cm depth was also established for gluteus medius activity. A reference line was drawn from the mid point of the greater trochanter to the iliac crest of the pelvis in order to determine the probe location (Figure 1 C). Individual adjustment on probe tilt was conducted by the sonographer with the aim of improving visualization of connective tissue layers of the gluteus medius and minimus as well as the bony periosteum of the acetabulum and the femoral head of the hip joint (Figure 1 D). Posteriorly, participants were asked to lift up the leg and foot against the girth to assess the change in thickness during the maximum voluntary contraction for 3 seconds during 3 repetitions (Figures 2 A and D). B-mode ultrasonography was performed in order to

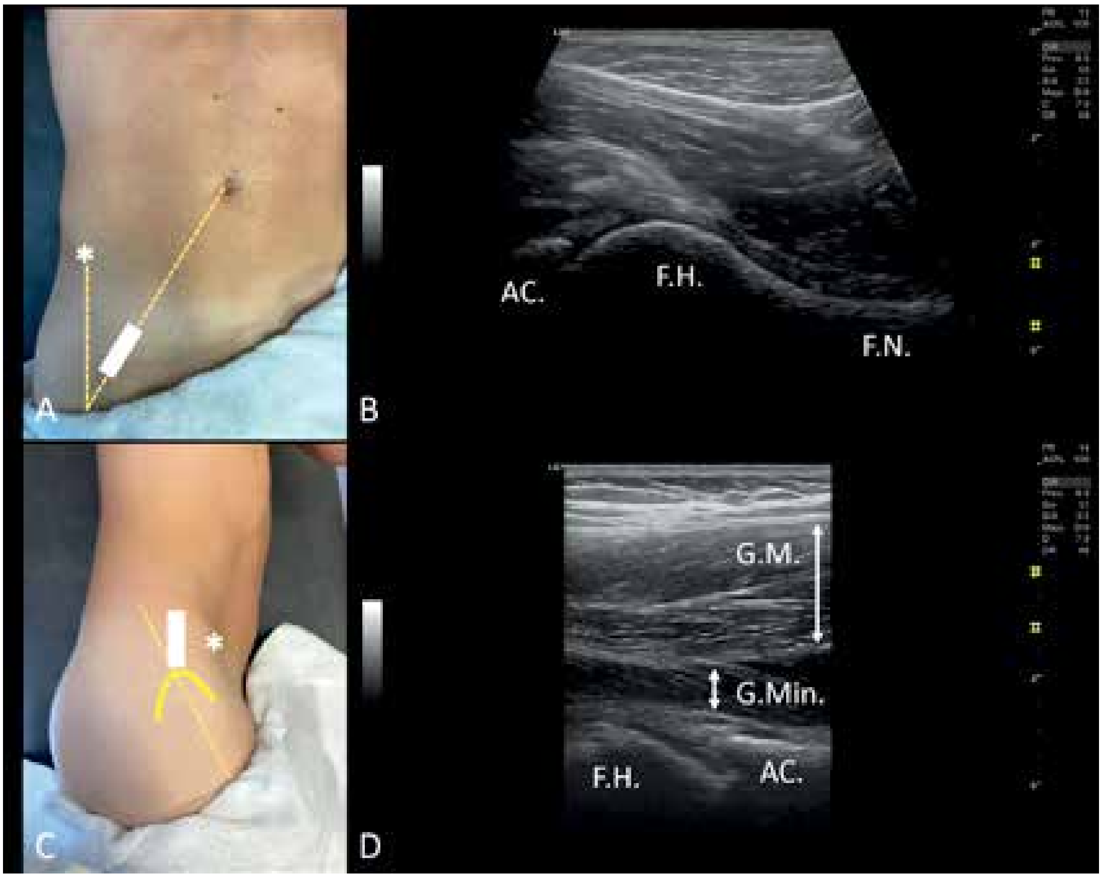


Figure 1. USI assessment and probe location of hip joint and gluteal muscles. Ultrasonographic evaluation of the hip and gluteus region. **A** – Probe location for longitudinal assessment of femoral hip alpha angle. **B** – Probe location for gluteus medius assessment at hip joint level; **C** – Hip joint view by virtual convex ultrasound mode; **D** – gluteus medius and minimus view at hip joint level

AC – acetabulum, G.M. – gluteus medius, G.Min. – gluteus minimus, F.H. – femoral head of the femur bone, F.N. – femoral neck of the femur bone.

record ultrasound images for gluteus medius muscle thickness changes at rest and during contraction (Figures 2 B–C, E–F). Velocity changes during the resting state and maximum registered contraction of the gluteus medius were collected using the slope caliper with M-mode, and the mean of 3 measurements was used (Figures 3 C, D). Before testing the study participants, the ultrasound imaging protocol was practiced on three pilot subjects, who were not included in the final data set. Muscle activity during contraction and muscle rest was recorded through M-mode at the highest scan rate of 2.44 s, providing a temporal resolution of 2.2 ms per pixel.

Ultrasound image processing and data extraction

The 2.0 ImageJ software (U.S. – National Institutes of Health; Bethesda, Maryland, USA) was employed to measure off-line images in DICOM format for femoral head alpha angle and gluteus medius muscle thickness at rest and muscle contraction [20]. A researcher blinded to group allocation carried out all the measurements, following an established protocol for image measurement using the external software (Figure 4). Structural features of femoral head alpha angle morphology, gluteus medius muscle thickness at basal state and muscle contraction were evaluated. However, gluteus medius muscle velocity contraction was determined directly with M-mode ultrasound. This variable was defined as the velocity (Vel. Cont., cm/s) from the basal rest thickness state until the highest thickness state during a voluntary muscle contraction (Figure 3 D).

Firstly, all images imported to ImageJ software were converted to 8-bit images and calibrated from pixels to cm using the reference scale of ultrasound images. For femoral head alpha angle extraction, the ROI manger tool was selected in order to add every step to the software. A reference line was drawn from the lack of the visible femoral neck until the circumference used as a reference of the femoral head. This circumference was drawn covering the inner borders of the visible part of the femoral head ultrasound images. Subsequently, the alpha angle was drawn by setting the first angle arm parallel to the visible

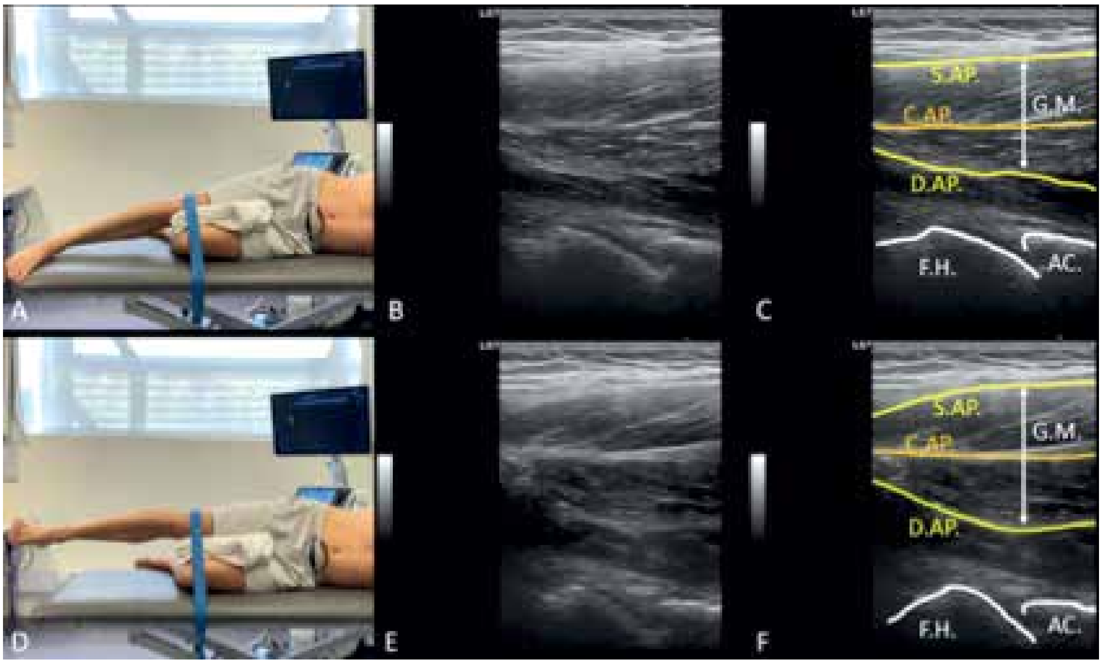


Figure 2. USI assessment for gluteus medius muscle at rest and during muscle contraction. Ultrasonographic evaluation of gluteus medius muscle at rest and during muscle contraction phase. Side lying on the side at rest (**A**) for identification of the hip joint and the gluteus medius and its connective tissue as a point of measurement of the thickness at rest (**B**, **C**). Side lying on the side in muscle contraction state with resistance at knee level (**D**) for identification of the hip joint and the gluteus medius and its connective tissue as a point of measurement of the thickness at muscle contraction (**E**, **F**)

AC – acetabulum, C.AP. – gluteus medius central aponeurosis, D.AP. – gluteus medius deep aponeurosis, G.M. – gluteus medius, F.H. – femoral head of the femur bone, F.N. – femoral neck of the femur bone, S.AP. – gluteus medius superficial aponeurosis.

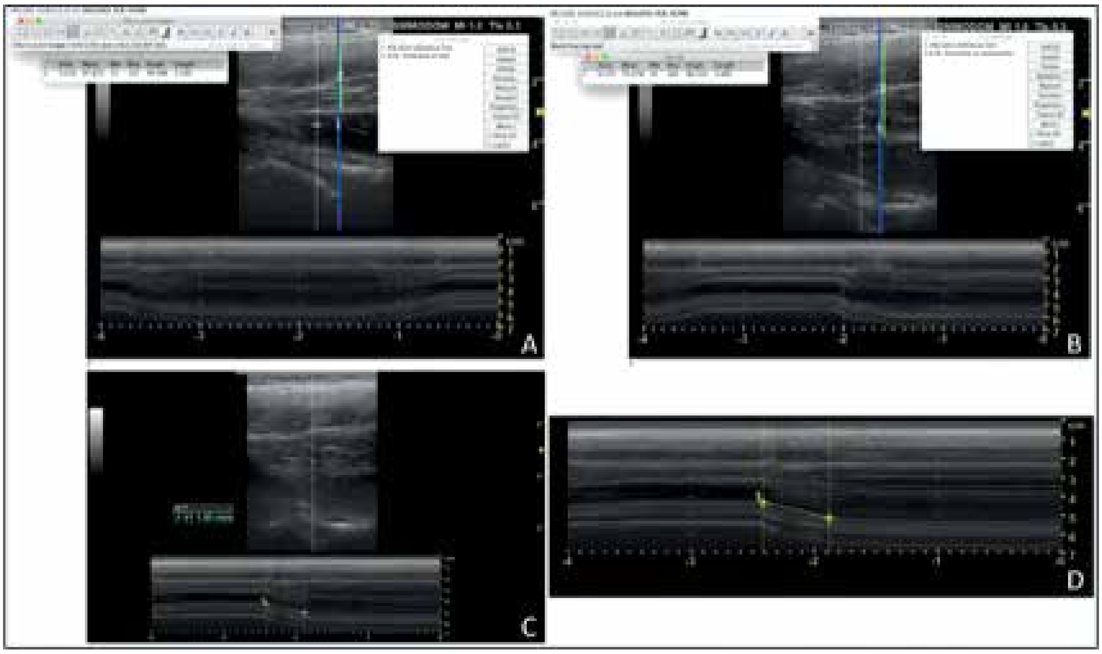
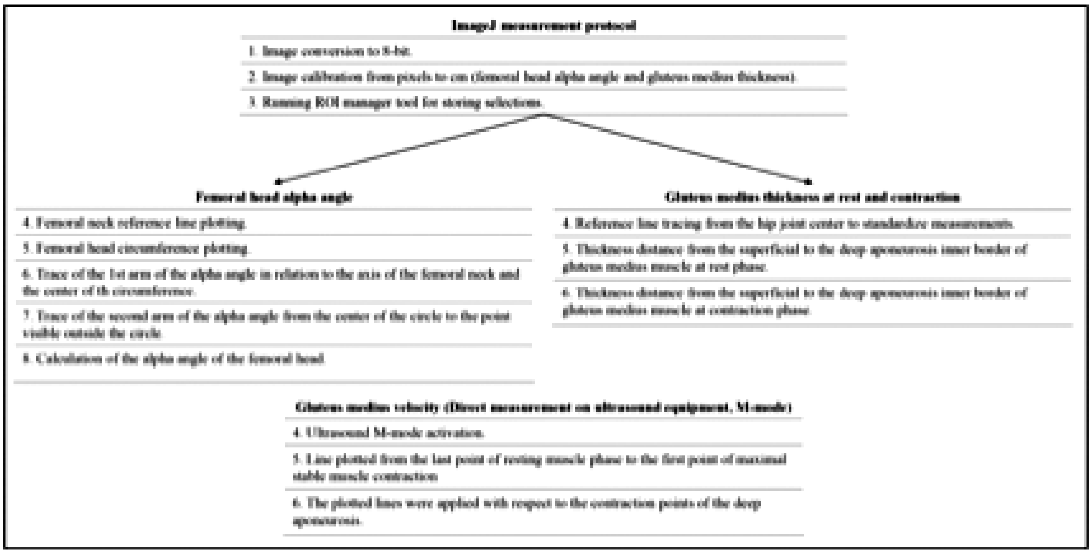


Figure 3. USI measurements for gluteus medius muscle thickness and velocity of contraction. Gluteus medius thickness and velocity of contraction measurements using ImageJ offline software and M-mode ultrasound. Gluteus medius muscle thickness at rest (**A**) and during muscle contraction (**B**) using ROI manager tool of ImageJ software (blue line, reference line of hip joint as a measurement point; green line, muscle thickness from inner border of the superficial and deep connective tissue. **C** – Gluteus medius velocity of contraction using M-mode ultrasonography, **D** – measuring the latest point of muscle rest state until the first stable point of the muscle contraction phase



ImageJ measurement protocol

1. Image conversion to 8-bit.
2. Image calibration from pixels to cm (femoral head alpha angle and gluteus medius thickness).
3. Running ROI manager tool for storing selections.

Femoral head alpha angle

4. Femoral neck reference line plotting.
5. Femoral head circumference plotting.
6. Trace of the 1st arm of the alpha angle in relation to the axis of the femoral neck and the center of th circumference.
7. Trace of the second arm of the alpha angle from the center of the circle to the point visible outside the circle.
8. Calculation of the alpha angle of the femoral head.

Gluteus medius thickness at rest and contraction

4. Reference line tracing from the hip joint center to standardize measurements.
5. Thickness distance from the superficial to the deep aponeurosis inner border of gluteus medius muscle at rest phase.
6. Thickness distance from the superficial to the deep aponeurosis inner border of gluteus medius muscle at contraction phase.

Gluteus medius velocity (Direct measurement on ultrasound equipment, M-mode)

4. Ultrasound M-mode activation.
5. Line plotted from the last point of resting muscle phase to the first point of maximal stable muscle contraction.
6. The plotted lines were applied with respect to the contraction points of the deep aponeurosis.

Figure 4. Protocol for measuring ultrasound images through ImageJ software and M-mode ultrasound. Protocol of steps performed for the measurement of the alpha angle of the femoral head and the thickness of the gluteus medius through image processing and evaluation using ImageJ. The velocity of contraction of the gluteus medius was evaluated directly through the ultrasound equipment

part of the femoral neck to the center of the circumference of the femoral head. The second arm extended from the center of the circle to the visible region of the femoral head that extended beyond the circumference [17] (Figures 5 A, B).

For B-mode gluteus medius muscle thickness was measured; images were calibrated using the set scale tool of the software. Afterwards, the ROI manager tool was activated and distances from the inner edge of the superior muscular aponeurosis to the inferior muscular aponeurosis of the gluteus medius at rest, as well as in the phase of muscle contraction, were drawn and saved. To locate the measurement point, a reference line was drawn at the height of the hip joint line (Figures 3 A, B). Subsequently, the difference between muscle contraction and the resting state was calculated to determine the change associated with muscle contraction. As mentioned in the previous section, the gluteus medius muscle velocity of contraction was calculated directly on the ultrasound equipment by plotting on the M-mode video sequence

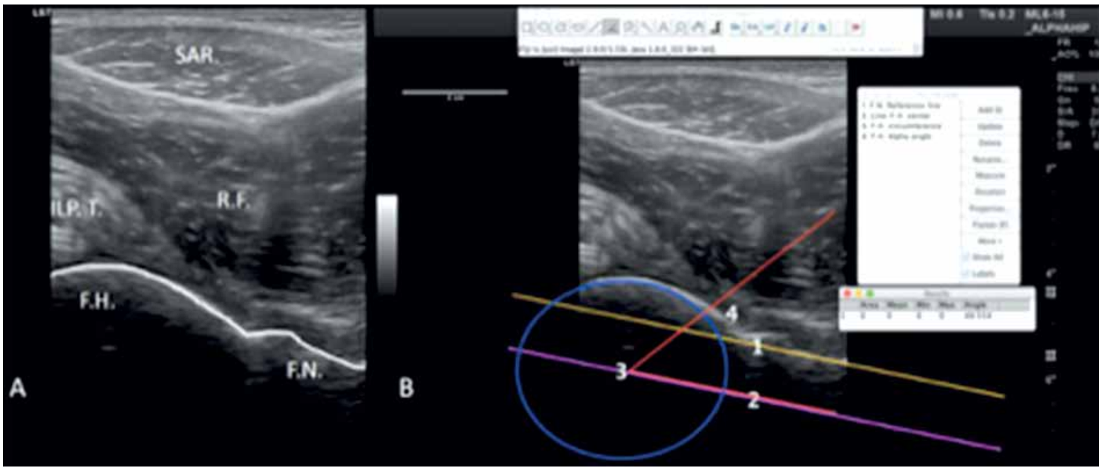


Figure 5. USI and ImageJ femoral head alpha angle assessment. Ultrasonographic and ImageJ evaluation of the hip joint and femoral head alpha angle. **A** – Ultrasonographic image of the femoral head and femoral neck. **B** – ImageJ extraction of the alpha angle of the femoral head through the use of the ROI manager tool and the sequence of steps described (yellow line (1), femoral neck projection reference line; purple line (2), projection line of the center of the femoral head drawn parallel to the femoral head; blue circumference (3), circumference delimited through the visible inner edges of the femoral head, the center corresponding to line 2 previously drawn; red angle (4), angle drawn from the reference line of the center of the circumference (arm 1) to the point of greatest convexity of the humeral head or the point of greatest depth in the case of epiphyseal overgrowth of the humeral head (arm 2))

F.H. – femoral head of the femur bone, F.N. – femoral neck of the femur bone, ILP. T. – iliopsoas tendon, R.F. – rectus femoris of the quadriceps muscle, SAR. – sartorius muscle.

the distance from the last point of the muscle resting phase to the first stable point of the contraction phase (Figures 3 C, D) [21].

Isometric hip muscle strength

Isometric hip muscle strength was measured using the assessment protocol described by Thorborg *et al.* [22], using a hand-held dynamometer (ActiveForce 2, Activbody, San Diego, USA), which was calibrated prior to the evaluation of each subject. The peak force was measured in newtons (N). For hip flexion, the subject was in the supine position, with the hip to be examined in 90° of flexion and the contralateral hip in extension. The dynamometer was fixed 5 cm proximal to the proximal border of the patella. For hip extension, the subject was in the prone position, with the legs placed at the end of the examination table, with the hip to be examined in a neutral position and the knee in 90° of flexion. The dynamometer was placed posteriorly on the thigh, 5 cm proximal to the knee joint line. For hip abduction and adduction, the subject was in a supine position, with the test leg placed at the end of the examination table and the opposite leg slightly flexed. The dynamometer was placed 5 cm proximal to the proximal edge of the lateral malleolus or 5 cm proximal to the proximal edge of the medial malleolus for hip abduction and adduction, respectively. Once placed and to stabilize the dynamometer, the researcher's upper extremity was between the wall and the lower extremity. For hip internal/external rotation with the hip at 90° of flexion, the subject was sitting on the edge of the table with the hip and knee at 90° of flexion. Resistance was applied 5 cm proximal to the proximal border of the lateral and medial malleolus, against internal and external rotation of the hip, respectively. In addition, isometric hip muscle strength ratios were calculated (flexion/extension, adduction/abduction and external/internal rotation). In all isometric hip strength assessments, the subject performed a maximal contraction against the examiner's resistance, holding the examination table bimanually. Assessment of isometric hip muscle strength has demonstrated good-excellent intra- and inter-examiner reliability [23]. The participant's rest between each trial of the same movement was 30 s. This rest period was introduced to prevent a decline in test strength due to fatigue [24]. The verbal command standardized by the researcher was "forward-push-push-push and relax". Three measurements were made for each movement, calculating the mean of the three measurements.

Passive hip range of motion

Passive hip ROM was measured in degrees using a digital inclinometer (ActiveForce 2, Activbody, San Diego, USA). Prior to passive hip ROM testing, subjects were placed in the supine position for hip flexion, abduction, and adduction measurements, in a prone position for hip extension measurements with 90° of knee flexion, and in a sitting position for the measurements of internal-external rotation (90° flexion) of the hip. For each measurement the investigator's free hand provided stabilization to the adjacent joints of the lumbopelvic region and the knee. The investigator passively moved the lower extremity to determine the final ROM of the hip. The end of the movement was defined as a firm final sensation without any further pelvic movement. Once the end of the movement had been determined, the degrees of each measurement were recorded. Three measurements were made for each movement in both hips (left and right), calculating the mean of the three measurements. Assessment of the passive hip ROM by inclinometer has been shown to have good reliability [25].

Statistical analysis

IBM SPSS v 25.0 (Armonk, NY; IBM Corp) was used in order to develop statistical analyses adjusting the α error at 0.05 and the *p*-value for statistically significant differences lower than 0.05 with a confidence interval (CI) of 95%. In order to evaluate variables' distribution, quantitative data were analyzed using the Shapiro-Wilk test. The mean ± standard deviation (SD) were used to illustrate parametric data (Shapiro-Wilk test with a p-value $\geq .05$) and completed with range (minimum–maximum), as well as median ± interquartile range (IR) for non-parametric data completed with range (minimum–maximum). Moreover, differences between male and female athletes in dominant and non-dominant hips were evaluated by Student's *t* test or the Mann-Whitney *U* test for parametric and non-parametric data, respectively. The effect size was determined using Cohen's *d* for quantitative data, categorizing results as small (*d* from 0.20 to 0.49), medium (*d* from 0.50 to 0.79) or large ($d > 0.8$) effect sizes [26].

Results

Homogeneity of the groups

Fifteen male ($n = 15$) and female ($n = 15$) athletes were recruited and evaluated bilaterally in both hips that were classified as the dominant ($n = 30$) or non-dominant side ($n = 30$). Statistically significant differences were determined for descriptive variables of age between males (22 ±6.50; 18–32) and females (20 ±2.75; 18–26). No significant differences were observed in the rest of the quantitative descriptive data (Table II).

Differences between genders on hip range of motion

Quantitative data of hip ROM are illustrated in Table III. Differences were observed in dominant and non-dominant legs between males and females in hip flexion, abduction and internal rotation (p < 0.05). No differences were observed in the rest of the hip ROM measures.

Differences between genders on isometric hip muscle strength

Quantitative data of isometric muscle strength showed statistically significant differences in dominant and non-dominant legs between males and females during all isolated measures (p < 0.05). No significant differences were observed in hip flexion/extension, adduction/abduction and external/internal rotation ratios (Table IV).

Differences between genders on gluteus medius muscle activation

Males demonstrated large gluteus medius thickness during contraction in the non-dominant leg (p = 0.002) and a larger gluteus medius contraction-rest difference in dominant (p = 0.01) and non-dominant legs (p < 0.001) compared with females. No statistically significant differences were observed in the rest of the measures (p > 0.05).

Discussion

The main findings of the present study were that asymptomatic male university athletes had less hip flexion and abduction and internal ro-

Table II. Quantitative data of range of motion of dominant and non-dominant leg for female and male athletes

Hip ROM	**Dominant leg (_n_ = 30)**	**Non-dominant leg (_n_ = 30)**	**Male vs. female dominant leg _P_-value (ES)**	**Male vs. female non-dominant leg _P_-value (ES)**
Flexion [°]:				
Male athletes	138.13 ±9.43 (121.95–158.14)*	149.37 ±9.03 (124–156.61)*	**0.023 (0.91)****	**0.006 (0.11)****
Female athletes	146.14 ±8.17 (131.15–160.51)*	150.32 ±8.87 (137.10–170.17)*		
Extension [°]:				
Male athletes	46.70 ±17.08 (24.47–68.23)†	45.97 ±11.17 (22.86–65.01)*	0.330‡	0.298**
Female athletes	42.02 ±18.33 (32.37–70.53)†	50.26 ±10.42 (32.81–66.79)*		
Abduction [°]:				
Male athletes	67.59 ±13.62 (55.19–106.79)†	70.98 ±17.84 (43.28–109.36)†	**0.007 (1.06)‡**	**0.010 (0.68)‡**
Female athletes	84.29 ±17.56 (61.99–151.60)†	84.33 ±21.17 (60.19–156.53)†		
Adduction [°]:				
Male athletes	27.57 ±16.84 (17.51–39.90)†	27.23 ±7.30 (15.80–40.21)*	0.220‡	0.068**
Female athletes	33.21 ±13.07 (19.44–41.99)†	32.78 ±8.64 (20.38–46.72)*		
IR [°]:				
Male athletes	58.92 ±11.37 (41.88–87.01)*	54.69 ±9.05 (39.46–71.67)*	**0.004 (1.23)****	**0.000 (1.84)****
Female athletes	70.88 ±7.81 (60.46–84.63)*	71.23 ±8.95 (61.13–91.34)*		
ER [°]:				
Male athletes	57.60 ±14.51 (46.17–94.65)*	64.81 ±14.51 (46.17–94.65)*	0.122‡	0.127**
Female athletes	71.25 ±14.38 (54.41–91.51)†	71.30 ±7.94 (59.46–84.07)*		

ER - external rotation, ES – effect size, IR – internal rotation, ROM – range of motion. *Mean ± standard deviation and range (min.–max.). **Student's t-test for independent samples was used according to parametric distributions. †Median ± interquartile range and range (min.–max.). ‡Mann-Whitney U test was applied according to non-parametric distributions. For all analyses, p < 0.05 (for a confidence interval of 95%) was considered as statistically significant (bold).

Table III. Quantitative data of isometric and strength ratios of dominant and non-dominant leg for female and male athletes

Peak force	Dominant side (*n* = 30)	Non-dominant (*n* = 30)	Male vs. female dominant leg *P*-value (ES)	Male vs. female non-dominant leg *P*-value (ES)
Flexion (Nw):				
Male athletes	341.46 ±63.42 (255.63–506.75)*	340.66 ±66.56 (237.82–502.39)*	**< 0.001 (2.02)****	**< 0.001 (1.75)****
Female athletes	228.77 ±46.77 (158.70–318.73)*	238.41 ±48.54 (178.34–345.39)*		
Extension (Nw):				
Male athletes	318.79 ±66.72 (197.27–448.40)*	312.64 ±57.89 (199.15–438.45)*	**< 0.001 (1.79)****	**< 0.001 (2.04)****
Female athletes	220.83 ±39.00 (149.76–306.75)*	219.11 ±28.81 (159.10–253.68)*		
Abduction (Nw):				
Male athletes	395.00 ±70.01 (288.49–529.39)*	395.06 ±88.52 (228.54–552.24)*	**< 0.001 (1.65)****	**< 0.001 (1.56)****
Female athletes	287.08 ±60.31 (191.86–409.73)*	284.53 ±46.63 (217.13–344.70)*		
Adduction (Nw):				
Male athletes	261.22 ±74.15 (133.20–353.52)*	258.81 ±63.97 (144.51–371.68)*	**0.001 (1.37)****	**< 0.001 (1.59)****
Female athletes	181.94 ±34.13 (141.96–243.67)*	176.78 ±34.95 (130.14–241.12)*		
ER (Nw):				
Male athletes	258.10 ±79.31 (156.01–430.86)*	245.27 ±71.46 (158.45–392.76)*	**0.008 (1.11)****	**0.002 (1.21)****
Female athletes	182.76 ±53.73 (114.12–296.45)*	174.52 ±41.80 (109.49–265.25)*		
IR (Nw):				
Male athletes	222.98 ±37.86 (150.56–290.25)*	198.88 ±84.73 (168.21–323.05)†	**< 0.001 (1.99)****	**< 0.001 (0.85)‡**
Female athletes	143.71 ±21.22 (118.09–177.54)*	144.98 ±30.37 (101.50–201.60)*		
Ratio F/E:				
Male athletes	1.03 ±0.24 (0.89–1.46)†	1.03 ±0.36 (0.78–1.87)†	0.525‡	0.735‡
Female athletes	1.05 ±0.22 (0.76–1.39)*	1.09 ±0.17 (0.82–1.36)*		
Ratio Add./Abd:				
Male athletes	0.66 ±0.16 (0.39–1.02)*	0.63 ±0.17 (0.41–1.18)†	0.553‡	0.799‡
Female athletes	0.62 ±0.12 (0.44–1.07)†	0.63 ±0.12 (0.45–0.86)*		
Ratio ER./IR:				
Male athletes	0.91 ±0.19 (0.66–1.21)*	0.94 ±0.19 (0.67–1.36)*	0.394**	0.185**
Female athletes	0.84 ±0.24 (0.53–1.18)*	0.85 ±0.16 (0.59–1.11)*		

*Abd. – abduction, Add. – adduction, E.R. – external rotation, Ext. – extension, Flex. – flexion, I.R. – internal rotation, Ratio Add./Abd. – strength ratio between adduction and abduction, Ratio E.R./I.R. – strength ratio between external rotation and internal rotation, Ratio Flex./Ext. – strength ratio between flexion and extension, Nw – newton. *Mean ± standard deviation and range (min.–max.). †Median ± interquartile range and range (min.–max.). **Student's t-test for independent samples was used according to parametric distributions. ‡Mann-Whitney U test was applied according to non-parametric distributions. For all analyses, p < 0.05 (for a confidence interval of 95%) was considered as statistically significant (bold).*

Table IV. Quantitative data of gluteus medius muscle activation of dominant and non-dominant leg for female and male athletes

USI G.M. measurements	Dominant side (*n* = 30)	Non-dominant (*n* = 30)	Male vs. female dominant leg *P*-value (ES)	Male vs. female non-dominant leg *P*-value (ES)
TH. rest [cm]:				
Male athletes	2.81 ±0.72 (1.83–4.78)*	2.61 ±1.49 (2.08–4.87)†	0.60**	0.66‡
Female athletes	2.67 ±0.73 (1.63–4.05)*	2.47 ±0.37 (2.08–3.82)†		
TH. cont. [cm]:				
Male athletes	3.96 ±0.72 (3.01–5.98)*	3.73 ±1.35 (3.1–5.91)†	0.07**	**0.002 ()‡**
Female athletes	3.42 ±0.80 (2.34–5.26)*	3.12 ±0.60 (0.55–4.61)†		
TH. dif. cont. – rest [cm]:				
Male athletes	1.14 ±0.35 (0.51–1.8)*	1.09 ±0.38 (0.64–1.58)†	**0.01 (0.97)****	**< 0.001 (1.33)‡**
Female athletes	0.74 ±0.47 (0.15–1.55)*	0.64 ±0.29 (-1.67–0.95)†		
Vel. cont. [cm/s]:				
Male athletes	1.06 ±0.99 (0.3–3.14)†	0.92 ±0.64 (0.5–3.18)†	0.13‡	0.07‡
Female athletes	0.63 ±1.0 (0.17–3.11)†	0.62 ±0.92 (0.2–3.37)†		

*TH. cont. – thickness at muscle contraction, TH. rest – thickness at muscle at rest, TH. dif. cont. – rest – thickness difference between muscle contraction and rest, Vel. cont. – velocity of muscle contraction. *Mean ± standard deviation and range (min.–max.) as well as Student's t-test for independent samples were used according to parametric distributions. **Student's t-test for independent samples was used according to parametric distributions (Shapiro-Wilk test showing a p-value ≥ 0.05). †Median ± interquartile range and range (min.–max.) as well as Mann-Whitney U test were applied according to non-parametric distributions. ‡Mann-Whitney U test was applied according to non-parametric distributions. For all analyses, p < 0.05 (for a confidence interval of 95%) was considered as statistically significant.*

tation ROM than females in both dominant and non-dominant legs. In addition, males had greater isometric hip muscle strength in all isolated movements in dominant and non-dominant legs and large gluteus medius thickness during contraction in the non-dominant legs and a larger gluteus medius contraction-rest difference in dominant and non-dominant legs when compared with females.

Hip ROM have been associated with bony morphology, ligamentous or muscle mechanical properties and may be related to gender-specific differences [8, 27–29]. According to previous studies [30, 31], our results showed that hip flexion and internal rotation were higher in females than males. These results can be explained through the difference of hip joint anatomical variability between genders. The male femoral neck and acetabulum have a smaller degree of anteversion than the female femoral neck or acetabulum [32]. Chadayammuri *et al.* [28] found that femoral torsion and acetabular anteversion were significantly associated with female sex ($p < 0.001$) and demonstrated that hip ROM can predict hip bony morphology (e.g. femoral torsion and central acetabular version). An increase of hip flexion and, specifically, internal rotation ROM have been associated with femoral head asphericity and acetabular coverage and femoral antetorsion in healthy or symptomatic population [33]. Also, we found that hip abduction ROM was higher in females than in males, as noted in previous research [34]. Hip abduction ROM was not associated with femoral torsion or acetabular version [28], but it has been correlated with acetabular inclination [35]. D'Lima *et al.* [35] observed that acetabular abduction of less than 45° decreased hip flexion or abduction ROM. However, regarding hip external rotation ROM, we were surprised that no significant differences were observed between genders. In contrast with our results, several studies have found differences in hip external rotation ROM in a variety of positions (e.g. prone or seated) [30, 31]. The differences in our findings may relate to lumbopelvic movements or technique during hip ROM measurements. Nevertheless, hip external rotation ROM may be an important factor to assess in future screening tests in pre-season and in-season periods. Finally, no differences were found in hip extension and adduction ROM between genders. Only one study reported differences in hip extension ROM [34], but to the best of our knowledge, no studies have investigated differences in hip adduction between males and females. Assessing hip ROM and taking into account these differences between genders may be useful for prevention or treatment strategies through joint mobilization or exercise therapy.

Another finding of our study was that males were significantly stronger during all isometric hip muscle strength measurements when compared with females in dominant and non-dominant legs. These results are not surprising; however, data of isometric strength ratios of the hip musculature did not show differences between genders. Our results show greater values of isolated isometric hip muscle strength when compared with previous research in the general population but hip strength ratios were similar [22, 23]. In sports such as soccer or rugby, one of the proposed risk factors for groin pain or hip pathology is hip muscle weakness during isometric, concentric and/or eccentric contractions [36, 37]. Therefore, data of this study can be helpful for clinicians, physical therapists or athletic trainers taking into account normative values of hip muscle isolated or ratio strength by gender to prevent or manage hip intra-articular pathologies [36] and hip muscles injuries (e.g. adductor muscle or rectus femoris) [38].

Finally, USI assessment of the gluteus medius demonstrated that males have a greater thickness difference between muscle contraction and rest compared to females. Dieterich *et al.* [39] observed lower values of gluteus medius thickness measurements compared with our results and did not separate by gender or dominant side. Other studies have investigated gluteus medius and minimus muscle thickness summed for total thickness, making comparison difficult, because we did not measure gluteus minimus thickness at rest or contraction [9, 40]. Although no significant differences were observed in thickness at rest, males had slightly greater values compared with women. USI has been utilized to assess the morphology of the gluteus medius muscle, and especially M-mode ultrasound has been used to assess the onset of gluteus medius muscle activity during different hip movements in the healthy population [19] and people with chronic hip pain [41]. We found no significant differences between asymptomatic males and females in the onset of gluteus medius activity during side-lying abduction. But in people with anterior hip pain, changes in muscle activation or different movement patterns have been observed, e.g. early activation of the gluteus minimus and superficial gluteus medius can be produced by a protective strategy of these individuals to reduce their pain during certain activities [41]. The present study may propose a new approach to analyze and quantify the onset of gluteus medius activity in asymptomatic and athletic populations. Regarding other lower limb areas and the study of the muscle activity on the lower limb, Romero-Morales *et al.* found excellent intra- and inter-examiner reliability of M-mode ultrasonography of the soleus muscle in healthy individuals [42]. Other properties such as muscle texture have also been described as a valid and reliable tool for assessment of muscle tissue [43].

The present study has several limitations that should be acknowledged. First, the sample included comprised asymptomatic participants. Second, the small sample size means the results need to be taken with caution. Third, the authors only analyzed the gluteus medius muscle during hip side-lying abduction. Finally, a variety of sports have been represented in this study but sports-specific differences may not have been analyzed. Thus, further studies may investigate gender differences in hip ROM or muscle strength in an symptomatic population with hip-related pain. Furthermore, future research may include M-mode USI of other muscles around the hip joint and explore the influence on hip joint pathology. Finally, other ultrasonography modalities, such elastography, should be considered in future studies in order to assess the stiffness of the soft tissues which are involved in hip disorders.

We found that ultrasonography, both B-mode and M-mode, can be considered a valid tool in healthy individuals for muscle activity and ROM assessment. Gender differences should be taken into consideration for these variables for the diagnosis and management of hip musculoskeletal conditions.

In conclusion, our data suggest that asymptomatic female athletes have greater hip flexion, abduction and internal rotation ROM, less isometric hip muscle strength and different gluteus medius thickness and onset activation compared with asymptomatic male athletes. Prevention strategies may take into account gender differences and further studies are needed to determine gender differences in hip ROM, hip muscle strength and gluteus medius M-mode ultrasound in symptomatic populations.

Conflict of interest

The authors declare no conflict of interest.

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