信大・医短・紀要
Vol 25, 1999

An Electromyographic Investigation of the Quadriceps Muscles During the Performance of Multiple Angle Isometric Exercises

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ABSTRACT

In clinical practice, physical therapists often employ various forms of quadriceps strengthening exercise to target the vastus medialis oblique (VMO) and the vastus medialis (VM) component of the quadriceps muscle. These strengthening exercises usually consist of multiple angle isometrics (MAI) performed throughout the range from 0° to 120° knee flexion. There is no evidence that any of these exercises is able to selectively target the individual component of the quadriceps muscle group. The aim of this study is to provide electromyographic evidence of quadriceps muscle selectivity during the performance of MAI exercise. Eleven subjects (7 females and 4 males) participated in this study. The mean age of subjects was 19.36+1.43 years, and the mean weight was 53.00+5.16 kg. Ag/AgCl surface electrodes were attached to the subjects' thigh, at sites corresponding to the vastus lateralis (VL), VM, VMO, and the rectus femoris (RF). Subjects were asked to perform isometric knee extension exercises at 7 positions corresponding to 20°, 30°, 45°, 60°, 75°, 90°, and 110° knee flexion. Each exercise was performed for 3 repetitions ; with a 5-seconds hold period, and a rest interval of 30 seconds. The order of exercise was randomized. The raw EMG data was processed using a Butterworth band pass filter (10 to 240 Hz), rectified and integrated (IEMG). The IEMG data was analyzed using a paired T test. The level of significance was set at 0.05. In general, the results showed that the mean IEMG of the RF, VMO and VL increased as knee flexion angle increased while the mean IEMG of the VMO remained relatively unchanged throughout the tested range. The VM/VL

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ratio decreased, while the VMO/VL ratio increased as knee flexion angle increased. These results demonstrate that it is possible to selectively exercise the different components of the quadriceps muscles using multiple angle isometric exercises between 20° and 110° knee flexion.

Key Words :
Electromyography, Quadriceps, Vastus medialis, Vastus lateralis, Isometric exercises

INTRODUCTION

In patients with patellofemoral disorders and other conditions affecting the knee, physical therapy treatment often involves exercises to the quadriceps muscles[1~3]. In particular, the vastus medialis (VM) and the vastus medialis oblique (VMO) muscles are selectively strengthened at the expense of the vastus lateralis (VL) and other muscles[4~6]. However, there is little evidence to suggest that it is indeed possible to target the VM and VMO muscles during the performance of these exercises[7~16].

Mirzabeigi et al[7] investigated the VMO in comparison with the VL, the vastus intermedius (VI), and VM during the performance of nine types of exercises in eight normal subjects. These knee exercises included isometric knee extension with (1) the hip at neutral, (2) the hip at 30° external rotation and (3) the hip at 30° internal rotation ; isokinetic knee extension (4) through full range ; and (5) through the terminal 30 degrees arc ; and (6) ipsilateral and (7) contralateral full knee extension in side lying ; (8) standing ; and (9) jumping from full squat. Their results suggested that the VMO muscle could not be significantly isolated during these nine exercises.

Willett et al[8] investigated the effect of weight bearing terminal knee extension in different positions of lower extremity rotation on the VMO/VL ratio in 16 normal subjects. Their results show that the performance of weight bearing knee extension, regardless of the position of the lower extremity rotation, did not selectively activate the VMO.

Herrington and Payton[9] investigated the effects of taping the patella in 20 subjects with patellofemoral pain during the performance of maximal isometric quadriceps contractions. Their results showed that there was no difference between the VMO/VL ratios before and after the application of the corrective tape. This study, however, did not have a control group.

In a controlled study, Miller et al[10] investigated the effect of leg rotation on the VMO/VL ratios during the performance of closed kinetic chain exercises which are usually prescribed for patellofemoral pain in 9 controls and 6 symptomatic subjects. The exercises included step-up and step-down with (1) leg neutral, (2) internally rotated and (3) externally rotated ; and modified wall slides with (4) leg neutral, (5) internally rotated and

(6) externally rotated. Their results showed that external rotation of the leg might affect the VMO/VL ratios in individuals without patellofemoral pain, but not in symptomatic patients. In another similar study by the same authors[11], it was further demonstrated that closed kinetic chained exercises do not preferentially recruit the VMO in subjects with patellofemoral pain.

Zakaria et al[12] investigated the VMO/VL ratios during the performance of open chain kinetic exercises in 20 normal females. The exercises included unilateral quadriceps setting with (1) the ankle in neutral, (2) with ankle in dorsiflexion, and (3) with bilateral hip adduction. Their results showed that there was no preferential activation of the quadriceps during all the three exercises. Their results were supported in another similar study by Karst and Jewett[13] who also demonstrated that the concurrent use of hip adduction during open chain knee extension exercises do not result in preferential strengthening of the VMO. In contrast, Hanten and Schulthies[14] demonstrated that performing hip adduction exercises might selectively activate the VMO. Again, in another similar study by Ng and Man[15], it was shown further that there was no significant effect on the VMO/VL ratios from different hip and ankle positions alone. However, there was a significant hip/ankle interaction such that hip internal rotation combined with ankle dorsiflexion could produce a significantly higher VMO/VL activity ratio. The contradictory results obtained from these studies could be due to different methods of EMG employed (surface EMG versus fine wire EMG), different electrode placements and techniques, and the performance of similar but not identical exercises.

Anderson et al[16] investigated the VMO/VL ratio during squat stance (narrow and wide) and at different knee flexion angles (30, 60 and 90 degrees). Their findings showed that there was no difference in the VMO/VL ratios between the narrow and wide squat stance. However, there was a significantly higher VMO/VL ratio with increasing knee flexion angles. Their findings suggest that the VMO was active throughout the 90 degrees range, and that increasing the knee flexion angles elicited greater activity of the VMO relative to the VL.

Another common knee exercise often used to treat various disorders of the knee is the multiple angle isometric (MAI) exercises. These MAI exercises have been claimed to preferentially activate the VMO, particularly during terminal extension. To date, there have been very few studies that had investigated the preferential activation of VMO during MAI exercises.

The aim of this study is to investigate the activation of the VMO and VL muscles during the performance of multiple angle isometric exercises in normal subjects using surface electromyography.

METHODS

Subjects

Eleven subjects (7 females and 4 males) participated in this study. The mean age of subjects was 19.36+1.43 years, and their mean weight was 53.00+5.16 kg. Subjects were free from any symptoms affecting their lower limbs. All subjects signed an informed consent form before being admitted into the study.

Instrumentation

A four channel electromyographic unit was employed to record the EMG signals from the VMO, VM, VL and rectus femoris (RF) muscles using Ag/AgCl surface electrodes (*M–150*, Nihon Kohden, Tokyo, Japan) in a bipolar fashion. The EMG signals were recorded simultaneously on a digital audiotape (DAT) data recorder, model *RD 135 T* (TEAC, Tokyo, Japan) and also on a computer using the *BIMUTAS* software (Kissei Comtech, Matsumoto, Japan). The subjects' muscle force was recorded on a dynamometer, the *Musculator GT-30* (OG Giken, Tokyo, Japan). The chair of the dynamometer allowed the subject to be seated while the lever arm was adjusted and locked to correspond to the tested angles.

Procedure

Subjects performed stretching exercises (quadriceps and hamstrings) and warm-up on a bicycle ergometer for 5 minutes. The skin overlying the tested muscles were cleaned with 70% isopropyl alcohol and abraded with *Skin Pure*, a skin preparation gel for bioelectrical measurements (Nihon Kohden, Tokyo, Japan) in order to reduce the skin impedance to less than 5 kiloOhms. Skin impedance was measured using an impedance meter prior to attaching the electrodes to the EMG unit. Ag/AgCl surface electrodes were attached to the subjects' thigh, at sites corresponding to VMO, VM, VL and RF in a bipolar fashion (Fig. 1), according to the method described by Zipp[17]. The ground electrode was sited at the skin overlying the patella. The electrodes were attached to a 4-channel EMG unit and the EMG signals were recorded simultaneously on a DAT data recorder as well as on a computer using the *BIMUTAS* software.

Subjects were seated on a testing chair with the hip flexed to 90° and the right lower leg attached to the lever arm which was locked at the required testing angle. The lever arm was in turn attached to the trans-

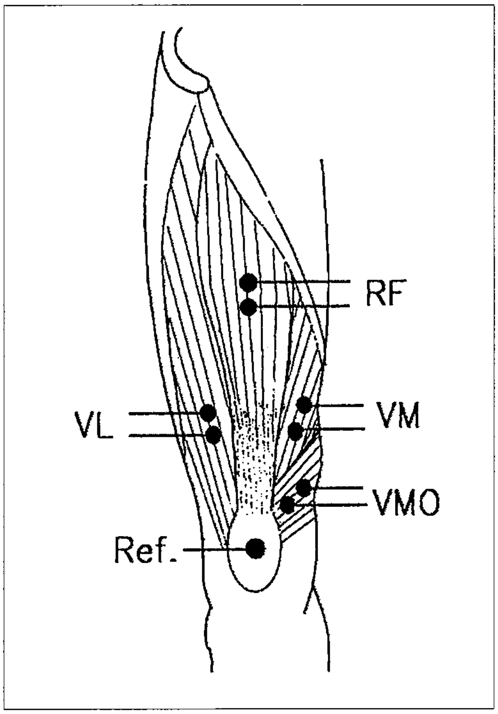

Fig. 1 Electrode placment for bipolar surface EMG electrodes and common reference electrode (Ref). The EMG activity was recorded from the rectus femoris (RF), the vastus lateralis (VL), the vastus medialis (VM) and the vastus medialis oblique (VMO).

ducer of the dynamometer, which provided a digital display of the force being recorded during the test. Subjects were asked to perform isometric knee extensions exercises at 7 positions corresponding to 20°, 30°, 45°, 60°, 75°, 90°, and 110° knee flexion. The EMG signals from the four components of the quadriceps muscles were recorded during the performance of these exercises. The sampling rate was set at 1000 Hz. Each exercise was performed for 3 repetitions, with a 5-seconds hold period, and rest interval of 30 seconds. The order of exercise was randomized to minimize the confounding effects of muscle fatigue.

Data Analysis

All data were recorded and processed using the *BIMUTAS* software (Nihon Kissei, Japan). The raw EMG data was processed using a Butterworth band pass filter (10 to 240 Hz), and then rectified and integrated (IEMG). In order to determine if the four muscles (RF, VL, VM and VMO) could be selectively activated at each of the 7 positions of knee flexion, a paired t-test was carried out on the mean IEMG for each of the muscles. In addition, it was necessary to determine the activation of the VM and VMO muscles in relation to the VL muscle, in order to compare the results of this study with previous studies[7~16]. The main aim of comparing the VM/VL ratio and the VMO/VL ratio was to determine the muscle balance between the two opposing medial and lateral components of the quadriceps muscle. It has been claimed that muscle imbalance rather than specific muscle weakness is the cause of patellofemoral dysfunction[18]. In this regard, the IEMG data for VM and VMO muscles were divided by the VL muscle, to give the VM/VL ratio and the VMO/VL ratio respectively. These ratios for each of the seven knee flexion angles were analyzed using the paired T test. Statistical analysis was carried out using the *SPSS 7.5 for Windows* (SPSS Inc., Chicago, USA). The level of statistical significance was set at $p<0.05$.

RESULTS

Fig. 2 summarizes the mean force-angle relationship of the quadriceps muscle. The quadriceps force-angle relationship showed the peak force occuring at 60° and 75° knee flexion (Fig. 2).

The mean IEMG of the RF, VL, VM, and VMO muscles in relation to knee flexion angles, as well as the results of the paired-T tests, are given in Fig. 3, 4, 5, and 6 respectively. The mean IEMG of the RF, VL and VMO increased as knee flexion angle increased (Fig. 3, 4, 6). The mean IEMG of the VM, however, did not change with varying knee flexion angles and remained fairly constant throughout the tested range (Fig. 5). Results from the paired-T tests showed a sig-

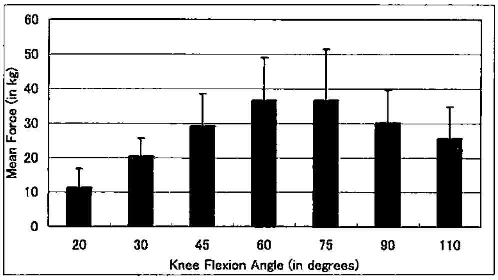

Fig. 2 Force-Angle relationship of Quadriceps muscle (mean + SD).

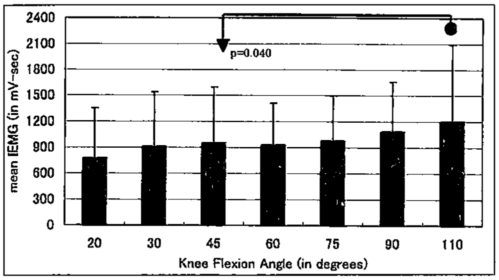

Fig. 3 Mean IEMG (+SD) of Rectus Femoris (RF) in relation to angle of knee flexion and results of paired t-tests.

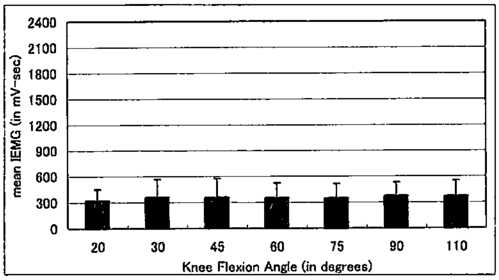

Fig. 5 Mean IEMG (+SD) of Vastus Medialis (VM) in relation to angle of knee flexion and results of paired t-tests.

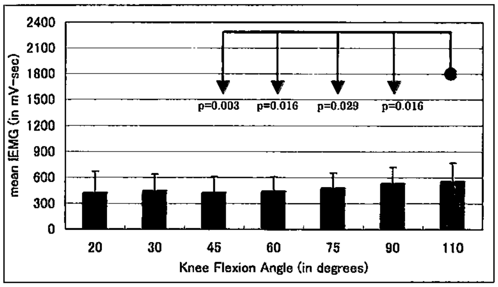

Fig. 4 Mean IEMG (+SD) of Vastus Lateralis (VL) in relation to angle of knee flexion and results of paired t-tests.

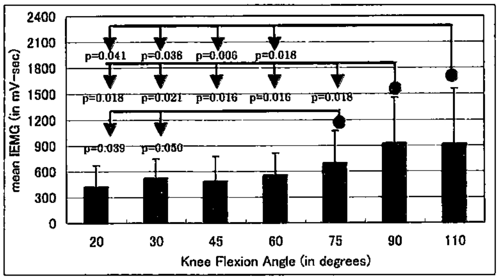

Fig. 6 Mean IEMG (+SD) of Vastus Medialis Obliquus (VMO) in relation to angle of knee flexion and results of paired t-tests.

nificant difference between the mean IEMG of RF at 45° and 110° knee flexion (p=0.040). The mean IEMG of the VL showed significant differences between 110° and 45° (p=0.003), 60° (p=0.016), 75° (p=0.029) and 90° (p=0.016) (Fig. 4). The mean IEMG of the VMO (Fig. 6) showed significant differences between 110° and 20° (p=0.041), 30° (p=0.038), 45° (p=0.006), and 60° (p=0.018). There were also significant differences between 90° and 20° (p=0.018), 30° (p=0.021), 45° (p=0.016), 60° (p=0.016), and 75° (p=0.018), as well as between 75° and 20° (p=0.039), and 30° (p=0.050) (Fig. 6).

The relationships of the VM/VL and VMO/VL ratios, as well as the results of the paired-T tests, are given in Fig. 7 and 8 respectively. In general, the results showed that the VM/VL ratio decreased (Fig. 7), while the VMO/VL ratio increased as knee flexion angle increased (Fig. 8). Fig. 7 shows significant differences in the VM/VL ratios between 110° and 20° (p=0.042), 45° (p=0.035), 60° (p=0.013) and 90° (p=0.026); and between 90° and 60° (p=0.040). From Fig. 8, the VMO/VL ratios were significantly different between 20° and 75° (p=0.045), 90° (p=0.018), and 110° (p=0.040). The VMO/VL ratios were also significantly different between 90° and 30° (p=0.047), 45° (p=0.015), 60° (p=0.011), and 75° (p=0.026); as well as between 45° and 110° (p=0.022) (Fig. 8).

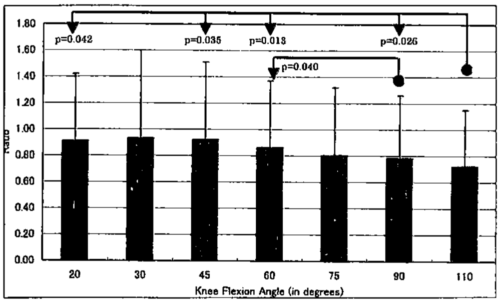

Fig. 7 Mean VM/VL ratio (+SD) in relation to angle of knee flexion and results of paired t-tests.

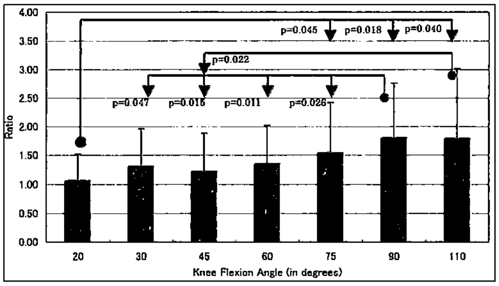

Fig. 8 Mean VMO/VL ratio (+SD) in relation to angle of knee flexion and results of paired t-tests.

DISCUSSION

Fig. 2 demonstrates the force-angle relationship of the quadriceps muscle with the peak force occurring at between 60° and 75° knee flexion. This finding is in agreement with our present knowledge of the force-angle relationship of the quadriceps muscle[19~21]. It can be surmised that the performance of the quadriceps muscle of the subjects in this study is within the normal limits of the general population.

The mean IEMG of the various muscles demonstrated a unique pattern for each component (Fig. 3 to 6). As the knee flexion angle increased, the mean IEMG of the VM component remained relatively unchanged (Fig. 5). The mean IEMG of the VL component increased only slightly from 60° to 110° of knee flexion (Fig. 4). In contrast, the mean IEMG of both the RF and VMO components increased dramatically from 60° to 110° of knee flexion (Fig. 3 and 6 respectively). It is highly probable that the mean IEMG activity of the RF component, being a two-joint muscle, increased due to its lengthened position and hence a better mechanical advantage as knee flexion angle increased. The VMO muscle, however, is only a one-joint muscle and therefore, does not have the same advantage as the RF. The behavior of the VMO in this study is in agreement with the results from the study by Anderson et al[16], but in direct conflict with the rationale of exercising the VMO during terminal extension only from 0° to 30° knee flexion. This study also found that the mean IEMG of VMO remained relatively unchanged within itself and relative to the VL from 20° to 60° knee flexion (Fig. 6 and 8). This finding may help to explain why other studies[7~13] which confined their investigation of the VMO to less than 60° knee flexion did not report any increase in the mean IEMG of the VMO or an increase in the VMO/VL ratio. The rationale of exercising the VMO during terminal extension only should be re-examined in light of this critical finding which is also supported by the results from Anderson et al's[16] study.

Fig. 7 shows the VM/VL ratio decreased significantly with increased knee flexion angle. In order to isolate the VM muscle during exercise, the optimal angle positions are between 20° to 60° knee flexion. In contrast,

Fig. 8 shows the VMO/VL ratio increased significantly with increased knee flexion angle. In order to isolate the VMO muscle during exercise, the optimal angle positions are between 75° to 110° knee flexion.

The results from this study clearly demonstrate that it is possible to selectively target different components of the quadriceps muscle by using multiple angle isometric exercises. The VM component can be isolated at the beginning of the range up to 60° knee flexion, whereas the VMO component can be isolated at the end of the range from 75° to 110° knee flexion.

CONCLUSION

The results from this study challenges the present method of prescribing strengthening exercises for the VMO component of the quadriceps muscle during terminal knee extension exercises from 0° to 30° degree knee flexion. The results also clearly demonstrated that it is possible to selectively target the different components of the quadriceps, vis-a-vis the VM and VMO, by performing multiple angle isometric exercises in the specified range.

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受付日：1999年 9 月24日
受理日：1999年11月29日