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Optimization of the position for isometric exercise to strengthen the vastus medialis oblique muscle based on surface electromyography tests: an observational study

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Abstract

Background: The vastus medialis oblique (VMO) is the main dynamic stabilizer of the knee joint. Due to its anatomic structure, the muscle works at high speed and with high strength, but it tends to weaken relatively fast and atrophy.

Aims: The study aimed to determine if vastus medialis muscle (VM) shows the highest bioelectric activity during isometric contraction in flexion or extension position of the knee joint.

Material and methods: Tests were conducted on 48 cases; the bioelectrical activity of the VM muscle was measured with the use of surface electromyography (sEMG). The electric potentials of the muscle were tested in two positions of the knee joint extension from 5° to 0° and flexion of 90°. Tests were conducted three times in each of the positions. The statistical analysis was based on two analyzed parameters: the average value of excitation and the maximum value of excitation of the vastus medialis muscle.

Results: The VMO muscle shows a higher bioelectric activity in the extended position of the knee joint than when the joint is flexed, in a statistically significant way ($p<0.01$). The result is significant for both the average and the maximum muscle activation values.

Conclusions: In the extended position of the knee joint, the vastus medialis muscle shows the highest bioelectric activity during isometric contraction, which makes it the best position for isometric exercise to strengthen this muscle.

Key words

rehabilitation, vastus medialis oblique muscle, surface electromyography, bioelectric activity, exercising position, isometric exercises, movement analysis.

Introduction

The quadriceps femoris is one of the main muscles that provide active stabilization of the knee joint. It is responsible for the extension movement of this joint. It protects the body against falling backward, and stabilizes and maintains balance during walking and standing. It consists of four parts: the musculus vastus intermedius, the musculus rectus femoris, the musculus vastus lateralis, and the vastus medialis muscle (VM), with a common end tendon forming the patellar ligament, which ends on the tuberosity of the tibia [1, 2].

The VM muscle plays the key role of a static and dynamic stabilizer of the knee. It operates with high strength and speed, with a tendency for “weakening”. This results from its structure, which is dominated by fast-twitch muscle fibers [3]. The VM muscle is adjacent to the femoral bone on the medial and anterior sides. The muscle fibers are arranged parallelly and arch in the distal, lateral, and frontal directions. Its anterior belly reaches much lower than the belly of the lateral head to the base of the patella. The end attachment is located on the upper-medial edge of the patella. Some fibers go to the medial patellar retinaculum, while others run at an angle over the patella and laterally to the distal attachment of the iliotibial tract. Other fibers of the muscle enter the joint capsule. In subject literature, the muscle is sometimes referred to as the vastus medialis obliquus (VMO) muscle. This name refers to the lowest, distal, transverse bundles of fibers of the VM muscle [4], which is connected with a different course of these fibers, and, thus – different function. The distal fibers of the VM muscle pull the patella in the medial direction to counteract the lateral forces and thus prevent the lateralization of the patella [5, 6].

The VM muscle protects the knee joint from the occurrence of dangerous overloads and ensures the correct trajectory of movement of the patella during the movement of the knee joint. However, inefficient work of the VM muscle carries very negative consequences for the motor system in the lower limb and, as a consequence, for the whole body. The failure of the muscle is usually caused by its weakening or atrophy, which may occur as a result of such dysfunctions as mechanical trauma to the muscle – pulling, tearing or contusion, pathological changes in the knee joint – gonarthrosis, incorrect anatomic development, knee valgus, damage to the ligament apparatus, excessive lateral pressure syndrome (ELPS). All of them lead to hypokinesia, i.e., reducing the motor activity of the limb as a result of the pain and changes to the movement pattern resulting from disease and long limb immobilization at the initial stage of the treatment process. A large group are surgeries in the knee joint, such as total knee replacement or the reconstruction of ligaments. In the first days after such surgeries, the area of the knee joint is often swollen and painful, which makes it more difficult to start the physiotherapy and rehabilitation processes. This results in decreased muscle tonus and atrophy of the quadriceps, particularly its medial head [7, 8].

The VM muscle may also be weakened in young, physically active persons who are amateur joggers. During long running workouts, at a constant pace and intensity, the VMO works only in specific positions. This may lead to disturbed muscular balance of the individual heads of the quadriceps. The resulting imbalance between the lateral and medial heads of the quadriceps has a negative influence on the ergonomics of the movement while running, which additionally increases the pathology of the muscle and may, in time, lead to the occurrence of overload trauma in the patellofemoral joint [3].

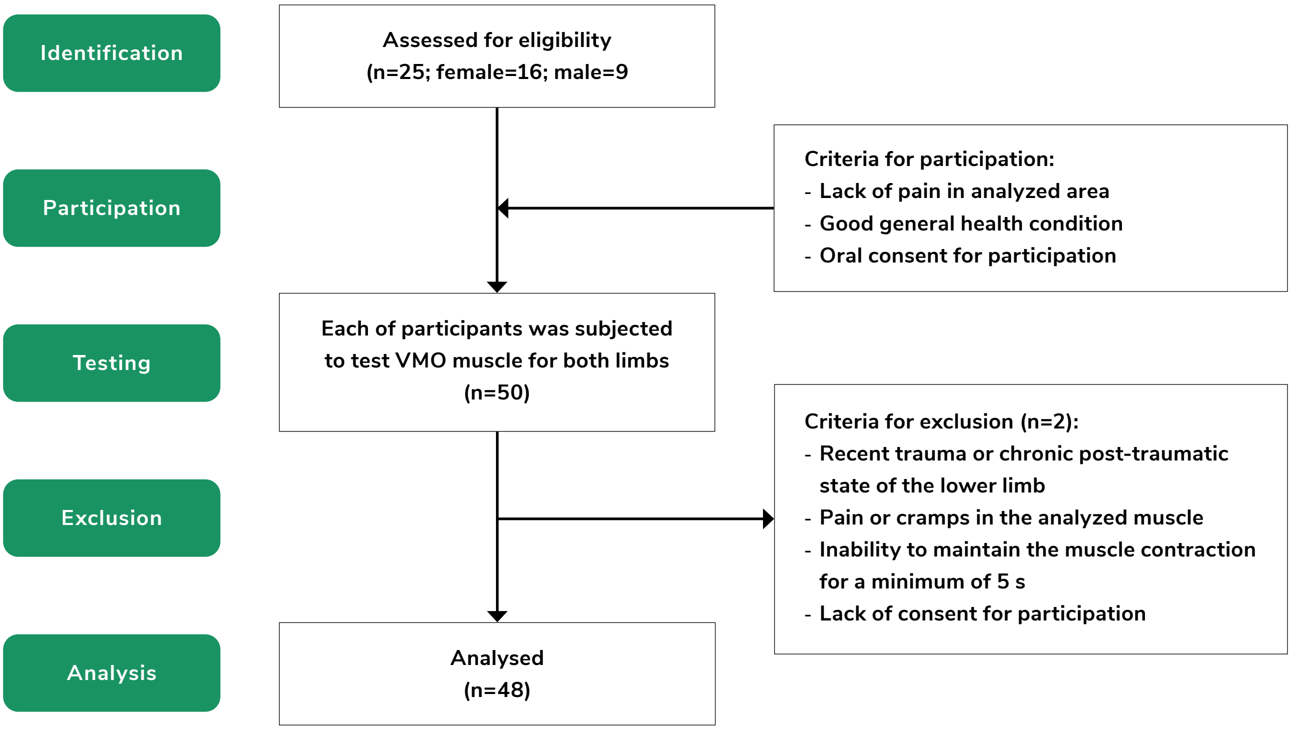
Aims

The study aimed to find and determine such position of the knee joint in which the VMO muscle shows the highest bioelectric activity during isometric contraction. To this end, the surface electromyography test was used. The test was supposed to show what exercises and in which position will be the most effective for physiotherapists working with patients who have deficits in the strength and mass of the vastus medialis.

Materials and methods

Tests were conducted on 25 students of the medical faculties of the Health Sciences Department of the Collegium Medicum at Jagiellonian University. The age of the group was 20-26, an average age of 22.6 years (±1.6). The group of subjects included 16 women with an average age of 23 years (±1.1) and 9 men with an average age of 22 years (±2.12). Each participant was subject to tests of the VM muscle in both limbs, resulting in 50 cases (n=50). All students participated in the tests consciously and voluntarily. The full test was conducted on 48 cases (n=48). The flow of participants in the tests, along with the inclusion and exclusion criteria, are presented in **Figure 1**.

Figure 1. The flow of participants in the tests and the inclusion and exclusion criteria.



Participants were informed about the purpose of the tests and expressed their consent. The tests were conducted in order to determine the influence of limb position on the efficiency of work of the VMO muscle.

Before starting the tests, each participant was subject to formal analysis to determine if they met the inclusion criteria. In order to ensure identical conditions, the tests were conducted with the use of the BIODEX System. It enabled the researchers to achieve a constant resistance force for each isometric contraction and the same starting position for all test participants. Additionally, thanks to the BIODEX system, resistance was always applied to the same spot, regardless of the test.

Surface electromyography (sEMG) tests were conducted with the use of the TeleMayo G device with MyoResearch software, Noraxon MT400. The equipment was used to measure the excitation of the VM muscle during isometric contraction. The Noraxon MT400 software was used to record and save all measurements. After the end of the test, the Noraxon software was used to prepare reports that contained the following information: duration of the test [s], mean [M], and maximum [max] excitation value [μV].

The statistical analysis of the results was conducted in the Statistica 13.3 software by StatSoft and in Microsoft Excel 2020. In order to select the appropriate statistical test, it was necessary to analyze compliance with a normal distribution of the analyzed properties. To this end, the Shapiro-Wilk test was applied. The statistical significance of the analyzed properties was verified using the parametric t-Student test for dependent samples. The adopted level of statistical significance for the conducted parametric tests was 0.01 ($\alpha=0.01$), which means a 1% level of uncertainty. Results on the level $p<0.01$ were considered statistically significant. The results are presented in the form of graphics and tables.

The tests were conducted in the isokinetic room of the Physical Therapy Department of the Collegium Medicum of Jagiellonian University.

Each participant was appropriately prepared before conducting the electromyographic test. Preparing the patients for tests and applying electrodes was compliant with SENIAM recommendations [9]. Before the electromyographic test, the patient's skin was prepared for applying surface electrodes, using alcohol-based disinfectant to clean and degrease the desired spots. Disposable, pre-gelled electrodes with silver chloride of a conductive diameter smaller than 1 cm were used. In compliance with the methodology of bipolar surface electromyography, the test used three electrodes, of which two were active electrodes and the third one was the reference electrode. According to the guidelines of SENIAM, active electrodes were placed in 2/3 of the distal part of the VMO muscle, while the reference electrode was placed above the tuberosity of the tibia. During the application of electrodes, the patients were sitting down, with a flexed knee joint and the torso leaning slightly backward.

The tests were conducted with the use of the BIODEX system, which allowed us to obtain identical test conditions. The bioelectric activity of the medial head of the quadriceps was measured on the BIODEX recliner in the simple seat position with back support. The VMO muscle was tested in the extended position of the knee joint (from 5°to 0°) – position No. 1; (**Fig. 2**) and in the flexed knee joint position (90°) – position No. 2 (**Fig. 3**).

In both positions, resistance was applied at the anterior surface of the distal part of the shank. The participants were asked to attempt to perform an isometric contraction of the quadriceps in a specific position of the knee joint with maximal resistance. During the test, the patient maintained the dorsal bend of the ankle joint; they could not raise their buttocks above the recliner or lean on their arms. Two commands were used during the test: “start” and “stop”. At the “start” command, the patient extended the lower limb in the knee joint and maintained constant muscle tension for a period of 5-10 seconds. The "stop" command informed the participants that the test had been recorded and they could now relax their muscles.

Three measurements (tests) were taken in each position at intervals of 1 minute. A 5-second report was generated from each test, containing information about the average [M] and maximum [max] value of muscle excitation.

Then, a collective report was generated for the excitation of the VM muscle in the extended position and with the knee flexed at the angle of 90°. The report contained:

- average value of muscle excitation from three tests [μV];
- average value of maximum muscle excitation from three tests [μV];

Figure 2. The extended position of the lower limb of the participant during sEMG test with use of the BIODEX system – position No. 1.

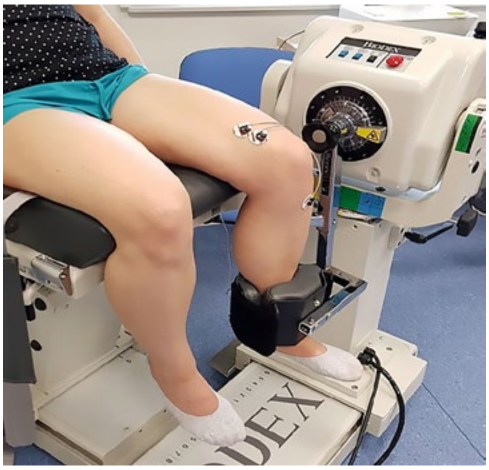


Figure 3. Position of the lower limb of the participant in flexion of the knee joint at the angle of 90° during the sEMG test with the use of the BIODEX system – position No. 2.

For each analysed muscle, two collective reports were generated, respectively for the electric activity of the muscle in the extended position and with the knee joint flexed at the angle of 90° degrees. The obtained values were grouped and compared in terms of significant statistic differences.

Results

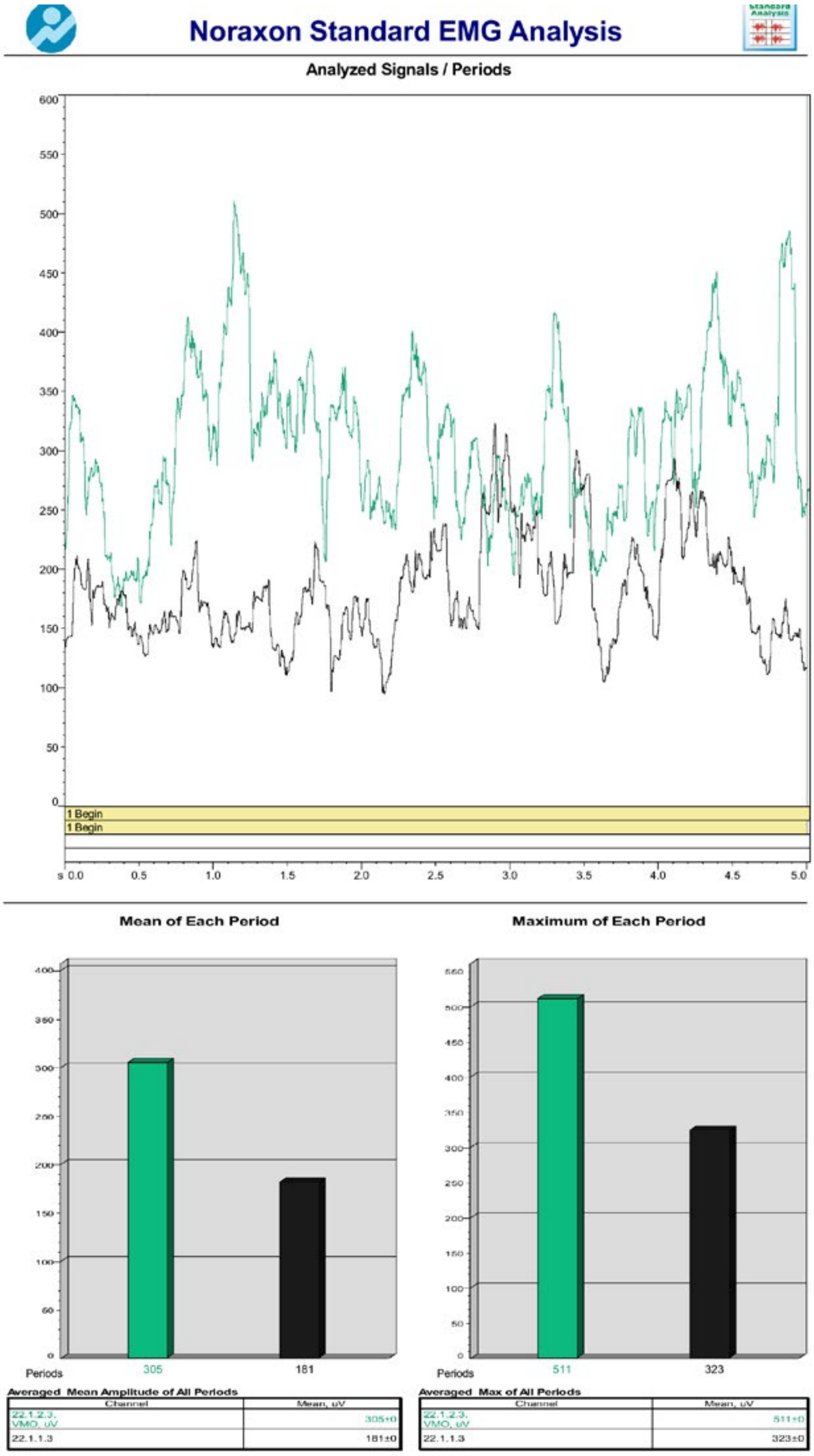
In order to verify whether the bioelectric activity of the VM muscle significantly differs depending on the position of the knee joint, parameters from the collective reports were used to compare: the average values of bioelectric activity [μV] and the maximum values of bioelectric activity [μV] of the muscle during contraction in the extended position – position No. 1, and in the position with the knee flexed at an angle of 90° – position No. 2.

A sample collective report comparing the bioelectric activity of the muscle depending on the initial position is presented in **Figure 4**.

First, the average muscle excitation during contraction in the extended position of the knee joint [position 1] was compared with the average muscle excitation in the flexed knee position of the knee joint [position 2]. The average value of bioelectric potential generated during contraction in the extended position is more significant than the average value of muscle excitation when the knee is flexed. The average value of muscle excitation is 263.5 [μV] (±161.8) – for position No. 1, and 199.4 [μV] (±137.4) – for position No. 2. The difference in average muscle excitation depending on the position was 64.5 [μV]. The above distribution of the data is presented in **Figure 5**.

The maximum muscle excitation values in positions No. 1 and position No. 2. were compared in the same way. The average value of the maximum electric potential of the muscle is also higher during contraction in the extended position of the knee than the electric activity of the muscle measured in the flexed knee position. The average for position 1 equals 429.9 [μV] (±264.3), and for position 2 it is 317.1 [μV] (±214.7). The difference between maximum muscle excitation values depending on the initial position was 112.8 [μV]. The above distribution of the data is presented in **Figure 6**.

Figure 4. Collective report generated with use of Noraxon software. The diagram shows the bioelectric excitation of the VM muscle during a 5-second contraction in the extended (green) and flexed knee (black) positions. The tables present the average and maximum values obtained in the tests.



Noraxon Standard EMG Analysis

Analyzed Signals / Periods

Mean of Each Period

Maximum of Each Period

Averaged Mean Amplitude of All Periods

Channel	Mean, uV
22.1.2.3. VMO, uV	305±0
22.1.1.3	181±0

Averaged Max of All Periods

Channel	Mean, uV
22.1.2.3. VMO, uV	511±0
22.1.1.3	323±0

Figure 5. Average values of excitation of the VM muscle during contraction in subsequent knee positions: 1 – muscle contraction in extended knee position: mean = 263.5 [μV] (SD=161.8; min=77.7; max=765); 2 – muscle contraction in flexed knee position: mean = 199.4 [μV]; (SD=137.4; min=36.8; max=635); n=48.

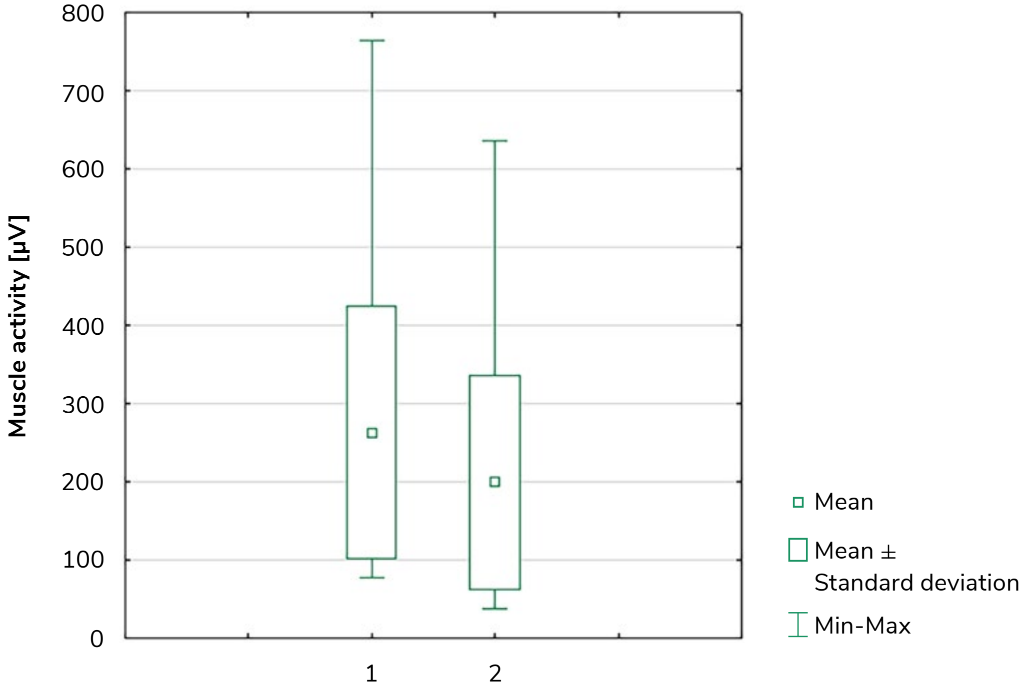
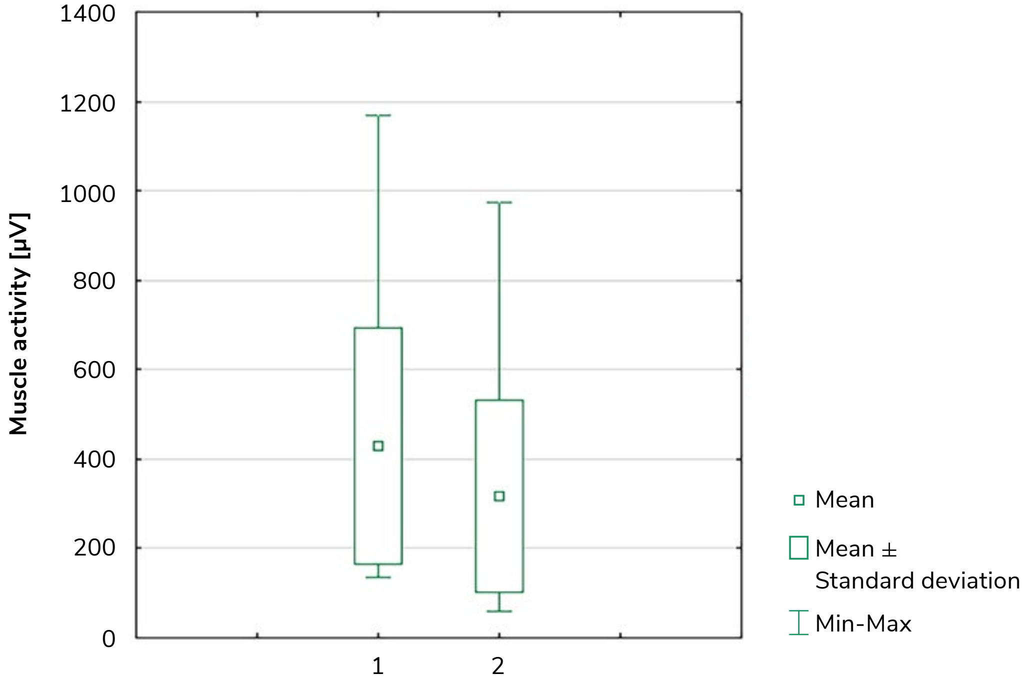


Figure 6. Maximum values of excitation of the VM muscle during contraction in subsequent knee positions: 1 – muscle contraction in extended knee position: mean = 429.9 [μV] (sd=264.3; min=134; max=1167.3); 2 – muscle contraction with knee position: mean = 317.1 [μV]; (sd=214.7; min=60.1; max=972.3); n=48.



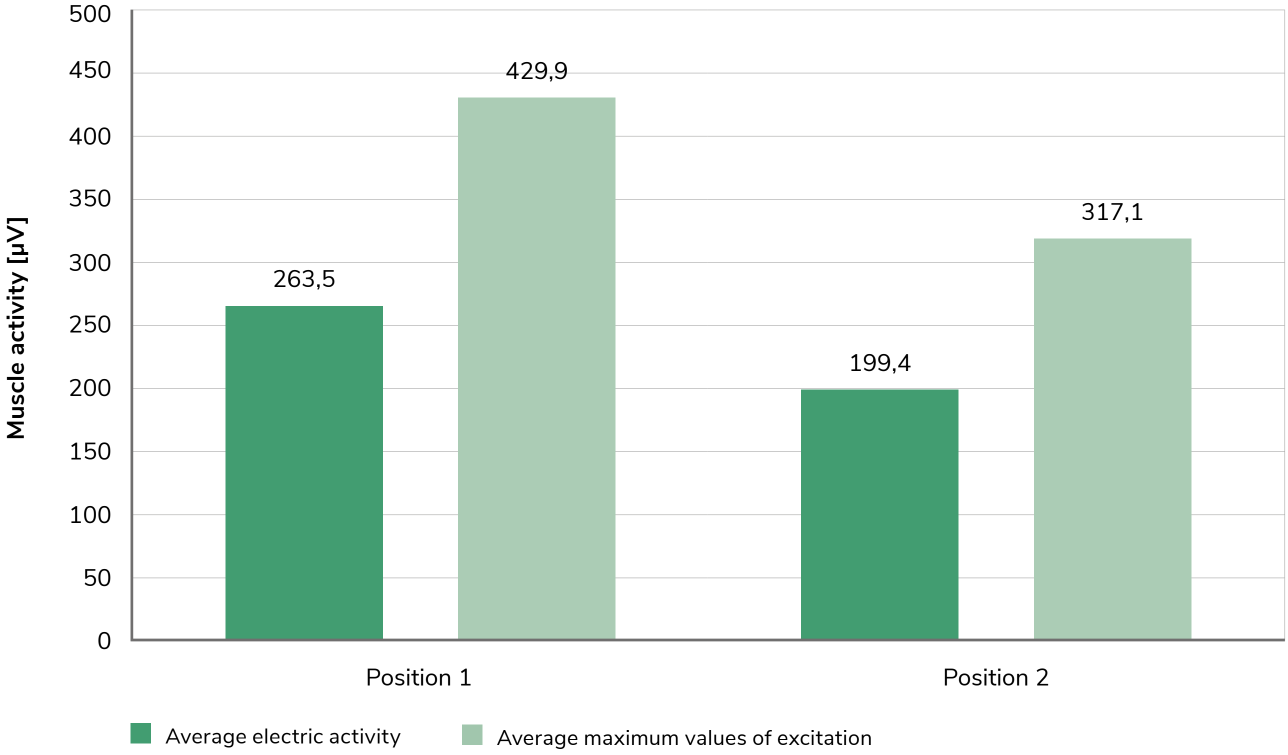
Then, the obtained results for both parameters were compared (**Fig. 7**). The diagram presents the values of the average and maximum bioelectric activity of the VM muscle depending on the initial position of the knee joint in which the tests were conducted.

The data presented in the figures above (**Figs. 5-7**) demonstrate that both the average and maximum values of the electric potential of the VM muscle are higher during contraction in the extended position of the knee joint. Based on that, one may assume that the muscle shows higher bioelectric activity in position 1. In order to verify whether these differences are statistically significant, the t-Student test of the significance of differences between the average values was conducted (**Table 1**).

The t-Student test value for average bioelectric potential values was t-4.93; p<0.01. This demonstrates that there is a statistically significant difference between the average values of bioelectric activity of the muscle depending on the position of the knee joint. This means that in the extended position of the knee joint, the average value of the bioelectric potential generated during the contraction of the VMO muscle is significantly higher than in the flexed knee position.

The result of t-Student test for the maximum values of the bioelectric activity of the muscle, which was t=5.66; p<0.01, revealed a statistically significant difference between the average values of the analyzed parameter depending on the position of the knee joint. Thus, in the extended position of

Figure 7. Comparison of the analyzed parameters – the average electric activity and the average maximum values of excitation of the VMO muscle during contraction depending on the initial position. Position 1 – extended knee joint position, position 2 – flexed knee joint, n-48.



the knee joint, the maximum values of bioelectric activity generated during contraction are significantly higher than in the flexed knee position.

In conclusion, it may be stated that the position of the knee joint in which the VM muscle is activated significantly influences the muscle excitation level. The VMO muscle shows a significantly higher bioelectric activity concerning all analyzed parameters in the extended position of the knee joint than when the joint is in the flexed position.

Table 1. Parametric t-Student test for dependent samples. The test was conducted for an average and maximum value of bioelectric potential during the contraction of the VM muscle, depending on the initial position of the knee joint.

Average values of bioelectric potential				
	M ± SD	t-test value	df	p
Extension	263,5 ± 161,8	4,93	47	**0,000010**
Flexion	199,4 ± 137,4			
Maximum values of bioelectric potential				
	M ± SD	t-test value	df	p
Extension	429,9 ± 264,3	5,66	47	**0,000001**
Flexion	317,1 ± 214,7			

Abbreviations: *M, mean; SD, standard deviation; df, degrees of freedom; p, level of statistical significance.*

Discussion

Medical literature provides numerous publications on sEMG, conducted in compliance with strictly defined standards. Together with electroneurography, it is used as an additional diagnostic test in many neuromuscular diseases. However, there are fewer articles on surface electromyography sEMG, which is a valuable source of information about the functional assessment of the patient's muscles for orthopedic and physical therapy purposes. The use of the sEMG technique in scientific research may positively influence the development of knowledge on physical therapy. It may be used to verify the usefulness of various therapeutical methods, exercises, and clinical tests applied by orthopaedists and physical therapists [10, 11].

The aim of the present article was to analyze whether and how the position of the knee joint during isometric contraction influences the bioelectric activity of the VMO muscle. The tests were motivated by the will to determine a position, in which the muscle will show the highest bioelectric activity during isometric work, translating into determining the optimum exercising position to strengthen the muscle during rehabilitation. The results of our work may be considered and used in the professional work of physical therapists while eliminating the muscular imbalance between the elements of the quadriceps that results from dysfunctions of the knee joint.

In the described tests bioelectric activity of the muscle was measured here times in both positions. As a result, an average result of the bioelectric activity of the muscle was obtained, which was not prone to interferences. Furthermore, the results were processed based on two parameters: the average and maximum value of the bioelectric activity of the muscle, in order to compare whether the obtained results were significant for both selected parameters.

In the publication entitled "The Influence of Various Forms of Physical Exercise on the Bioelectric Activity of the Quadriceps - Preliminary Findings" [12], the authors tested various forms of physical activity, i.e., isometric exercises, exercises in open kinematic chain, elements of therapeutical methods – PNF and stationary bike exercises, in terms of the bioelectric activity of the quadriceps. For this purpose, the sEMG test was applied. The authors demonstrated that the medial and lateral heads of the quadriceps show the highest activity during isometric contraction with the synergy of the dorsal bend of the foot in the position of knee joint at 0°. The results obtained by the authors of that study are identical to the results presented in this paper, which confirms that the tests were conducted correctly and increases their substantive significance. The authors of the study also pointed out that similar values of bioelectric activity were obtained during isometric contraction of the quadriceps against external resistance in the OKC exercise when the knee joint was flexed at 90°, 45°, and 15°. Thus, it will be reasonable to use isometric exercises in the position close to 5° – 0° in early post-trauma or post-surgery rehabilitation in the knee joint, especially, if a higher degree of bending the knee is hindered or painful.

Moreover, physical therapy aimed at restoring the strength of the VM muscle should involve isometric exercises in the extended position of the knee joint because this causes the highest excitation of the muscle, which has been proved in this article. Bronikowski et al. [12] specified that in the first phase of post-surgical rehabilitation of the knee joint, it is recommended to use isometric exercises in the extended position of the knee joint. They pointed out that these exercises brought the best results, as they activated the quadriceps the strongest. At the same time, they are safe for the patient because, as opposed to open kinematic chain exercises, they generate low loads to periarticular structures.

The results obtained in this study concern the bioelectric activity of the VM muscle in an isolated position during isometric work. The methodology was used to recreate the conditions of working with patients during exercises to strengthen the weakened muscle. The obtained results may translate into the work of the muscle in such dynamic conditions as walking or concentric exercises. Świtoński and Głowacka [13], in their publication, determined the distribution of the bioelectric activity of the VM depending on the walking cycle. The tests were conducted with the use of sEMG. It was noted that the muscle activity was the highest from 0% to 40% of the walking cycle, then it decreased and remained near zero from 40% to 80% of the cycle, and finally rose again in the range of 80-100%. The maximum bioelectric potential of the muscle was noted in the range from 0% to 10% of the walking cycle. The above data reveal that the highest results of the VM muscle activity were noted during the initial support phase – contact of heel with the ground and pressing the whole foot to the ground – and in the final phase of transport. This means that the VM muscle is the most active in the extended position of the knee joint and that its activity is low, nearing zero, in the flexed knee position. The research conducted by the quoted authors allows us to conclude that the VM muscle shows higher activity in the extended position of the knee joint and also during isometric contraction. Although the aforementioned tests were conducted on one subject only, which might raise doubts about whether the obtained results are different for the rest of the population, the results obtained by the authors of this paper and the shape of the muscle activity curve are similar and comparable to data obtained by other authors available in subject literature [14].

Based on the results obtained in this study, below are three exercises in which the VM muscle will show the maximum bioelectric activity:

1. Initial position: lying on the back/sitting up straight with support, with a roller below the knee joint. Objective: to extend and maintain the isometric contraction of the quadriceps for 5-10 seconds while simultaneously consciously activating and maintaining a constant tension of the medial head of the quadriceps for the whole duration of the exercise. Progress of the exercise: extending the duration, placing a load in the distal part of the crus.

2. Initial position: lying to the front, feet placed in the dorsal bend position. Objective: to extend and maintain the isometric contraction of the quadriceps for 5-10 seconds while simultaneously consciously activating and maintaining a constant tension of the medial head of the quadriceps for the whole duration of the exercise. Progress of the exercise: extending the duration of the exercise.

3. Exercise, which is a modification of the one proposed by Worobel et al. [15]. However, the authors proposed a half-squat to the angle of approx. 45° in the knee joint, but our results demonstrate that a much lower angle – close to 5° – will be better.

4. Initial position: standing on both legs with knee joints flexed at a minimal angle (close to a straight position). Objective: to maintain the isometric contraction position for 5-10 seconds while simultaneously consciously activating and maintaining a constant tension of the VM muscle for the whole duration of the exercise Progress of the exercise: extending the duration of the exercise.

Conclusions

The level of bioelectric activity of the VMO muscle depends on the position of the knee joint in which the muscle is activated. In a position similar to the knee joint extension, the VMO shows the highest bioelectric activity during isometric contraction. In situations of a deficit of strength and mass of the VM muscle, it should be strengthened through exercises based on isometric contraction in a position of the knee joint close to the extended position. The surface electromyography test is a useful tool for the assessment of the bioelectric potential of muscles during isometric contraction.

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