Rev Bras Cineantropom Hum

original article

DOI: http://dx.doi.org/10.5007/1980-0037.2017v19n5p585

Acute effects of passive static stretching on the vastus lateralis muscle architecture of healthy young men

Efeitos agudos do alongamento estático passivo sobre a arquitetura muscular do vasto lateral de jovens saudáveis

Eurico Peixoto César[1]
Letícia de Oliveira Teixeira[2]
Daniel Vieira Braña Côrtes de Souza[1]
Paulo Sergio Chagas Gomes[3]

Abstract – The aim of the study was to investigate the acute effects of passive static stretching (PSS) on the fascicle length (FL) and fascicle angle (FA) of the vastus lateralis muscle (VL) in two different joint positions. Twelve physically active men (26.9 ± 7.5 years, 178.6 ± 7.0 cm, and 82.5 ± 16.8 kg) were placed in the prone position for the acquisition of ultrasound images (US) of VL, registered with extended and totally flexed knee up to the heel contact with the gluteus, before and after a PSS routine comprised of three 30-s repetitions maintained in the maximal discomfort position as reported by the participant. Results of the paired t-test indicated an increase in FL (16.2%; $p = 0.012$) and reduction in FA (15.5%; $p = 0.003$) in pre vs. post stretching comparisons for the extended knee position. There was also a significant increase in FL (34%; $p = 0.0001$) and reduction in FA (25%; $p = 0.0007$) when compared the extended knee vs. flexed knee positions. There were no significant differences in muscle architecture variables for the flexed knee position. The results showed high and moderate correlation of FL and FA for the extended *($r = -0.89$ and $r = -0.74$)* and flexed knee *($r = -0.76$ and $r = -0.78$) position, pre and post stretching*, respectively. It was concluded that the static stretching acutely affects the vastus lateralis muscle architecture only in the extended knee position, but not in the flexed knee position.

Key words: Muscle stretching exercises; Skeletal muscle; Ultrasonography.

Resumo – *O objetivo do estudo foi verificar os efeitos agudos do alongamento estático passivo (AEP) sobre o comprimento (CF) e ângulo do fascículo (AF) do músculo vasto lateral (VL) em duas diferentes posições articulares. Doze homens (26,9 ± 7,5 anos; 178,6 ± 7,0 cm; e 82,5 ± 16,8 kg), fisicamente ativos foram posicionados em decúbito ventral para aquisição de imagens de ultrassonografia (US) do VL, registradas com joelho estendido e totalmente flexionado, até o conato do calcanhar com o glúteo, antes e após uma rotina de AEP composta por três repetições de 30 s com manutenção da posição no limite de desconforto relatado pelo participante. O teste t de Student para amostras pareadas indicou aumento no CF (16,2%; $p = 0,012$) e redução no AF (15,5%; $p = 0,003$) nas comparações pré vs. após alongamento na posição com o joelho estendido. Também houve aumento significativo do CF (34%; $p = 0,0001$) e redução do AF (25%; $p = 0,0007$) na comparação entre as posições de joelho estendido vs. flexionado. Não foram encontradas diferenças significativas nas variáveis da arquitetura muscular investigadas na posição com o joelho flexionado. Os resultados apontaram para correlação alta e moderada do CF e AF com joelho estendido ($r = -0,89$ e $r = -0,74$) e joelho flexionado ($r = -0,76$ e $r = -0,78$), pré e após alongamento, respectivamente. Concluiu-se que o alongamento estático afeta de forma aguda a arquitetura muscular do vasto lateral apenas na posição de joelho estendido, mas não na posição com joelho flexionado.*

Palavras-chave: *Exercício de alongamento muscular; Músculo esquelético; Ultrassonografia.*

1 "Presidente Antônio Carlos" University. Barbacena, MG. Brazil

2 Gama Filho University. Rio de Janeiro, RJ. Brazil.

3 State University of Rio de Janeiro. Rio de Janeiro, RJ. Brazil.

Received: March 23, 2017
Accepted: September 14, 2017

INTRODUCTION

Static stretching contributes to the reduction of passive stiffness and to increase of range of motion (ROM)[1]. Changes in the muscle-tendon mechanical properties are of great influence to increase the ROM of a joint, being the effect attributed to the structure extensibility, including sarcomeres, aponeuroses and connective tissues[2]. Among the different types of stretching, static stretching one is one of the most commonly used, where muscles are extended to the point of discomfort and maintained for a certain period, with 30 seconds of insistence time repeated 3 to 4 times to increase ROM and reduce passive stiffness[3].

Although acute changes in muscle-tendon properties and passive stiffness are well documented[1,4] after static stretching exercises, little is known about their effects on muscle architecture variables, such as fascicle length (FL) and fascicle angle (FA). FA is the angle formed between the insertion of the fascicle and the internal muscle aponeurosis and FL is the distance from the junction point of the fascicle with the external aponeurosis[5]. These muscular architecture variables drastically affect the functional characteristics of a muscle and the force production capacity[6], since FA is related to the amount of contractile tissue per unit of muscle area. Thus, in hypertrophied muscles, FA is significantly increased, and higher FL is associated with higher muscle contraction rate[5].

Changes in muscle architecture caused by conventional strength training in trained youth and adults are already well documented, such as increased cross-sectional area (CSA) and FA, but with less apparent modifications in FL[7-9]. However, little is known about the isolated acute effect of static stretching on muscle architecture. Most studies indicate alterations generated in muscle architecture during stretching exercises and not the acute effect generated after this routine[10]. Moreover, the few studies that verified the acute effect of static stretching on muscle architecture showed controversial results, possibly due to the different methods adopted and muscles tested[11-13].

In the study conducted by Morse et al.[1], no significant changes were observed in FL and FA immediately after an extensive routine of five 1-min repetitions of static stretching in the triceps sural muscle. However, muscle architecture variables were measured during dorsiflexion movement and not at rest. In contrast, Sá et al.[13] measured FL and FA of the vastus lateralis and femoral biceps muscles before, immediately after three 30 s repetitions of static stretching and 10 min after three sets of strength exercises preceded by the stretching routine. The authors verified a significant increase in the FL of femoral biceps immediately after the stretching routine, but no alterations in FA and in these same muscle architecture variables of the vastus lateralis muscle. It should be noted that in this study, US measurements were performed in only one position (supine position).

According to Lieber and Friden[6], muscle architecture and the muscle-tendon composition differ profoundly between muscle groups and in different positions. In this sense, static stretching provides different effects as a function of volume, insistence time in the discomfort position, intensity, joint position and type of muscle group tested. In addition, as suggested by Cè et al.[11], possible changes in muscle architecture caused by static stretching may explain the decline in strength performance presented by some studies, but for a more correct conclusion, different joint positions should be tested, since force production varies substantially according to this variable.

In this sense, due to the need to verify the isolated effect of static stretching on the muscle architecture in different joint positions, the present study aimed at verifying the acute effect of three 30-s repetitions of passive static stretching (PSS) on muscle architecture variables of the vastus lateralis muscle (VL) at two different knee angles.

METHODOLOGICAL PROCEDURES

The present study was approved by the Ethics Research Committee of the Gama Filho University under protocol number 173.786. The involvement of volunteers occurred after signing the informed consent form (ICF), in addition to completing a questionnaire for risk stratification (Par-Q), where one or more positive answers to the seven questions in the questionnaire served as exclusion criteria, and a detailed explanation of the objectives and procedures of the present study. They were informed that at any time they would be free to leave the study. The study was conducted according to the recommendations defined in Resolution 466/2012 of the National Health Council.

Sample

Twelve physically active men (26.9 ± 7.5 years, 178.6 ± 7.0 cm, and 82.5 ± 16.8 kg) visited the laboratory on four different occasions. Volunteers were invited through posters fixed in classrooms. Inclusion criteria were: a) participant should be able to touch the heel in the gluteus during the knee flexion movement; b) participant should practice physical exercises three or more times per week; c) participant should not have any type of injury or impairment in the right lower limb that restricted the knee flexion movement. The first visit was aimed at familiarizing with procedures and the completion of the ICF and the questionnaire for risk stratification. Visits 2 and 3 were used to determine the reliability of US measurements and in the last visit, the experimental procedure was performed. The maximum interval between visits was 72 h.

Instruments

FL and FA measurement images were obtained by ultrasound device (LOGIQe, GE Healthcare, USA) with a 40 mm linear transducer and a 10 MHz excitation frequency. To avoid depression of the skin surface and to maintain the same level of pressure on the muscle, an apparatus was used to fit the transducer that surrounded the thigh by means of elastic bands, being positioned at the measurement site. Gel was used for the acoustic coupling (Ultrex-gel, Farmativa Indústria e Comércio Ltda).

All images were analyzed using public domain software (ImageJ, National Institute of Health, USA, version 1.42). As the used transducer used has 40 mm, an estimation model [14] was used to calculate FL using the following equation: CF: $(l1 + h) / (\text{sen}\ \alpha)$. Where l1 is the visible FL measured in the image; h is the vertical distance from the end point of l1 to the superficial aponeurosis and α is the angle between the fascicle and the deep aponeurosis. When aponeuroses were not parallel, the angle between the fascicle and the deep aponeurosis was subtracted from the angle of the measured fascicle (Figure 1A).

Procedures

In order to acquire the images, the following procedures were performed: a) with participant standing, a marking was made at the center of the patella and at the point related to the anterior superior iliac crest. From these two points, a straight line was drawn connecting them, thus identifying the line of action of the rectus femoris muscle; b) from the center of the patella, using the straight line drawn for the action of the rectus femoris, a universal goniometer was positioned and 15° lateral was identified from that point, identifying the line of action of the VL; c) the trochanteric and lateral tibial points were marked to measure the femur length and; d) from the line of action drawn from the VL, a proximal point was marked at 60% of the femur length, where the apparatus for fitting the US transducer (Figure 1B) was positioned.

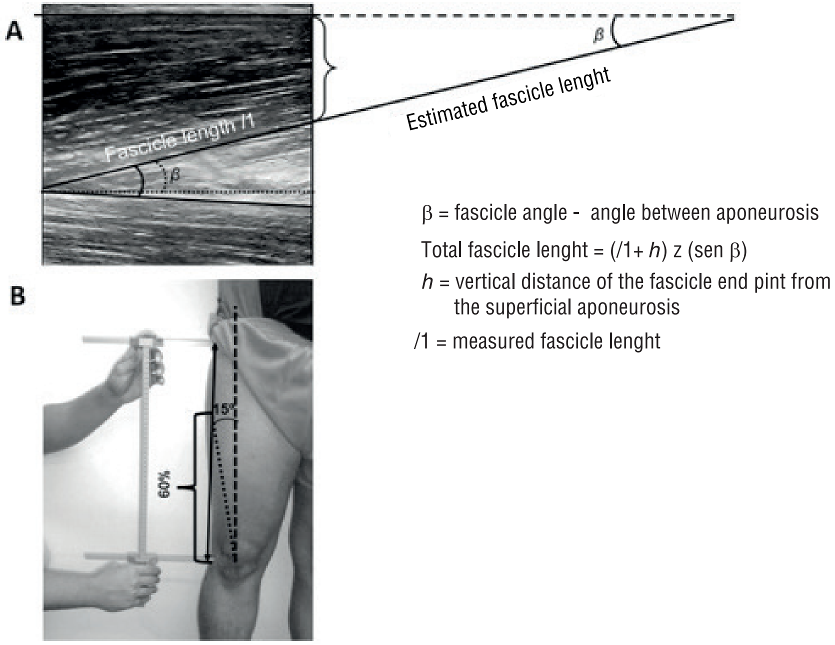

Figure 1. Procedure for FL estimation (A) and Identification of the anatomical site for placement of the US transducer (B).

Once demarcations were made, the participant was placed in a ventral decubitus position with the right knee extended and supported on a padded apparatus and the distal part of the thigh wrapped in an inextensible band, fixing the limb and ensuring that there was no hip rotation. Three US images were captured in this position, with an interval of about 1 min between them. Then a passive, slow and gradual mobilization of the knee flexion was performed until there was contact of the heel with the gluteus. In this position, three more US images were recorded. After this procedure, with the subject positioned in the ventral position, three repetitions of passive static stretching were performed to the quadriceps, with a slow and gradual knee flexion until the heel touched the gluteus. Then, hyperextension of the participant's hip was performed up to the limit of reported discomfort, maintaining this position for 30 s. Subsequently, three US images of the vastus lateralis muscle were captured with extended knee and three with flexed knee. All images were analyzed and the mean results for each position were used as the value for the statistical calculations.

Statistical analysis

The Shapiro-Wilk test showed normal distribution for variables tested. The reliability of the measurement was made by means of the intraclass correlation coefficient (ICC parallel method), of the typical measurement error (TME), which according to Hopkins[15], is determined by the relationship between standard deviation of the differences obtained between measurement pairs and the square root of two. Finally, the degree of agreement among measures was verified, according to Bland and Altman[16]. The comparison between measures before and after the stretching routine for each joint position was made through the Student t test for paired measures. In addition, Pearson's correlation was used to verify the relationship between FL and FA in the different positions tested. Analyses were performed using commercially available software (SPSS 17.0 for Windows®, IBM Corporation, New York, USA, Prism 5.0 for Mac, Graphpad Software, La Jolla, Calif., USA) and significance level of *5%* was adopted.

RESULTS

The reliability results of FL and FA measurements were based on 10 of the 12 recruited subjects due to problems with the US measurement in two of them, where the difference between the two tests in one section was 69.6% for one subject and 87.8% for the other. The reliability results for FL were R = 0.916, BIAS 4.1 and TME 7.4% and for FA were R = 0.928, BIAS 3.0 and TME 5.3%.

High reliability and reproducibility values of measurements and low associated error are observed. ICC showed that for FL and FA, approximately 92% and 93%, respectively, of the variance in the mean among measurements is real, denoting good association among measures performed. The comparison between test and retest for the two variables showed no significant statistical difference. TMEs were also low with values below 8.0% for both variables. The Bland-Altman graphic representations (Figure 2A and 2B) showed that in both dependent variables used, all measures are within the determined confidence limits (± 1.96 SD) with low associated error (BIAS) and absence of heterocedastic error.

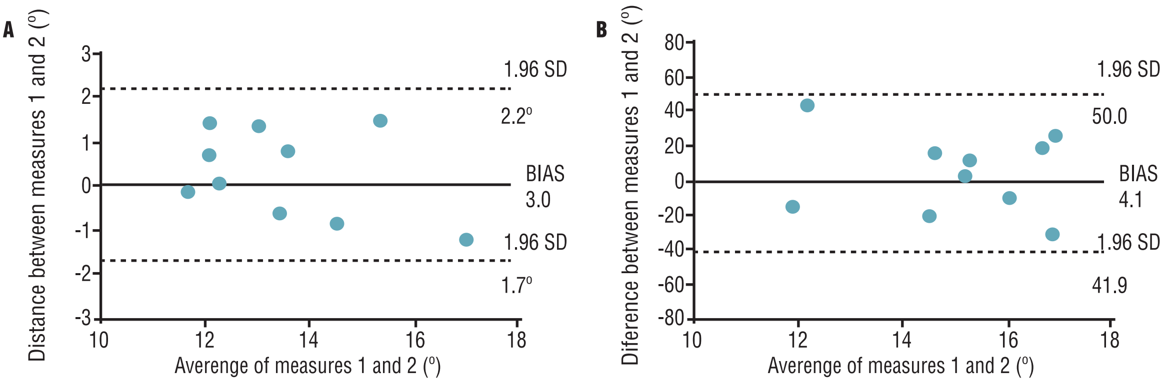

Figure 2. Bland-Altman graphic representations for (A) Fascicle Angle and (B) Fascicle Length. (°) = degrees.

The Student's t-test for paired measures identified a significant increase in FL (34%, p <0.05) and reduction in FA (25%; P <0.05) in the comparison between extended and flexed knee positions (Figure 3A and 3B).

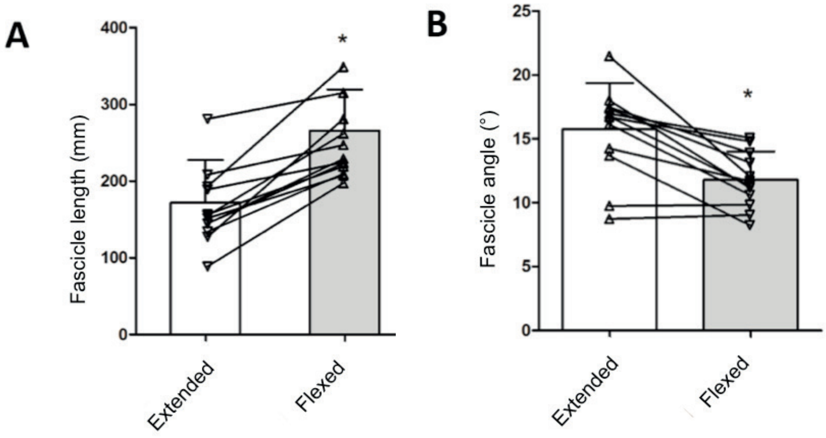

Figure 3. Comparison of FL (A) and FA (B) at extended and flexed knee positions. Columns represent the means and standard deviations and the symbols connected by rows represent the raw data of each subject tested. * FL (p = 0.0001) and FA (p = 0.0007).

Static stretching promoted a significant increase in FL (16.2%, p <0.05) and in FA (15.5%, P <0.05) in the position with knee extended but not flexed (FL , p = 0.430 and FA, p = 0.493) (Figure 4A and 4B). These results exceed TME and indicate the real effect of the intervention on the study variables.

Figure 5 shows the relationships of FL and FA with extended knee (5A and 5B) and flexed knee (5C and 5D), before and after stretching, respectively, with a moderate to high correlation among variables for both positions tested.

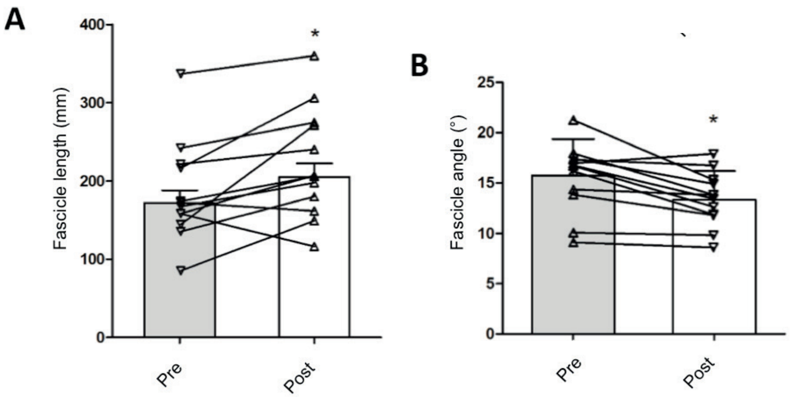

Figure 4. Effect of passive static stretching on FL (A) and FA (B) for the extended knee position. Columns represent the means and standard deviations and the symbols connected by rows represent the raw data of each subject tested. * FL (p = 0.012) and FA (p = 0.003).

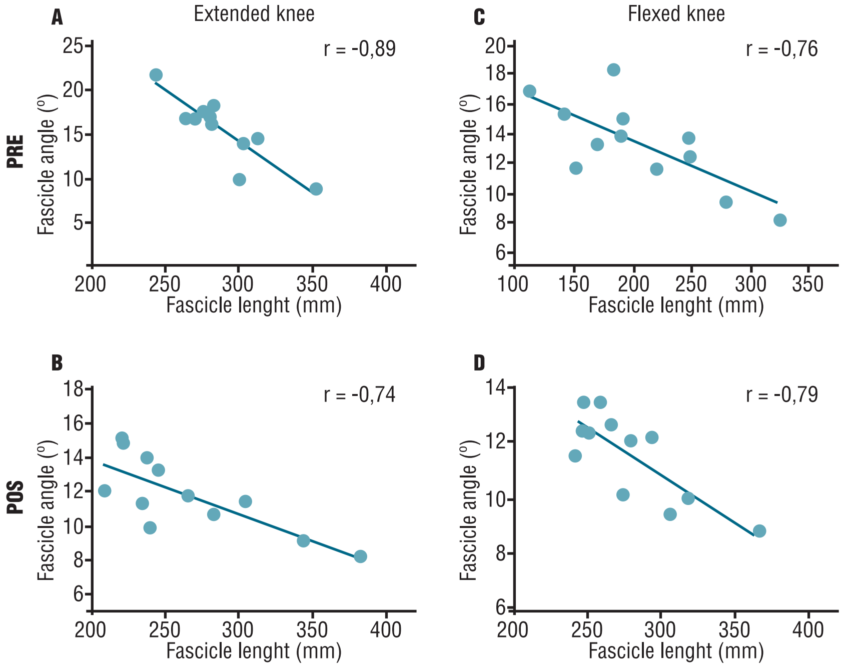

Figure 5. Relationship between FL and FA for extended knee in pre (A) and post stretching (B) conditions and the relationship between FL and FA for flexed knee pre (C) and post stretching (D) conditions. r = Pearson's correlation coefficient; (°) degrees.

DISCUSSION

The aim of the present study was to identify the acute effects generated in the LV muscle architecture after static stretching. The main findings were a significant increase of 16.2% in FL and reduction of 15.5% in FA in the pre vs. post stretching for the extended knee position (Figure 4). In addition, there was an increase in FL and reduction in FA when extended knee position was compared with the flexed knee position (Figure 3). Considering that all the differences reported here are greater than TMEs (7.4% for FL and 5.3% for FA), it could be inferred that the effect of stretching on the studied variables was real. However, no changes were observed in FL and FA in the flexed knee position in the pre and post stretching comparisons.

It is well known that the arrangement of muscle fibers is directly associated with muscle strength production[17]. FA is associated with CSA and muscle efficiency, that is, how much force generated in sarcomeres is effectively transferred to aponeurosis. FL is related, in part, to muscle contraction rate[7]. Some studies have reported the acute effect of static stretching on muscle architecture[1,11-13], but the results were inconsistent with each other. While some authors observed an increase in FL and a reduction of FA[1,12] in the gastrocnemius muscle after 5 1-min repetitions of static stretching, others only found FL changes for the vastus lateralis muscle, but not for the femoral biceps muscle[13] after three 30-s repetitions, and did not find any type of alteration for the gastrocnemius muscle after six 45-s repetitions[11]. Differences in the amount of stretching exercises in the protocols to acquire US images, in the joint position in which the measurements were made and in the muscle groups tested, may explain such discrepancies in results.

In the present study, there was an increase in FL with concomitant reduction in FA immediately after static stretching only in the extended knee position, which reinforces some findings in literature[1,12]. However, no change was observed for the flexed knee position. A possible explanation for this would be the greater level of passive tension generated in the position with more stretched muscle, which would remove all the additional complacency caused by the stretching routine, being no longer possible to change FL or FA. This hypothesis has already been demonstrated in literature[18,19].

Although studies have already investigated the acute effect of static stretching on muscle architecture, a large part of them verified this during stretching and used unusual volumes (e.g., 5 min) in a specific group (gastrocnemius) and in only one joint position[1,12]. Another study that measured the muscle architecture parameters after static stretching[13] had influence of strength training performed after stretching, which makes it impossible to know its isolated effect. Therefore, the findings of the present study may be important for understanding the isolated effect of usual static stretching routines on the muscle architecture as a function of the joint position in which the muscle is located, in addition to allowing associations with force performance.

Some authors suggest an angle-dependent relationship, showing that only in positions where the muscle is at a shorter length (e.g., extended knee position), deleterious effects on force promoted by stretching are more common. However, when the muscle is positioned at a greater length (e.g., flexed knee), the decrease in strength performance becomes less evident, since more elongated muscle position is able to remove the additional complacency caused by stretching[18- 21]. This fact may be associated to the findings of the present study, where changes in FL and FA were observed only for extended knee position.

It is important to emphasize that there are few studies that have verified the isolated acute effect of static stretching on the muscle architecture variables studied here. Most of them identified changes in muscle architecture during stretching rather than after the session. Kato et al.[2] verified the changes in the medial gastrocnemius muscle architecture during five 60-s repetitions of static stretching and reported a significant but low inversely proportional relation ($r^2 = 0.46$; $P < 0.001$), with the increase of FL and concomitant reduction in passive torque from the first to the fifth stretching session. These results indicate that changes in passive stiffness associated with ROM gain after static stretching are strongly associated with increased FL. Corroborating these findings, some studies have pointed out that the effects of stretching on the passive stiffness of the muscle-tendon unit occur mainly due to changes in the relative stiffness of the muscle and not the tendon[10,22,23]. Another study sought to identify changes in the gastrocnemius muscle architecture during stretching and reported a gradual increase in FL and reduction in FA as ROM increased[10] from 10° of plantar flexion to 30° of dorsiflexion. These findings corroborate the results of the present study.

FA is the angulation of muscle fibers in relation to the muscle action line[5]. It has long been evidenced that during muscle contraction, a rotation of the muscle fiber occurs, promoting its increase[24]. The same pattern occurs for structural adaptations to strength training, which promotes implications for the transfer of the force generated in the muscle fiber to the aponeurosis, since, for muscles with the same AST and muscle fiber length, a greater fascicle angle will promote lower efficiency in the transmission of force from muscle fibers to aponeurosis[25]. Associations of hypertrophy with increase in FA and also with reduction in muscle efficiency with concomitant increase in force production due to the increase in the contractile material are pointed out in literature[5,7]. Thus, it may be advantageous to present lower FA during muscle contraction, as this will imply lower loss of efficiency in the transfer of force from the muscle fiber to the tendon. However, there is little evidence for improved force performance after stretching, which is most noticeable at positions where the muscle is at a longer length, near its maximal ROM[19].

CONCLUSION

It could be concluded that static stretching can acutely alter the muscle architecture (FL and FA) of the VL muscle only in extended knee position, but not in a very elongated position (flexed knee), probably due to the higher levels of passive tension in the latter position, as is already well documented in literature. In this case, it seems that the perceived changes are exclusive to positions where the muscle is in shorter length, but not in longer lengths. Thus, stretching routines such as that used in the present study may be useful before sports practices that require increased ROM or that force production is required at positions where muscle is stretched.

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CORRESPONDING AUTHOR

Eurico Peixoto César
Rodovia MG 338 km 12, Colônia
Rodrigo Silva
Barbacena, MG, Brasil
CEP: 36.201-143
E-mail: euricocesar@unipac.br;
euricopcesar@gmail.com