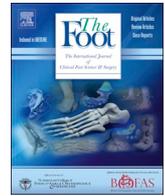




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Original Article

Ultrasound evaluation of the quadriceps muscles in pronated foot posture

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ABSTRACT

Objective: The main goal of this study was to investigate the size of all portions of the quadriceps muscles in individuals with pronated foot posture compared to normal foot posture using ultrasound imaging.

Design: Twenty nine females with pronated foot posture and 29 age-, body weight-, body height-matched females with normal foot posture were recruited from university communities. The muscle thicknesses of the rectus femoris (RF), vastus medialis (VM), vastus medialis oblique (VMO), vastus lateralis (VL) and vastus intermedius (VI) were measured using ultrasound imaging.

Results: The thicknesses of the RF and VMO were significantly smaller in individuals with pronated foot posture compared to normal foot posture ($p < 0.05$). No significant differences were observed in the VM, VL, and VI muscle thicknesses in both groups.

Conclusion: Based on the results of the present study, it seems that besides the foot and lower leg muscles, an integrated assessment of proximal knee muscles, especially quadriceps, is required in individuals with pronated foot posture.

1. Introduction

Foot pronation, as a triplanar complex motion, is composed of dorsiflexion, abduction and eversion movements of the ankle and subtalar joints complex [1]. Despite the fact that attention was focused on the subtalar joint pronation in the literature, recent articles suggested not to consider foot pronation as a single joint motion; therefore, a recently proposed definition of weight bearing foot pronation has defined pronation as a “motion of the foot articulation that allows the foot to become more prone to the support surface thereby increasing the ground contact surface area of the foot” [2].

From the biomechanical perspective, variations from normal foot posture may have an impact on the lower extremity functional alignment [3,4]. These variations are proposed as an intrinsic risk factor for developing lower extremity injuries [5].

Excessive pronated foot posture has been suggested as an intrinsic risk factor for patellofemoral pain (PFP) [6,7]. The results obtained by Barton et al., revealed that individuals with PFP had a more pronated

foot posture than asymptomatic controls [8].

Furthermore, several studies indicated the association of abnormal foot posture with knee injuries especially medial tibiofemoral osteoarthritis (OA) [9,10,11,12]. Gross et al. showed an association between the planus (low-arched foot) foot morphology and medial tibiofemoral cartilage damage [10]. In addition, the results of Levinger et al. showed that patients with medial tibiofemoral knee OA possessed a more pronated foot posture when compared to controls [9].

According to the “ground-up” approach, any biomechanical malalignment in distal structures may affect the proximal ones [13]. In other words, due to the coupled motion of the knee and ankle joint complex within a closed kinematic chain, excessive pronation in the ankle and foot complex may not only affect the foot complex but also may have an effect on the alignment of the knee joint.

For example, the subtalar joint acts as a functional unit to connect the foot and shank [14]. Function of the subtalar joint during weight bearing activities is critical to dampen the rotational forces imposed by the body weight [15]. The talus fits tightly into the ankle joint mortise;

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therefore, the subtalar joint motion may affect the tibial rotation during gait cycle. Transverse motion of the talus during subtalar joint pronation is coupled with internal rotation of the tibia while the tibia is externally rotated during supination [6].

Taken together, it seems that an abnormal pronated foot posture and the knee joint malalignment are linked together especially during weight bearing activities [10].

Malalignment of the knee joint, in turn, may cause changes in the length-tension relationship of the surrounding knee musculature. These length-tension changes may affect the receptors threshold of capsuloligamentous and musculotendinous structures of the knee, leading in conveying abnormal afferent information [16]. It has been hypothesized that the alteration in the afferent information to the central nervous system, in turn, had an effect on the efferent information to the muscles resulting in inhibition of muscle kinetic response [17,18] and consequently muscle atrophy [19].

Despite several studies that have investigated the association between foot posture and knee joint injuries (Gross et al.; [9,11,12] limited number of studies have assessed the quadriceps muscle size in knee [20,21,22] injuries.

The muscle thickness, as a parameter of muscle mass, is associated with muscle strength and is defined as a distance between superficial and deep fascia of a muscle using musculoskeletal ultrasound imaging (USI) [23,24].

The real-time USI is a safe, valid, non-invasive and easily accessible method that has been used to measure the muscle thickness in different muscle groups [25,26,27,21,22]. Several assessment tests for muscle strength such as manual muscle testing are not able to differentiate strength changes of each part of the quadriceps muscle. Using ultrasound imaging, the thicknesses of individual parts of the quadriceps muscles can be easily measured and differentiated in order to find selective changes (i.e. atrophy) of each part of the muscle in a variety of settings. Furthermore, ultrasound size measurement of rectus femoris (RF) muscle have been investigated as a sensitive indicator of muscle wasting, especially during immobilization [28,29,30].

Regarding aforementioned neural mechanism and “ground up” biomechanical approach, it seems that a study is needed to assess the thickness of the quadriceps muscle in individuals with pronated foot posture. To the best of our knowledge, no study has been conducted to investigate the size of all portions of the quadriceps muscles in individuals with pronated foot posture compared to normal foot posture. Therefore, the aim of this study was to assess the thickness of vastus medialis (VM), vastus lateralis (VL), RF, vastus medialis oblique (VMO) and vastus intermedius (VI) muscles in individuals with pronated foot posture in comparison with the normal foot posture using real-time ultrasound imaging.

1.1. Methods

1.1.1. Participants

Out of 70 healthy females who met the inclusion criteria, 29 females with pronated foot posture (foot posture index (FPI) score more than 5) and 29 age-, height-, physical activity and body weight-matched healthy females with normal foot posture (FPI score equal or less than 5) as controls were purposefully recruited from university communities to participate in this case-control study. All participants reported their physical activity level equal to 3 out of 10 on the Persian version of the Tegner activity level [31]. Sample size was calculated a priori to determine that a sample of 58 participants was needed while the power setting at 90% with an alpha level of 0.05. Being a reliable and valid tool, the six-item foot posture index (FPI) was used to classify pronated and normal foot postures [32,33]. None of the participants had a recent trauma, lower limb fractures, surgical history or pain in the lumbar region and lower limb for at least 3 months prior to participation in this study. In addition, participants with negative scores of FPI (or supinated

feet) were excluded from this study. Data was collected between December 2015 and December 2016 at the biomechanics laboratory of the university. This study was approved by the ethics committee of the Tehran University of Medical Sciences and all participants signed a written consent form prior to the study.

1.2. Procedure

Regarding the assumption of independence for data [34] only one side of each participant was considered for ultrasound scanning. FPI was used to classify both feet of each participant. If both feet were pronated, the foot with highest score (pronated: 6–12) was chosen to be included in this study. If both feet were classified as normal, the foot with closer values to zero (normal: 0–5) was selected for the study. However, if the FPI scores of both feet were the same, the dominant side was chosen to scan. FPI was scored in all participants by an experienced physiotherapist who was not involved in the ultrasound scanning.

1.2.1. Ultrasound imaging

The participants were asked to lie supine with knees in extension near the natural resting position of 10–20° [24], and a bolster was placed between both feet and surrounded by a strap to prevent hip external rotation. The participants were asked to relax their quadriceps muscles during ultrasound examination. An anthropometric tape measure was used to determine the precise location of the measurement for each individual portion of the quadriceps muscles. The distance between superior pole of the patella (as the reference point) and ASIS was measured and 20% and 50% of this distance as well as 2 cm above the patella were marked with a cosmetic pencil. The thicknesses of the RF and VI were measured at 50% of the identified distance between superior pole of the patella and ASIS. Considering the medial location of the VM muscle, the thickness was measured at 12.5% of the thigh circumference in the medial direction from 20% of the identified distance; accounting for medial location of the VMO, the thickness measurement was taken at 12.5% of thigh circumference in the medial direction from 2 cm above the patella; considering the lateral location of the VL muscle, 10% of thigh circumference in the lateral direction from 10% of the identified distance was determined to measure the muscle thickness [21,22]. The specified points for each muscle were marked with a cosmetic pencil prior to ultrasound measurements in order to identify precise location during ultrasound scanning.

Two-dimensional B-mode ultrasound imaging (HS-2600 by Honda Electronics Co, Japan) with a 50 mm, 5–10 MHz linear array transducer (HLS-475M by Honda Electronics Co, Japan) was used to obtain images from RF, VI, VM, VMO and VL. To achieve acoustic coupling and to minimize muscle compression, an adequate amount of transmission gel was used. All images were captured separately with the linear probe oriented in the transverse plane perpendicular to the skin and were saved in a de-identified format. All images were obtained and measured by a trained physiotherapist in the use of rehabilitative ultrasound imaging who was blind to the group allocations. Before the initiation of the data collection, an extensive pilot testing was carried out in order to find out the most suitable parameters (i.e. gain, depth, acoustic power and range) of the ultrasound imaging device in which the muscle boundaries and the femur were visible.

The ultrasound images were saved in JPEG format for subsequent analysis using Image J software (National Institute for Health, Bethesda, MD, USA). Three images were captured for each muscle with the probe removed between each scan.

Muscle thicknesses for the RF and VL were defined and measured as the distance between the superficial and the deep fascia of the muscles along with the most superficial border of the femur [21,22]. To measure VM thickness, the widest distance between the superficial and the deep fascia of the muscle was selected. Thicknesses of the VI and VMO muscles were measured as the distance between the superficial border

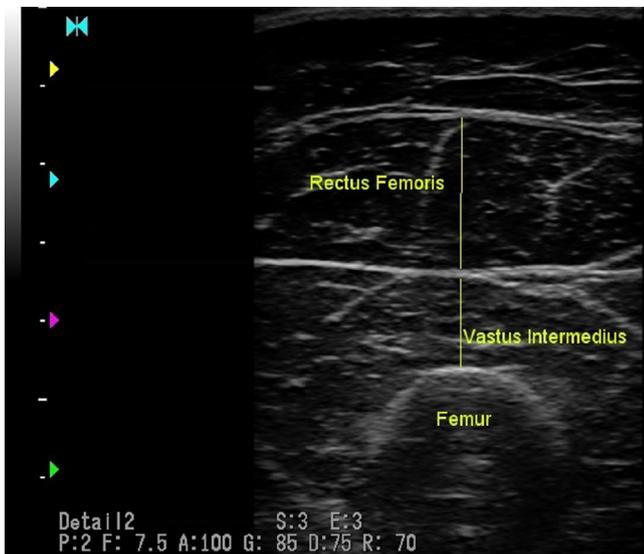


Fig. 1. Ultrasound measurement of the thickness of the rectus femoris and vastus intermedius muscles. The vertical lines represent the thickness of the rectus femoris and vastus intermedius.

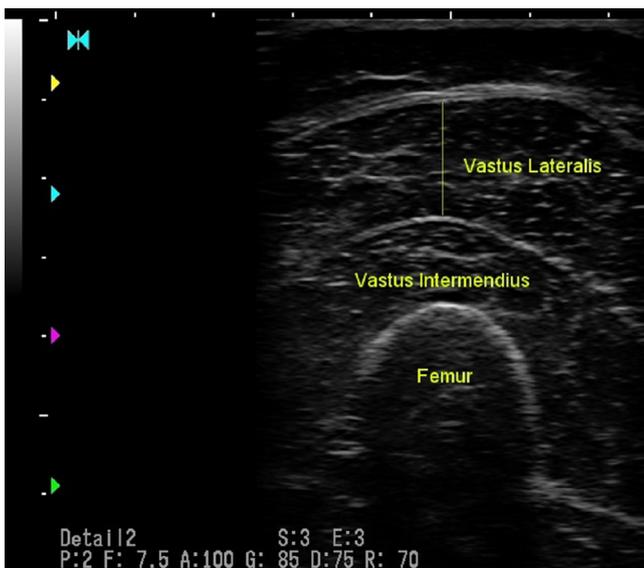


Fig. 2. Ultrasound measurement of the thickness of the vastus lateralis muscle. The vertical line represents vastus lateralis muscle thickness.

of the muscles and the most superficial border of the femur [21,22]. The average measurement from 3 images, for each muscle, was used for further analysis (Figs. 1–3).

To examine the intrarater reliability of ultrasound measures for the size of all portions of the quadriceps muscles, the measures taken from 3 separate images compared, using the intraclass correlation coefficient, in 20 participants with normal foot posture. The standard error of measurement (SEM) and minimal detectable change (MDC) were also calculated.

1.2.2. Statistical analysis

Statistical analyses were carried out using SPSS 22.0 (SPSS Inc. Chicago, IL). The Shapiro-Wilk and Kolmogorov–Smirnov tests were used to check normal distribution of the data. Individuals with pronated foot posture were matched with control group based on their age, height and body weight using MedCalc software version 18. Paired t-test was used to assess the significant differences in the thicknesses of

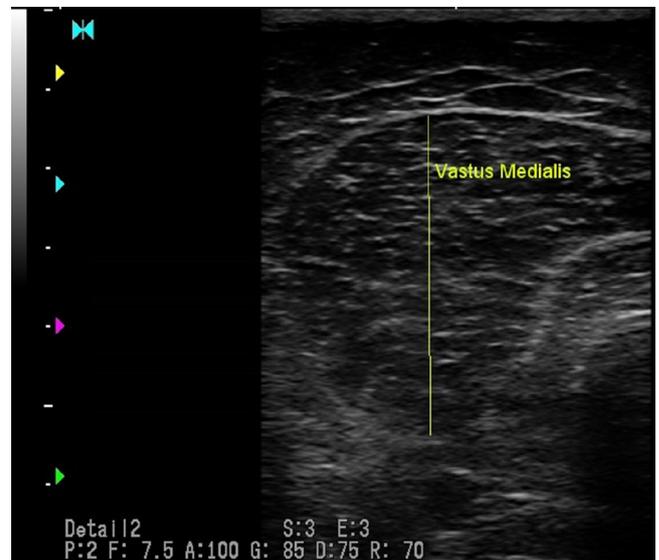


Fig. 3. Ultrasound measurement of the thickness of the vastus medialis muscle. The vertical line represents vastus medialis muscle thickness.

the VL, VM, RF, VI and VMO between individuals with pronated and normal foot postures. According to Cohen, effect size estimates were calculated for observed differences [35]. The level of significance was considered at $p < 0.05$. In addition, the Bonferroni correction was used to control the family-wise error rate for multiple comparisons.

1.3. Results

Number of 29 females with flexible pronated foot posture (median FPI: 9, range: 7–10, age: 24.33 ± 4.95 years, height: 1.64 ± 0.04 m, mass: 61.06 ± 8.38 kg, BMI: 22.61 ± 2.98 kg/m²) and 29 females with normal foot posture (median FPI: 3, range: 2–4, age: 24.24 ± 4.02 , height: 1.61 ± 0.07 m, mass: 60.62 ± 8.47 kg, BMI: 23.23 ± 2.6 kg/m²) participated in this study. No statistically differences were found between the groups in basic demographic data and also physical activity level ($p > 0.05$).

The intrarater reliability of ultrasound measures for the size of all portions of the quadriceps muscles was excellent, and the ICC values ranged from 0.987 to 0.995 (Table 1). The ICC, SEM and MDC values for the thicknesses of the VMO, VL, RF, VI and VM are presented in Table 1.

The mean thicknesses of the VL, RF, VM, VMO and VI as well as comparison of both groups' thicknesses are presented in Fig. 4. The thickness of RF was significantly smaller in individuals with pronated foot posture compared to normal foot posture ($p = 0.005$) and the effect size was moderate (effect size = 0.56). In addition, the VMO thickness was significantly smaller in pronated foot posture group compared to normal feet group ($p = 0.042$); however, the effect size

Table 1

Intratester reliability of the VMO, VL, RF, VI and VM thicknesses using ultrasound imaging (n = 20).

Muscle thickness	ICC	Confidence interval	p-value	SEM	MDC
VMO	0.990	0.979–0.996	< 0.001	0.28	0.78
VL	0.994	0.986–0.997	< 0.001	0.25	0.69
RF	0.995	0.989–0.998	< 0.001	0.17	0.47
VI	0.987	0.973–0.995	< 0.001	0.38	1.05
VM	0.990	0.979–0.996	< 0.001	0.51	1.41

VMO: Vastus medialis oblique; VL: Vastus lateralis; RF: Rectus femoris; VI: vastus intermedius; VM: vastus medialis; SEM: Standard error pf measurement; MDC: Minimal detectable change.

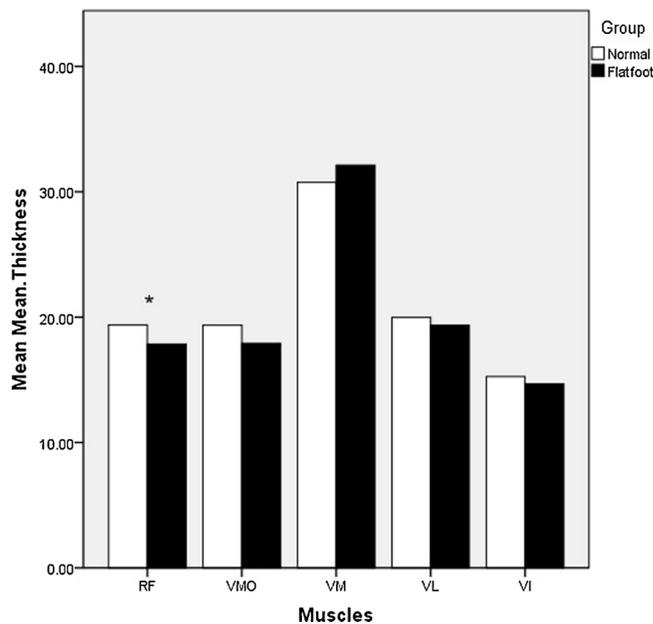


Fig. 4. The thickness of the quadriceps muscles (mm) in individuals with pronated foot posture (n = 29) and normal foot posture (n = 29). Note: * denotes statistical significance (P < 0.01).

was small (effect size = 0.4). No significant differences were found between both groups for the thicknesses of the VL, VM and VI muscles (Fig. 4). After correction for multiple comparisons by the Bonferroni method, only the RF thickness was significantly different between pronated and normal foot posture groups and the difference in VMO thickness was not statistically significant between both groups (Table 2).

2. Discussion

The main objective of this study was to compare the thickness of each portion of the quadriceps muscles in individuals with pronated and normal foot postures. The results of this study showed that the thickness of the RF was significantly smaller in individuals with pronated foot posture compared to normal foot posture group. The muscle thicknesses of VL, VI, VM and VMO were not different in individuals with pronated foot posture compared to normal foot posture group.

To the best of our knowledge, this is the first study to assess the size of the quadriceps muscles (RF, VL, VM, VI and VMO) in individuals with pronated foot posture. Most of the studies assess the sonographic characteristics of the quadriceps as a whole or individual part of it in adults with patellofemoral pain syndrome (PFPS) [36,37,20,21,22]. Measuring the thicknesses of the RF, VI, VL, VM and VMO in patients with unilateral PFP, Giles et al. found that all portions of the quadriceps muscles atrophied in the affected limb of individuals with unilateral PFP compared to the contralateral asymptomatic limb. However, no differences were found in the size of the quadriceps muscles between PFP patients and healthy control group [21,22].

Table 2

Comparison of the size of the quadriceps muscles (mm) between individuals with pronated foot posture (n = 29) and normal foot posture (n = 29).

	Pronated foot Mean ± SD	Normal foot Mean ± SD	Mean difference (95% CI)	p-value
RF	17.85 ± 1.9 (15.09–23.11)	19.38 ± 2.55 (14.51–23.24)	1.53 (0.49 to 2.58)	0.005
VL	19.35 ± 3.11 (14.67–27.5)	20 ± 3.48 (13.17–28.63)	0.65 (–0.9 to 2.2)	0.398
VM	32.12 ± 4.9 (23.88–42.96)	30.75 ± 4.75 (20.48–41.67)	1.38 (–3.5 to 0.75)	0.196
VMO	17.09 ± 3.05 (12.86–23.12)	19.35 ± 2.91 (15.31–24.95)	1.45 (0.06 to 2.85)	0.042
VI	14.68 ± 3.89 (7.38–25.04)	15.26 ± 3.6 (9.07–22.44)	0.58 (–1.36 to 2.52)	0.546

There are some differences in anatomical features of the RF compared to the vastii (i.e. VL, VM and VI) muscles. The RF is a biarticular and multipennate muscle while the vastii muscles are monoarticular and unipennate [23]. Passing over hip and knee joints, the RF muscle is more susceptible to biomechanical variations of the lower extremity other than the vastii muscles as it could be affected by the augmentation of the biomechanical malalignments at the both pelvis and the knee joints. Originating from AIIIS (anterior inferior iliac spine) and ilium above the acetabulum, it seems that the RF muscle may be affected by the pelvic position. Being monoarticular muscles, the vastii muscles may only be influenced by the biomechanical malalignments at the knee joint; however, it seems that these alterations may not be sufficient to affect the size of these muscles.

Furthermore, the location of the acquisition of ultrasound imaging for measuring each muscle thickness is an important issue that should be taken into consideration. The results of Blazeovich et al., who measured the muscle thicknesses at multiple regions of the four quadriceps muscles in recreationally active adults, showed that the thicknesses of the RF and VL decreased proximo-distally along the thigh, while the thickness of the VM increased. The thickness of the VI also varies in the anterior and lateral portions of the muscle [38]. In the present study, similar to Giles et al. study, the location of ultrasound imaging was selected based on the results of Kawakami et al. work, which showed maximum cross-sectional area of each portion of the quadriceps muscle [39,21,22]. However, the thicknesses of the vastii muscles from selected locations were not different between both groups in the present study. There is a possibility that potential differences may be presented in other locations of each portions of the muscles as the thickness of each muscle varied along the thigh according to Blazeovich et al. [38]. Further research is needed to verify this assumption.

The results of this study showed that the RF thickness was smaller in pronated foot posture adults compared to normal foot posture group; however, the muscle thicknesses of other portions of quadriceps were not different between both groups. It seems that the chronicity of the lower limb malalignment was not long enough to induce gross changes in the size of the muscle as a whole since all participants of this study were young adults.

2.1. Study limitation

The present study had some limitations that should be considered. Individuals with pronated foot posture were not matched based on their dominant limb with the control group and were only matched based on the age, height and body-weight. In other words, the foot with higher FPI score of pronated foot posture individuals and lower FPI score in normal foot posture group were determined for further assessment whether the corresponding limb was dominant or not. Individual matching based on the dominant limb is recommended for future studies.

Furthermore, classification of the pronated foot posture and the control groups in this study was only based on the 6-item FPI. According to Cornwall et al., despite the high levels of intrarater reliability of the FPI, the interrater reliability was only moderate [33]. They suggested that FPI should be used with extreme caution as a research tool [33]. Therefore, using only the FPI as a classification tool for foot postures may need some consideration.

In addition, this study was conducted only on young, healthy females with pronated and normal foot postures; therefore, generalizability of the results to males or other age ranges is not logical.

3. Conclusion

Smaller muscle thickness of the RF was found in individuals with pronated foot posture compared to normal foot posture group. Since a close biomechanical relationship existed in the lower extremity structures, it seems that besides the foot and lower leg muscles, an integrated assessment of proximal knee muscles, especially quadriceps, is required in individuals with pronated foot posture. The quadriceps strengthening exercises seems to be beneficial in individuals with pronated foot posture in order to prevent from possible knee joint problems in future. Further research is recommended to examine the size of the quadriceps muscle in a large cohort of individuals with symptomatic pronated foot posture to draw a certain conclusion.

Conflict of interest

The authors have not any conflict of interest.

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