ELECTROMYOGRAPHICAL ANALYSIS OF THE QUADRICEPS DURING KNEE EXTENSION AT DIFFERENT SPEEDS

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SUMMARY

The patellofemoral pain syndrome (PFPS) is a common disorder of the knee; it's often caused by an excessive lateral traction of the patella. Subjects with this syndrome usually present a disruption in the activation of Vastus Mediallis Obliquus (VMO), which provides the patellar medial pull. Non-operative treatment includes quadriceps strengthening in order to promote better patellar stability and traction. Many researchers have been trying to selectively recruit the VMO, in order to improve treatments. The main purpose of this study is to investigate, using electromyography, the interference of angular speed and different ways of fixing the elastic tube on the quadriceps activity. Ten male subjects without any kind of muscle or joint injury participated in this study. Subjects with a Q angle value out of 10-15° were excluded from this study. The elastic tube was fixed parallel and oblique to the subjects' body. Knee extensions were performed at 60°/sec and 120°/sec. No selective activity of the VMO was found. By comparing the levels of muscular activity, there was an increase of the electromyographic activity level in all portions of the quadriceps at the two angular speeds, only for parallel-fixed elastic tubes. These results suggest a synergic activity between VMO and the other portions of the quadriceps.

Keywords: Rehabilitation; Electromyography, Patella, Knee injuries.

INTRODUCTION

The Patellofemoral Pain Syndrome (PFPS) is a musculoskeletal disorder clinically presenting with insidious pain on retropatellar region, being worsened by squatting, stepping up and downstairs, and by a prolonged seated-position time(1). PFPS cause is considered as multifactorial(2). Although the various studies addressing this topic, many researches are still being performed aiming to optimize its diagnosis and rehabilitation programs(2,3,4).

Patellofemoral joint is stabilized by an integrated system of contractile and non-contractile structures. Quadriceps contraction is recognized as the major influencing factor on patellar traction(2).

The quadriceps is composed by the following muscles: vastus intermediate (VI), vastus lateralis (VL), vastus mediallis longus (VML), vastus mediallis obliquus (VMO) and rectus femoralis (RF). During knee extension, all quadriceps portions, except for the VMO, promote trends of patellar lateralization(5). VMO fibers present a medial inclination of 55° from the femoral diaphysis(6) and their function is to promote dynamic medial stabilization of the patella(5).

This contractile and non-contractile structures system allows for an appropriate stability of the patella. Any dysfunction on these structures results in an inappropriate dislocation of the patella from the femoral trochlea(3,7). The balance on muscular activity between the VL and the VMO is seen as essential for an adequate arthrokinematic relationship between the patella and femoral trochlea(8). When present, dysfunctions on VMO activity may create excessive lateral tractions on the patella(3). There is a well-established relationship between VMO failure and PFPS symptoms(2). It is possible that the inadequate patellar traction is secondary to the unbalance of the VMO activity compared to VL(8).

Due to the importance of the VMO for patellar stability, rehabilitation is focused on the specific strengthening of this muscle portion, associated to a reduced patellofemoral stress(1). Some authors evaluate this specificity through the analysis of the VMO/VL ratio or through direct comparison of activation levels among those muscular portions(7,9).

Travnik et al.(6) suggest the existence of higher concentrations of type-I fibers in VML and of type-IIb in the VMO. Their results did not show significant differences among VMO, VML and VL for type-IIa fibers. However, VL presented a higher proportion of type-IIb fibers. Those differences evidence different specific muscular demands and functions. The performance of motor gestures in a higher or lower speed or force creates different patterns of motor recruitment. The influence of the speed in performing knee extension on the levels of electromyographic activity of the quadriceps was little probed in literature. Matheson et al.(7) suggest the possibility that, by addressing knee extension exercises in different angle speeds and resistance kinds, different levels of muscle activation are achieved for VMO over the VL.

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The objective of this study was to determine, through electromyographic analysis, the bias of speed and load on the activity of VML, VMO, VL, RF, and on VMO/VL ratio during knee extension.

MATERIALS AND METHODS

The sample was composed of 10 male individuals, with a mean body mass of 73.7 ± 7.1 kg, mean height of 1.74 ± 0.03 m, all of them used to practice some kind of regular physical activity. Individuals with previous knee joint and/or quadriceps muscle injury and Q angle out of the 10-15° interval were excluded. Measurements of the Q angle were made by the same evaluator. All individuals signed an Informed Consent form, and the research was approved by the Committee on Ethics in Research from Health Sciences College, Porto Alegre Institute.

Test Protocol

The test consisted of knee extensions from 90° to 0° of flexion (0° being considered as full extension), with the individual positioned in ventral decubitus and with resistance created by an elastic tube. One of the ends of the elastic tube was fixated on ankle joint and the other was fixated on two different points according to the kind of fixation desired. One of the points promoted a resistance force traction line virtually parallel to the thigh (Parallel Fixation - PF) (Figure 1) and the other, in a higher position, in which force traction line became oblique to the thigh segment (Oblique Fixation - OF) (Figure 2).

A metronome was used for determining both mean angle speeds of performance. Average angle speeds of 60°/sec (V60) and 120°/sec (V120) were chosen for being usually employed for the performance of those exercises. Participants were submitted to a previous training until they could follow the rhythm of the metronome for both speeds. Tests involved combinations between each model of elastic tube fixation and each angle speed, totaling four tests (PF-V60, PF-V120, OF-V60, and OF-V120). For each test situation, five repetitions were analyzed.

Quantification of Imposed Resistance

In order to determine the imposed resistance to muscles, it was necessary to quantify the torque created by "leg-foot" segment weight (⇓s), the torque created by the elastic tube (⇓tb) and the inertial component of the motion (defined by the result of inertia moment versus angle acceleration). The calculations required for quantifying ⇓tb, ⇓s and the inertial component were made through routines developed by software MATLAB® 5.3. Figure 3 shows the chart of free body of the leg-foot segment during a test situation in an intermediate range.

From the free body chart of the leg-foot segment (Figure 3) and based on Euler's motion equation, it is possible to establish a relationship among involved torques (Equation 1). It was determined that torques in clockwise movement (extensor torque) are presented as positive values and in counterclockwise movements (flexor torque) as negative values.

Equation 1:

$$\Downarrow m - \Downarrow tb + \Downarrow s = V$$

where:

⇓m = muscle torque

⇓tb = elastic tube torque

⇓s = leg-foot segment weight torque

I = leg-foot segment inertia moment

⁄ = leg-foot segment angle acceleration

a) initial position b) final position

Figure 1 - Parallel Fixation of the Elastic Tube.

Equation 1 can be remade by isolating muscle torque (⇓m), obtaining the equation 2:

Equation 2:

$$\Downarrow m = V + \Downarrow tb - \Downarrow s$$

The right side of the equation 2 represents the resistance imposed to muscles, being named as resistance torque (⇓r).

Elastic Tube Torque

The ⇓tb depends on the material's tensile strength and on the angle formed between elastic tube traction line and leg-foot segment(10). The values of elastic tube strength were obtained through a calibration process, according to described by Loss et al.(11). Measurements were made on the elastic tube length and on the angle formed between the elastic tube traction line and the leg-foot segment for calculating the torque produced by the elastic tube. Those measurements were performed on both range ends, that is, at initial position (90° flexion) and final position (full extension). In intermediate ranges, angle values between the elastic tube traction line and the leg segment and the elastic tube length values were obtained through trigonometric interpolation.

Inertial Parameters

The inertial parameters used (weight, position of mass center and inertia moment of the leg-foot segment) were those described by Clauser et al.(12). The values for angle acceleration were obtained through double derivation of the angle position data, obtained with the electrogoniometer.

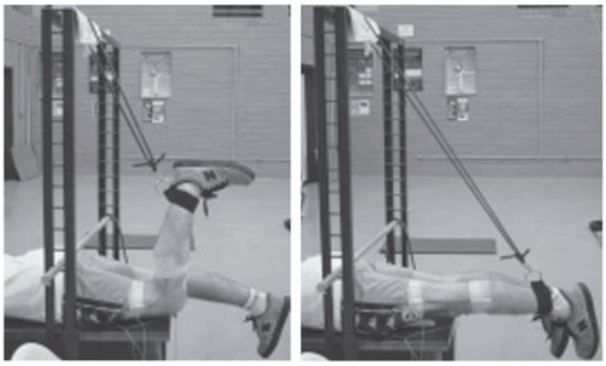
Angle Position

For tracking the knee angle position during performances, an electrogoniometer, from Biomectrics Ltd (Cwmfelinfach, United Kingdom), model XM180 was used. One of the shafts of the electrogoniometer was fixed along the longitudinal axis of the leg, and the other along the thigh longitudinal axis. A sensor was connected to a microcomputer Pentium III, through an analogical-digital converser, Computer Boards brand, model CIO-DAS 16, 16 bits, at an acquisition rate of 2000 Hz.

Electromyographic activity

The electromyographic sign was captured by using an electromyographer Bortec® brand (Calgary, Canada) and disposable surface electrodes with bipolar arrangement and a grounding electrode, positioned at the anterior tuberosity of the tibia. The electrodes were longitudinally aligned to the muscle fibers and fixed on the belly the most prominently as possible towards the following muscles: RF, VL, VML, and VMO. The sign acquisition rate was 2000 Hz for each channel. Standards suggested by Merletti and Di Torino(13) were used for recording the electromyographic signs, which are also recommended by the International Society of Electrophysiology and Kinesiology, as well as according to the references of Soderberg and Knutson(14), recommended by the International Society of Biomechanics and the Brazilian Society of Biomechanics. The electromyographer and the electrogoniometer were connected to the same analogical-digital converser, allowing a simultaneous and synchronized capture of signs.

For gathering and analysis of data, the software SAD32 (developed by the Engineering School, at UFRGS) was used. The sign was quantified through RMS value at 0.5-second intervals, with Hamming windowing and normalized by the value of maximum voluntary contraction (MVC) collected with knee in full extension. A Butterworth filter with frequency ranging from 20 Hz to 600 Hz, of order 3, was used. Total activity of each portion was expressed by the average of the five performances analyzed.



a) initial position *b) final position*

Figure 2 - *Oblique Fixation of the Elastic Tube.*

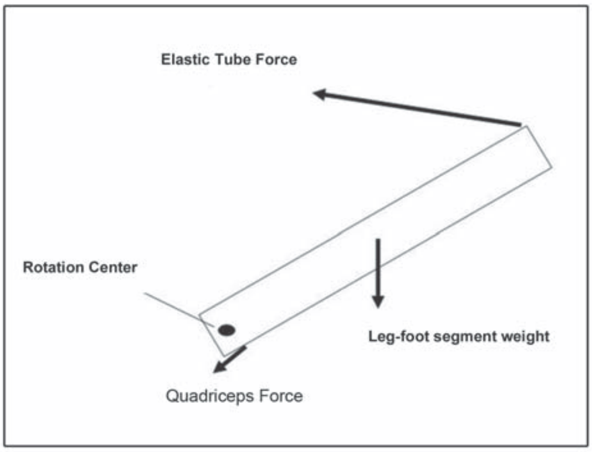


Figure 3 - *Free-body chart of the leg-foot segment.*

Statistic procedure

The Student's t-test was applied for comparing the variables of interest. The significance level considered was 5% ($p \leq 0.05$).

Results and Discussion

Elastic Tube Torque

The torque created by the elastic tube is independent from performance speed due to the elastic properties of the material. Figure 4 shows the elastic tube torque during PF and OF. As expected, OF created a greater torque when compared to PF due to angle differences between the action line of the elastic tube strength and the leg segment. Furthermore, the torque peak occurred in different angles of flexion. For the OF, the torque peak was 110 Nm and it was reached almost at 10^{o} of flexion, whereas for PF, the torque peak was 45 Nm and occurred almost at 50^{o} of flexion.

Leg-Foot Segment Weight Torque

The leg-foot segment weight torque (⇓s) is independent of the elastic tube fixation way and of the average angle speed of exercise performance, being uniquely dependent on motion angle variation. Figure 5 shows the ⇓s behavior due to the knee flexion angle.

Inertial Component

The magnitude of the inertial component is dependent on the inertia moment and on angle acceleration values. Thus, knee extensions performed in 60 and 120^{o}/sec present different values of angle acceleration, thereby alternating the values of the inertial component. Figure 6 shows inertial component values for performances in 60 and 120^{o}/sec, due to the knee flexion angle.

Resistant Torque

The ⇓r depends on the ⇓tb, ⇓s and on the motion inertial component, being defined through an equation(2). Since the increase of average angle speed results in higher values of angle speed along the knee flexion-extension, the ⇓r presents different values during the knee extension at V60 and V120, for the same elastic tube fixation way. Therefore, higher angle accelerations are expected, promoting increments only of the inertial component and those lead to changes on ⇓r values.

Figure 7 shows the values of ⇓r representing an individual (since the behavior and values for those curves was virtually the same for all tested individuals), for each test situation. The scale on the ordinates axis is different in the two graphs in order to facilitate data visualization. Regardless of the way in which the elastic tube is fixed, the test performed at 120°/sec created a behavior change for the ⇓r compared to the test at 60°/sec. The area formed between both curves is caused by the variation of the inertial component. In the test situation with PF (Figure 7a), the difference is present during almost all ADM, while for OF (Figure 7b), the difference is found only in one segment of the ADM. For PF, variation occurred basically from 60 degrees of knee flexion and remained until the end of motion. By analyzing the OF, this variation was present from the 60^{o} on, until approximately 10^{o} of knee flexion. During the test situation FP-V60, the resistant torque peak value was -40.11 Nm and, at FP-V120, the resistant torque peak value was -47.25 Nm. The difference of the torque peak value between both situations is 16.5%. During the test with FO-V60, the resistant torque peak value was -100.78 Nm, whereas during FO-V120, the resistant torque peak value was -107.13 Nm, with difference between torque peaks being 6.6%.

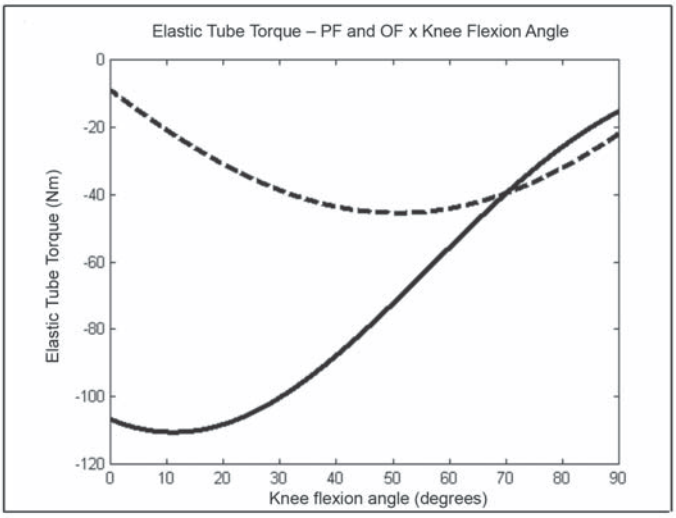
Electromyography

Among test situations, no VMO overactivation was found over other quadriceps portions. Intramuscular comparisons of the levels of myoelectrical activity during the OF did not present significant differences (Figure 8b). Conversely, during the PF, comparisons evidenced an increase of muscular activity for all portions analyzed, when knee extension was performed at a mean angle speed of 120^{o}/sec (Figure 8a).

Figure 8b shows greater muscular activities for the speed of 120°/sec, but this difference was not significant. Indeed, the level of myoelectrical activation did not increase with a faster mean angle speed. This is in accordance to what is shown on Figure 7b, where the difference of resistance torque (⇓r) for the different speeds was little. Thus, the increment of ⇓r due to the variation of the inertial component seems to be insufficient for requiring higher levels of muscle demand.

As opposite, during PF, the difference among resistance torques was stronger (Figure 7a). Due to the lower ⇓tb values during PF, the variation of the inertial component on ⇓r quantification seems to be sufficient for promoting an increase of muscular demand during knee extension. By performing the test with V120, there was a significant increase of the level of myoelectrical activity of the parts of VMO, VML, VL, and RF muscles compared to the motion at angle speed of 60^{o}/sec.

Similarly to other studies, when comparing each muscle activation intensity at different test situations, the VMO selective activation could not be identified(7,9). Those results suggest that



Oblique Fixation (OF): full line. Parallel Fixation (PF): dashed line.

Figure 4 - *Torque created by the elastic tube.*

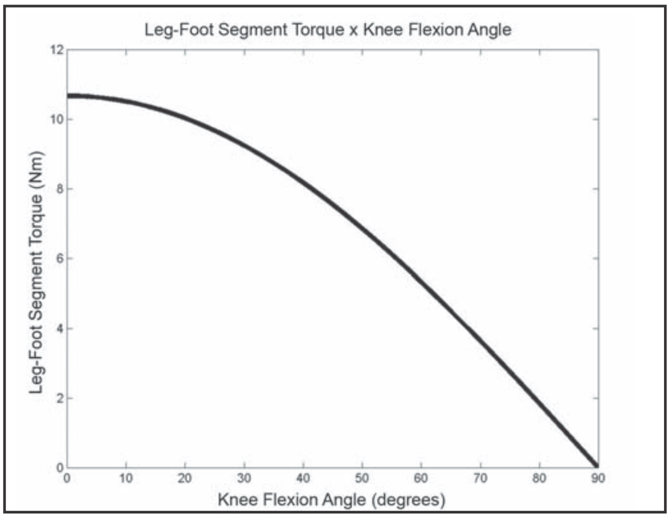


Figure 5 - *Torque created by the leg-foot segment weight according to knee flexion angle.*

the quadriceps may act as a muscle complex, in which the requirement of a stronger muscle activation is distributed among all its portions.

Matheson et al.(7) found a strong interaction among the RF, VL and VMO in different kinds of exercises for quadriceps strengthening. Tobin and Robinson(2) state that the VMO has an inherent ability to reach VL activity levels and this ability is lost in individuals with PFPS.

Grabiner et al.(5) say that the VMO is not able to contribute to knee extension, whereas the VL, additionally to create torque for extension, promotes a trend for patellar lateralization. They also identified that the VL efficiency in extending the knee is reduced when the patella is lateralized, concluding that the VMO function is indeed to promote medial dynamic stabilization of the patella and to optimize VL activity. Since that study involved healthy individuals, the results of this research confirm such authors' statements.

Matheson et al.(7) mention that, when a way to strengthen the VMO alone is not found, the relationship between the quadriceps muscle strengthening and the reduction of patellar pain is uncertain. However, they suggest that it is possible that the quadriceps muscle

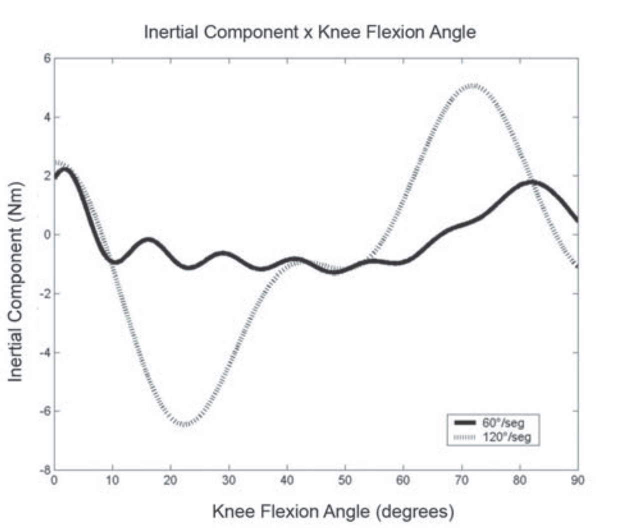
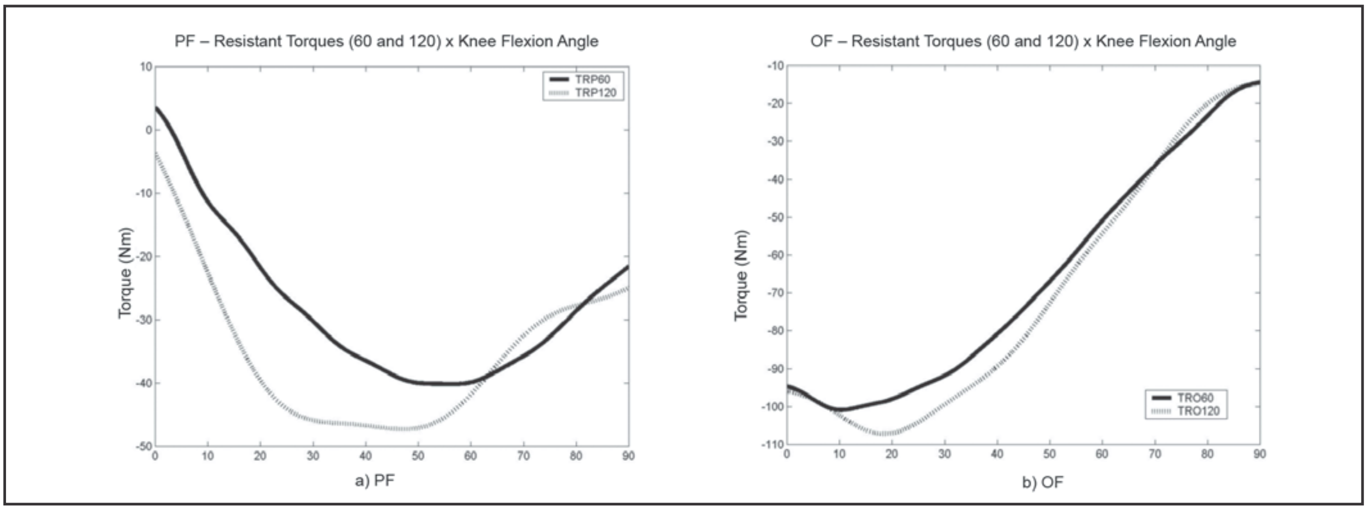


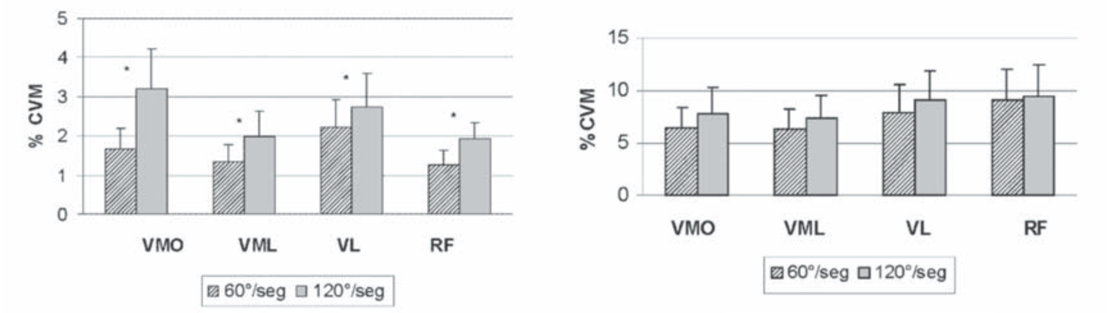
Figure 6 - *Inertial component for different angle average speeds.*



a) PF

b) OF

Figure 7 - *Resistant Torque and Leg Segment Torque.*



a) Parallel Fixation

b) Oblique Fixation

* significant values for $p<0.05$.

***Figure 8** - Intramuscular comparison of different loads and speeds with corresponding standard errors.*

strengthening, although non-specific, promotes force improvements in a given threshold allowing a sufficient medial stabilization. Grelsamer(15) states that the quadriceps strengthening is beneficial for PFPS treatment, provided the exercise does not cause pain.

It is possible that the PFPS etiology is an interaction among mechanical and neuromuscular factors. Since some studies indicate the potential existence of changes on neuromuscular control of the quadriceps in individuals with PFPS, the reason for those individuals rehabilitation success may also be bonded to reeducation of neuromotor aspects(3,5). Owings and Grabiner(3) suggest the presence of a rupture on quadriceps control for eccentric contractions. Voight and Wieder(8) say that individuals with PFPS may present with a neuromotor unbalance promoting a delay of the VMO reflex activation time over the VL. Those authors recommend that the treatment plan of patients with PFPS should consider mechanical and neuromuscular aspects(5,15). Another factor to be considered is the rehabilitation approaches potential of being able to broke the quadriceps reflex inhibition when this clinical condition is present and, thus, achieving improvement of symptoms.

Grabiner et al.(5) address this issue by suggesting that, due to the impossibility of strengthen the VMO alone, maybe the physical therapy objective should be focused in the recovery or achievement of a better neuromuscular control associated to quadriceps hypertrophy, thereby optimizing the active stabilization of the patella and reducing clinical symptoms.

CONCLUSION

The results of this study evidenced that the overactivation of the vastus mediallis obliquus was not possible through the variation of average angle speeduand/or through different ways of fixating the elastic tube. A prevalence of muscle activation was not found, regardless of the muscular portion addressed. In asymptomatic individuals, and, with extended hip, the activation of the vastus mediallis obliquus presents a close relationship with the rest of the quadriceps muscle. Results suggest a synergic action between the vastus mediallis obliquus and other portions of the quadriceps. The oblique fixation promoted a stronger resistance to knee extension and its variation could be used as a way to progress in quadriceps muscle strengthening programs. Speed variation during parallel fixation presented a significant difference on the levels of electromyographic activity in all portions assessed.

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