*Exercise Physiology*

# Muscle architecture of the vastus lateralis and rectus femoris in the production of knee extensor torque in physically inactive women

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**Abstract - Aim:** This study aimed to verify the data reliability of muscle architecture (MA) variables, and the relationship between MA and the isometric peak torque (PT) of the monoarticular and biarticular knee extensor (KE) muscle in physically inactive women. **Methods:** Ten physically inactive women (24.0 ± 1.64 years; 162.9 ± 5.34 cm; 63.5 ± 11.90 kg) participated in the study. An ultrasound device assessed the MA variables (muscle thickness, fascicle length, and pennation angle) of the Vastus Lateralis (VL) and Rectus Femoris (RF), and an isokinetic dynamometer assessed the PT. Pearson correlation evaluated the relationship between PT and MA variables, with a significance level of 5%. Additionally, the intraclass correlation coefficient, coefficient of variation, and standard error of measurement. **Results:** Excellent reliability between images was observed, and no significant relationships were observed between the PT and MA variables of the VL and RF. **Conclusion:** Isolated variables of the MA of a monoarticular or a biarticular muscle do not influence the production of the isometric PT of the KE.

**Keywords:** morphology, muscle, quadriceps, women, physical inactivity.

## Introduction

Muscle strength, which can be defined as the ability to exert large forces under isometric or slow-velocity conditions, is dependent on anatomical and neuromuscular characteristics[1]. The study of anatomical characteristics through muscle architecture can contribute to understanding the morphological organization of skeletal muscle related to aging, clinical conditions, and the application of physical training[2,3]. This is important because muscle architecture variables such as muscle thickness, pennation angle, and fascicle length are correlated with muscle strength and power[4].

In this context, for example, some studies have presented muscle architecture variables as potential predictors of knee extensor muscle torque[5−8]. It is known that muscle strength of this muscle group is important for the successful completion of many activities of daily living (e.g., stair climbing, sit-to-stand transitions) and athletic tasks (e.g. sprint, jump performance, dynamic balance)[7,9]. Therefore, muscle architecture could support clinicians and exercise professionals in inferring the individual's ability to produce force in situations where there is no immediate possibility of performing a muscle strength test.

However, in the case of knee extensors, there is a peculiarity. The vastus medialis, vastus intermedius, and vastus lateralis (VL) muscles are considered monoarticular, while the rectus femoris (RF) muscle is considered biarticular [10]. In the literature, it has been observed that monoarticular and biarticular muscles may have different roles in changing the joint angle and, consequently, in the control and production of muscle torque[11,12]. Thus, it seems to be important to consider the morphological characteristics of the mono or biarticular knee extensors separately[13] to avoid possible mistaken relationships and conclusions.

Of the quadriceps muscles, the RF and VL are the most studied in the literature and represent more than half of the total volume of this muscle group[14]. In addition, the VL is studied for its importance in activities of daily living[15], while the biarticular nature of the RF has intrigued researchers regarding its participation and regional morphological adaptation[12,16].

In this context, could the monoarticular and biarticular nature of the VL and RF muscles, respectively, differently influence the production of isometric knee extension torque? Although this question was raised with children and adolescents with cerebral palsy[9], to our knowledge, the literature is scarce on the topic, especially when considering women who do not practice physical activity.

It is known that to assess muscle strength, these women should be exposed to tests that are sometimes uncomfortable and intense[17]. In some situations, such as injuries, these assessments may not be recommended[5]. In this sense, the strength of the knee extensors inferred through muscle architecture variables may be a viable alternative.

Thus, this study aimed to verify the data reliability of muscle architecture variables, and the relationship between the isometric peak torque of the monoarticular knee extensor (VL) and biarticular knee extensor (RF) with muscle thickness (MT), fascicle length (FL), and pennation angle (PA), in physically inactive women. As it is only influenced by the knee joint, we hypothesized that the variables of the VL muscle architecture would be related to extensor torque.

## Methods

### *Study design*

Participants who met the inclusion criteria and agreed to participate in this reliability and correlational study were invited to attend the Biomechanics Laboratory of the Universidade Federal de Santa Catarina (UFSC). The evaluations performed were anthropometry, ultrasound of the VL and RF, and isometric knee extensor torque, in this sequence, in a single visit lasting 60 min.

### *Participants*

The following inclusion criteria were female; between 18 and 30 years of age; not performing physical activity in the previous 12 months; not having lower limb injuries. A questionnaire was not applied to classify the level of physical activity of the participants. However, all participants reported being in decisive periods of academic life. For this reason, their reported performing household activities once a week and not practicing physical activity for sport or leisure. Additionally, all participants lived close to the university and reported walking as the main form of transportation.

None of the participants were evaluated during the menstrual period. The control of the menstrual period was performed through anamnesis. All participants reported not being in the menstrual phase and reported using oral contraceptives for more than one year with 4 or 7 days of menstrual pause.

All participants signed an informed consent form, and all procedures were performed in accordance with the Declaration of Helsinki. The protocol of this study was approved by the Ethics Committee of the UFSC (protocol number: 86710718.0.0000.0121).

First, the locations for the acquisition of images with the ultrasound (LOGIQ S7 Expert, General Electric, GE Healthcare, USA) device were identified. The VL and RF were evaluated at 50% of the distance between the anterosuperior iliac spine and the superior edge of the patella, according to the procedures used in the study by Lopez, Pinto, and Pinto[18]. The participants then rested in the supine position on a stretcher for 5 min[18,19], with the lower limbs extended and relaxed.

Muscle architecture was assessed by a B-mode ultrasound device with a linear array probe (5.5 cm e 9.0 MHz - LOGIQ S7 Expert, General Electric, GE Healthcare, USA) placed on the dominant leg of the participants, according to the procedures presented by Melick et al[20]. All participants had the right leg as dominant. For the acquisition procedure, the transducer was positioned longitudinally to the femur, oriented parallel to the muscle fascicles and perpendicular to the skin [21]. A water-soluble gel was applied to the probe's scanning head to achieve acoustic coupling, and extra care was taken to avoid deformation of the muscle architecture.

An examiner with 700 h of imaging experience captured two images for the VL and RF. All images were analyzed with public domain software ImageJ (V.1.52; National Institute of Health, USA). The images were analyzed twice by an evaluator with 312 h of experience in the software ImageJ. The average between the analyzes of the two images was used statistical analysis. Muscle thickness (MT) was determined as the distance between the deepest and most superficial muscular aponeurosis. The fascicle length (FL) was defined as the length of the fascicular path between the superficial and deep aponeurosis. The pennation angle (PA) was defined as the angle between the deep aponeurosis and the fasciculus[22].

### *Maximal voluntary isometric contraction*

Isometric knee extensor torque was assessed through Maximal voluntary isometric contraction using an isokinetic dynamometer (Biodex Medical System 4, Shirley, New York, USA) following the protocol described by Orssatto [23]. Participants sat on the dynamometer with their hips flexed at 85° and performed a dynamic warm-up of two sets, with 10 repetitions and a 60-s interval between sets. The knee joint was then positioned at 70° of flexion (0° full knee extension) and the participants performed 5 s of submaximal isometric contractions as familiarization. A 120-s rest period was provided between these familiarization contractions. The warm-up was performed with 10 repetitions of concentric knee extension-flexion contractions at an angular velocity of 120°/s. Next, three contractions were performed, for 5 s each, with 120 s of rest between them, and performed "as fast and hard as possible"[24,25]. The torque curve was obtained using the MiotecSuite software (model 1.0.1108, MioTec Biomedical, Porto Alegre, RS, Brazil) with a sampling frequency of

**Table 1** - Descriptive and reliability statistics for muscle architecture data (n = 10).

| **Rectus femoris** | **Image 1** | **Image 2** | **Average** | **ICC** | **CV** | **SEM** |
|---|---|---|---|---|---|---|
| | **Mean ± SD** | **Mean ± SD** | **Mean ± SD** | **(95% CI)** | | |
| Muscle thickness (cm) | 1.5 ± 2.5 | 1.5 ± 2.5 | 1.87 ± 0.2 | 0.98 (0.91-0.99) | 14% | 0.04 |
| Fascicle length (cm) | 11.7 ± 1.12 | 11.5 ± 1 | 11.6 ± 1.1 | 0.95 (0.81-0.98) | 9% | 0.25 |
| Pennation angle (°) | 7 ± 12.4 | 8 ± 12.2 | 9.8 ± 1.53 | 0.98 (0.91-0.99) | 15% | 0.22 |
| **Vastus lateralis** | **Image 1** | **Image 2** | **Average** | **ICC** | **CV** | **SEM** |
| | **Mean ± SD** | **Mean ± SD** | **Mean ± SD** | **(95% CI)** | | |
| Muscle thickness (cm) | 2.21 ± 0.34 | 2.3 ± 0.35 | 2.24 ± 0.34 | 0.98 (0.93-0.99) | 15% | 0.05 |
| Fascicle length (cm) | 7.4 ± 1.51 | 7.5 ± 1.6 | 7.44 ± 1.52 | 0.99 (0.95-0.99) | 20% | 0.15 |
| Pennation angle (°) | 17.22 ± 2.7 | 17.3 ± 2.8 | 17.24 ± 2.6 | 0.98 (0.94-0.99) | 15% | 0.38 |

SD = standard deviation; ICC = intraclass correlation coefficient; 95% CI = 95% Confidence Interval; CV = Coefficient of Variation; SEM = Standard Error of Measurement.

2000 Hz. Peak torque (PT) normalized by body mass was used for statistical analysis.

*Statistical analysis*

Data are presented as mean ± standard deviation (SD). Data normality was assessed using the Shapiro-Wilk test. The intraclass correlation coefficient (ICC) was used to assess test-retest reliability between images of muscle architecture. Pearson correlation was used to assess the relationships between PT and EM, CF, and AP. The ICC value was interpreted as follows: < 0.5, poor; 0.5-0.75, moderate; 0.75-0.9, good; and > 0.9, excellent[26]. Additionally, the coefficient of variation (CV)[27] and standard error of measurement (SEM) were calculated [28].

The magnitude of the correlations was determined using the scale by Hopkins[29]: 0.0-0.1, trivial; 0.1-0.3, small; 0.31-0.5, moderate; 0.51-0.7, large;0.71-0.9, very large; 0.9-1, nearly perfect. The significance level was set at $p \leq 0.05$. Statistical analyses were performed using SPSS version 21 (Chicago, Illinois, USA). This study was part of another research involving other primary outcomes, therefore, the statistical power of the correlations of this study was calculated following the guidelines presented by Kang[30]. The sampling power for all variables was 'small', except for the muscle thickness of the rectus femoris, which presented 'medium' sampling power.

## Results

Ten young university women participated in the research (24.0 ± 1.64 years; 162.9 ± 5.34 cm; 63.5 ± 11.90 kg; 23.82 ± 3.36 kg/m$^2$), who had not engaged in any type of physical activity in the 12 months prior to data collection. Excellent reliability between images was observed for both muscles, with ICC ranging from 0.95 - 0.99 (Table 1). All muscle architecture variables evaluated were normally distributed ($p > 0.05$), as well as PT ($p = 0.087$). No significant relationships were observed between the PT and the variables of the muscle architecture of the VL and RF (Table 2). All relationships had a 'low' effect size, except for the relationship between PT and MT of the RF, which had a 'medium' effect size.

## Discussion

This study aimed to verify the data reliability of muscle architecture variables, and the relationship between the isometric PT of the monoarticular knee extensor (VL) and biarticular knee extensor (RF) with MT, FL, and PA, in physically inactive women. Our premise was that the architecture of monoarticular and biarticular muscles could contribute differently to the production of muscle torque. As a result, 'excellent' reliability was observed between the measures of the evaluated images, and no relationship was observed between the knee extensor PT and any VL and RF muscle architecture variables.

Reliability refers to the reproducibility of values of a test, assay, or another measurement in repeated trials on the same individuals[31]. Hence, it yields information regarding the overall consistency of a measure, the distinguishability of individual measurements, as well as the signal-to-noise ratio in a set of data[32]. In our study, we observed a good overall consistency of measurement through 'excellent' reliability.

The 'excellent' reliability of the data is reinforced by the SEM values, this is because reliability and SEM have an inverse relationship. If the reliability is close to perfect, the SEM will be small, indicating the examinee's observed score is very similar to the true score[33]. Additionally, the

**Table 2** - Relationship between normalized torque and muscle architecture.

| | | **Rectus femoris** | | | **Vastus lateralis** | | |
|---|---|---|---|---|---|---|---|
| | | **MT** | **FL** | **PA** | **MT** | **FL** | **PA** |
| Peak Torque | r | 0.55 | 0.14 | 0.31 | -0.09 | -0.13 | 0.19 |
| | p-value | 0.09 | 0.69 | 0.39 | 0.79 | 0.71 | 0.58 |

MT = muscle thickness; FL = fascicle length; PA = pennation angle.

estimated variation between measurements was 9-20%, that is, a low to medium variation, which confirms an acceptable variability and, therefore, an acceptable consistency between the measurements[27,34].

Regarding the variables of muscle architecture, their characterization can contribute to understanding the participation of morphological aspects in the ability to produce muscle strength, which can help clinicians and sports professionals in controlling and monitoring their interventions[3,35]. In this context, the muscle architecture of monoarticular and biarticular muscles may be a particularity to be further explored in the literature.

Similar to the present study, Ando et al.[5] did not observe any relationship between MT and PA of the VL and RF with knee extensor PT, in eleven healthy men who had not been involved in any type of resistance training for several years. For the authors, although these muscles are considered strong contributors to the production of knee extension force, their contributions were masked by the close relationship between knee extensor PT and muscle architecture in the vastus intermedius (VI). In addition to this strong relationship, only VI muscle architecture variables were included in the mathematical equation to predict the extensor PT. Thus, the findings of Ando et al.[5] assist in interpreting the lack of relationship observed in our study.

Interestingly, Ando et al.[5] used the 56% distance between the anterior superior iliac spine and the superior edge of the patella for their correlations. In our study, we used the 50% distance for the relationships between muscle architecture variables and peak torque. This information is important because the muscle architecture of different regions of the skeletal muscles may or may not be more requested to produce muscular force.

Recently, Watanabe et al.[12] hypothesized that regional activation of biarticular muscles allows them to functionally contribute differently to the joints they span. Thus, the muscle architecture of the region of interest used in our study may not have been relevant to produce the knee extensor PT.

This hypothesis can be confirmed by the study of Blazevich, Gill, and Zhou[36], who observed differences in MT, PA, and FL in the proximal, medial, and distal portions of the VL and RF muscles. In the same sense, Trezise and Blazevich[7] observed that the variables inserted in the mathematical model to predict the peak isometric torque of men undergoing strength training were the cross-sectional area and the PA of the proximal region of the VL. Thus, the monoarticular muscles, as well as the biarticular muscles, can contribute to different regions along their entire length in the production of muscular force.

Other factors can be taken into account to explain the findings of our study, such as the level of physical activity[6,8]. Strasser et al.[6], for example, observed a significant relationship between PT and MT of the VL and RF muscles in physically active young adults. Similarly, Gaspari et al.[6] evaluated female athletes with 13 years of physical training experience and observed a significant relationship between knee extensor isometric PT with FL and MT of VL. In other words, the lack of relationship observed in our results may have been influenced by the participant's level of physical activity.

It is known that physical training is capable of providing neural adaptations and muscle architecture that contribute to the production of muscle strength[37,38]. Thus, the continuous practice of physical training provides adaptations in muscle architecture that contribute to physical performance, such as the production of muscle strength[39]. However, it is noteworthy that our study aimed to evaluate physically inactive women, as this group is not widely explored in the literature.

Although it was not one of the objectives of this study, it is worth noting that the participants were not in the menstrual phase and were using contraceptives. It is important to take this information into account because there is still no consensus in the literature on the influence of the menstrual cycle on muscle strength, as well as the possibility that the use of contraceptives does not influence the production of strength[40]. Therefore, future studies can better elucidate these relationships and their implications for muscle architecture.

Taken together, our results reject the initial hypothesis, because regardless of the number of joints involved, the isolated variables of the VL and the RF may not be enough to predict knee extensor PT in physically inactive women. Although our results add information about an underexplored population group, women who have not performed physical activity in the previous 12 months, some limitations need to be presented.

The knee extensors have three monoarticular muscles and we evaluated only one of them. Apparently, the VI appears to be the most influential in producing knee extensor torque, which could add different information to our results. The sample size may have influenced the results observed in our study since the sample size calculation was not performed. Although a specific questionnaire was not applied to classify the level of physical activity, our study only evaluated women who reported not having been involved in any physical activity in the last 12 months. Additionally, the inclusion of a group of physically active women could increase information about the differences between the level of physical activity.

In practical terms, our results showed that the procedures adopted can help in the good reliability of the analysis of images captured by ultrasound of the RF and VL muscles. Additionally, our results indicate that the use of muscle architecture variables to predict the muscle strength of the knee extensors in physically inactive women is not recommended. In the clinical context, for this population, direct methods of muscle strength assessment would be more strongly recommended. Similarly, in scientific studies, muscle strength must be evaluated by dynamometry (isokinetic or handheld) and in conjunction with the ultrasound device. Together, the data obtained with the ultrasound device and the dynamometer can help the researcher in the general interpretation of the data.

## Conclusions

There was good reliability of the evaluated images and isolated variables of the muscle architecture of a monoarticular or biarticular muscle, such as the VL and the RF, respectively, do not influence the production of isometric PT of the knee extensors in physically inactive women.

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