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Electromyographic Analysis of Moderate Sustained Isometric Exercises for Vastus Medialis Components

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Abstract

Strengthening of the oblique portion of the vastus medialis muscle (VMO) by moderate isometric exercises, particularly at the early phase of rehabilitation program for acute knee injury is an important part of knee rehabilitation protocols. The goal of this study was to investigate whether moderate sustained isometric exercises at level of 20% and 30% MVC activate the oblique portion of the VMO to a significantly greater extent than longus part (VML) of this muscle. Nine healthy men with no history of knee injury were tested; Multi-channel surface EMG signals were recorded from vastus medialis oblique and vastus medialis longus of the right leg during 70-s isometric contractions at 10%, 20% and 30% of the maximal force using controlled laboratory study. Average Rectified Value (ARV) and Mean Power Frequency (MPF) computed from the surface EMG were significantly increased with contraction intensity for both VMO and VML muscles ($P < 0.05$). However, the rate of change over time in ARV and MPF were significantly greater for VMO than VML ($P < 0.05$). Moderate sustained isometric exercise at 20% and 30% MVC was effective in activating the medial stabilizer of the patella, and therefore, it may be used at the early phase of rehabilitation program to establish patella control as stable base for knee rehabilitation.

Keywords: vastus medialis oblique, EMG, muscle activation, moderate sustained isometric contraction; fatigue

Introduction

The oblique portion of the vastus medialis muscle (VMO) is anatomically positioned to act primarily as an active medial stabilizer of the patella [1]. From the biomechanical point of view, a normal alignment and function of the patellofemoral joint depends on an appropriate balance of medial and lateral forces exerted on the patella by passive structures (e.g., the patellar retinacula) and by active muscular forces [2]. Studies of muscle fiber orientations suggest that the vastus medialis muscle (VM) force component is directed medially by VMO at 40 to 55 degrees and by vastus medialis longus (VML) at 15 to 18 degrees with respect to the femoral shaft [1]. Because VMO muscle fibers place more profound medial force on the patella to offset the strong lateral pull of vastus lateralis muscle (VL), therefore, the muscle is often targeted in rehabilitation protocols to treat patellofemoral tracking disorders [3,4]. Treatment protocols for patella disorders often incorporate exercises to strengthen the VMO muscle preferentially [3,4,5]. Many studies have challenged selective activation of the VMO muscle in comparison with the vastus medialis longus and vastus lateralise muscles during isometric knee extension [6,7]. These studies have often examined exercises that require higher activation amplitudes that may be dangerous to be used during the early phases of rehabilitation for both post operative and acute non operative patella injury. The goal of the treatment following knee injuries is the restoration of maximum knee function while preventing recurrent injury. Muscle activation at levels of 20%-30% maximal voluntary isometric contraction (MVIC) are clinically considered to be safe and effective for retraining neuromuscular control and moderate muscle strengthening [8]. A moderate strengthening of the VMO muscle such that it stabilizes patella at normal anatomical position would act as a starting point for rehabilitation of knee function.

The main purpose of the present study was to analyze muscle activity in two components of the VM muscle over 70s-long sustained fatiguing isometric contractions at 10%, 20% and 30% MVC.

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Any changes in muscle activation and fiber membrane properties during sustained fatiguing contraction affect electromyographic (EMG) features such as amplitude and characteristic spectral frequencies [9,10]. Our research hypothesis was that the magnitude of the EMG changes would be larger in VMO in comparison with VML during sustained contractions at level of 20%-30% MVC, which is considered to be effective for moderate muscle strengthening.

Methods

Participants

Eleven healthy men (age, mean ± SD, 26 ± 3.4 year; body mass 75.4 ± 3.6 kg; height 1.76 ± 0.05 m) participated in the study. All participants were right leg dominant, with no history of knee injury. The study was conducted in accordance with the Declaration of Helsinki and approved by the local ethics committee. Participants provided informed written consent before participation in the study.

Procedures

The knee extension contractions were performed on a Kin-Com isokinetic dynamometer (Chattanooga, TN, USA). The participant was seated comfortably on an adjustable chair of the KinCom with the hip in 90° flexion. The chair position was modified until the knee axis of rotation (tibiofemoral joint) was aligned with the axis of rotation of the dynamometer's attachment arm. The participant was fixed with straps secured across the chest and hips. The right leg was secured to the attachment arm in 90° knee flexion and in neutral position with a Velcro strap as discussed previously (RF). Visual feedback of torque was provided on a screen positioned in front of the participant. The participant was asked to perform three maximal isometric knee extensions of 3-5 s duration in 90° knee flexion, with two min rest intervals between contractions. The participant was encouraged verbally during each trial to exceed the previously obtained torque level. The highest maximal voluntary contraction value was used as a reference for the definition of the submaximal force level for the subsequent sustained contractions. Participants were asked to maintain a constant force at 10%, 20% and 30% MVC for 70s with 20 and 30 min of rest in between contractions respectively. Visual feedback of the force produced was provided to the participant.

EMG Recordings

Surface EMG signals were recorded from two components of the right vastus medialis muscle during sustained isometric contractions (Figure 1). The length from the anterior superior iliac spine (ASIS) to the medial border of the patella was measured as an anatomical reference for positioning the electrodes [11]. Two adhesive arrays of eight equi-spaced electrodes (ELSCH008, SPES Medica, Salerno, Italy; interelectrode distance 5 mm, electrodes 5 mm × 1 mm) were placed at a distance from the patella of 10% and 30% (VMO and VML) of the measured anatomical length, distant from innervation zones. The muscle innervation zones were identified during test contractions with a dry array of 16 electrodes (silver bars, 5 mm long, 1 mm diameter, 5 mm interelectrode distance), as previously described [12]. Prior to placement of the adhesive electrode arrays, the skin was shaved, lightly abraded and cleansed with water. The surface EMG signals were amplified (EMG16, LISiN – Ottino Bioelettronica, Torino, Italy; bandwidth 10–500 Hz), sampled at 2,048 Hz, and stored after 12-bit A/D conversion.

Signal Analysis

In the sustained fatiguing contraction, surface EMG signals were divided into epochs of duration 10% of the contraction time. For each epoch, average rectified value (ARV) and mean power spectral frequency (MPF) were estimated from the central single differential channel of the array. The percent change in ARV and MPF over time were calculated by subtracting the final value from the initial value dividing by the initial value.

Statistical Analysis

Two-way analysis of variance (ANOVA) was conducted to assess the initial value of MPF and ARV at beginning of the sustained contraction with contraction levels (10%, 20% and 30% MVC) and electrode locations (VMO, VML) as dependent factors. A two-way ANOVA was also applied to the percent change in MPF and ARV over sustained contraction, with factors contraction levels and electrode locations. Pair-wise comparisons were performed with the Student-Newman-Keuls *post-hoc* test when ANOVA was significant ($p < 0.05$). Results are reported as mean and standard deviation (SD) in the text and standard error (SE) in the figures.

Results

Initial value of ARV and MPF significantly increased with contraction intensity for both VMO and VML muscle ($p < 0.05$). Initial value of ARV and MPF for VMO were significantly greater than VML ($p < 0.05$) (Table 1).

Average rectified value increased ($p < 0.0001$) during sustained isometric contraction. The percent increase in ARV was depended on force ($p < 0.0001$), muscle ($p < 0.05$) and on the interaction between force and muscle ($p < 0.05$; VMO during 20% and 30% MVC resulted in greater increases than VML) (Figure 2).

Means power frequency decreased ($p < 0.0001$) during sustained isometric contraction. The percent decrease in MPF was depended on force ($p < 0.0001$), muscle ($p < 0.05$) and on the interaction between force and muscle ($p < 0.05$; VMO during 20% and 30% MVC resulted in greater decrease than VML) (Figure 3).

Discussion

The results from this study confirm that sustained isometric exercises at level of 20% -30% MVC activated VMO muscle to a significantly greater extent than VML muscle.

Vastus medialis muscle is a composite of two individual components, VML and VMO. The fiber of VML muscle appears to be more closely aligned with the intermedius muscle and contributing to the knee extension, whereas the fiber of VMO muscle is more obliquely oriented which enable this muscle to play a key role in patella stabilization. Therefore, selective activation of the VMO muscle is often targeted in rehabilitation protocols to treat patellofemoral tracking disorders [3, 4].

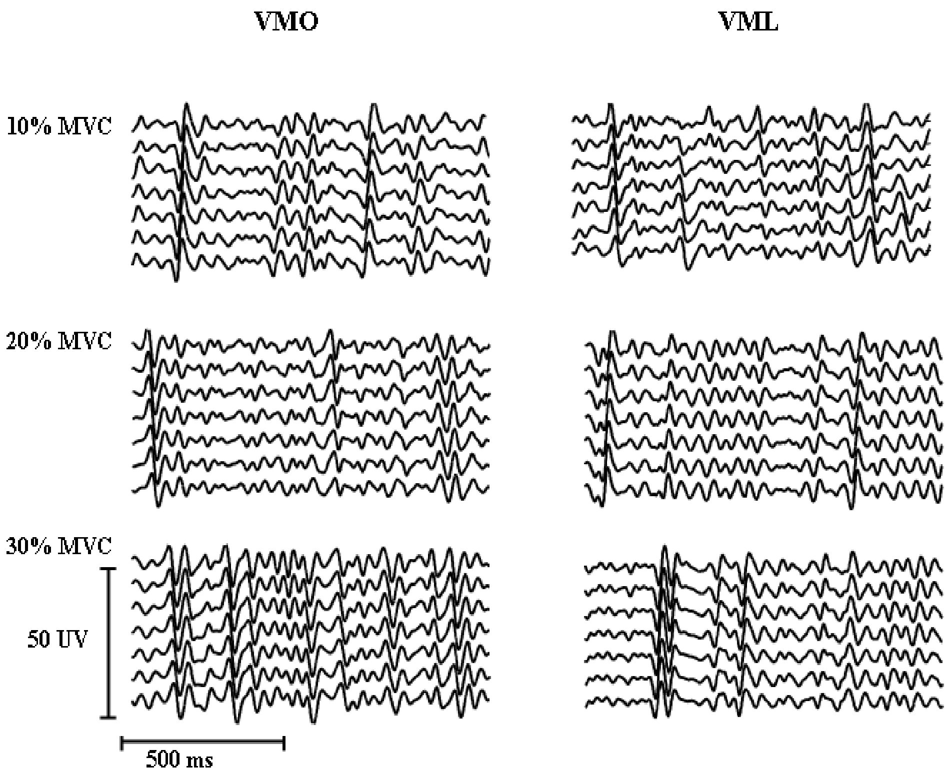

Figure 1: Example of 500 ms long epochs of surface EMG signals detected from vastus medialis oblique and vastus medialis longus of the right leg during sustained isometric contractions at 10%, 20% and 30% MVC.

Table 1: Average rectified value and mean power frequency (mean ± SD, n = 9) assessed for vastus medialis oblique (VMO) and vastus medialis longus (VML) at the beginning of sustained isometric contractions at 10%, 20% and 30% MVC.

		10% MVC	**20% MVC**	**30% MVC**
ARV	VMO	26.6 ± 5.5	37.7 ± 4.9*	49.1 ± 5.1*u*V*
	VML	17.4 ± 3.7	27.2 ± 4.2*	32.3 ± 4.5*u*V *
MPF	VMO	68.3 ± 3.9	76.5 ± 4.2*	79.5 ± 4.9Hz*
	VML	61.2 ± 2.7	65.5 ± 3.1*	71.1 ± 5.2Hz*

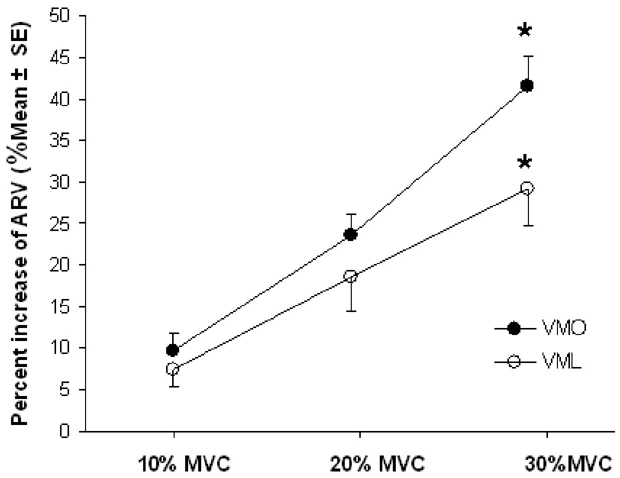

Figure 2: Percent increase in average rectified value (ARV) (mean ± SE, %, n = 9) for the vastus medialis oblique (10% distant from patella) and vastus medialis longus muscle (30% distant from patella) during sustained isometric contractions performed at 10%, 20% and 30% MVC (p <0.05).

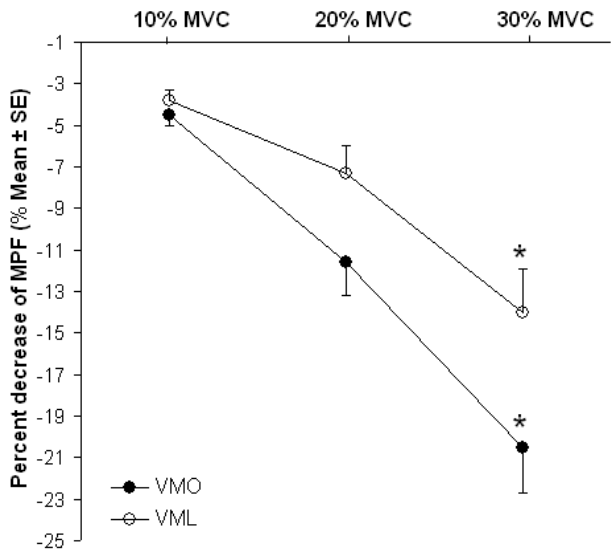

Figure 3: Percent decrease in mean power frequency (MPF) (mean ± SE, %, n = 9) for the vastus medialis oblique (10% distant from patella) and vastus medialis longus muscle (30% distant from patella) during sustained isometric contractions performed at 10%, 20% and 30% MVC. * p < 0.05.

Sustained isometric exercises chosen for this study was based on an implicit assumption; that is, the relative magnitude of the EMG changes for each VM components would be depended on the intensity of muscle activity in those components during a sustained contraction. In the current study, EMG features significantly increased with contraction intensity for both VMO and VML muscle. Moreover, both vastus medialis oblique and vastus medialis longus muscle showed a significant increase in average rectified value of EMG during sustained isometric exercises. The increased EMG activity observed in the load-bearing vastus medialis components support previous findings on muscle activity over sustained isometric contractions at the same or different force level [9,10]. Although average rectified value rate of change over time for both VM components increased significantly as force intensity increased, the increased force intensity affected the vastus medialis oblique and vastus medialis longus muscle differently. The VMO was activated to the greater extent than VML muscle during isometric contractions at 20% and 30% of MVC.

The increased EMG activity during sustained contractions can be explained by a greater muscle effort exerted by the participant to increase motor unit recruitment required to compensate for contractile failure caused by fatigue [13, 9]. During such contractions the activity of gamma afferent-mediated facilitation of *a*-motoneurones increases as result of metabolites accumulation, which may also contribute to the increased motor unit recruitment required to maintain force [14]. Moreover, during sustained contraction a greater increase in ARV was accompanied with a larger decrease in EMG mean power frequency in the vastus medialis oblique muscle, probably due to the higher metabolic accumulations and reducing the excitability of muscle fiber membrane [10]. The observation that EMG rate of changes in the vastus medialis oblique were greater than vastus medialis longus muscle during moderate sustained contractions (20% -30% MVC) indicates that isometric exercises at these moderate levels are effective in activating the key muscle responsible for patella stabilization.

The greatest EMG changes observed in vastus medialis oblique may be related to the greater activity of this muscle [15] to stabilize the patella during sustained knee extension. This mechanism could be a plausible activation strategy of the central nervous system that contribute to reducing the strong tendency of the vastus lateralis muscle (VL) to dominate the movement of the patella during knee extension. Kim et al. (1995) demonstrated that afferent information from medial compartment structures of the knee including medial collateral ligament, medial joint capsule and skin results in activation of the VMO muscle [16]. Given that this afferent input has a strong effect on the gamma-motoneuron system that provides continuous preparatory adjustments to muscle stiffness to protect the knee joint. Later, Dhaher et al. (2005) reported that higher muscle activity is associated with larger muscle stiffness, potentially providing greater joint stability [17]. Larger muscle activity, as seen in VMO muscle during sustained contraction, may indicate the increased stiffness of this muscle to counter valgus load exerted by VL muscle. The largest EMG changes in vastus medialis oblique may also be related to both morphological and architectural characteristics of muscle fibers. Compared with proximal portion of the VM muscle, the most distal part is characterized by more numerous terminal branches [18], higher percentage of fast twitch fibers [19], and greater fascicles angles [20]. These physiological characteristics would be expected to generate high relative peak tension and metabolic accumulation within the distal portion of VM muscle during sustained contraction. A greater metabolic accumulation may further increase activity of the gamma-motoneurones at this region and thus further contribute to the increased motor unit recruitment required to maintain force [14].

Taken together, the result of this study indicated that VMO was activated to the greater extent than VML muscle during moderate sustained isometric contraction. This finding may partly explain why muscle adaptation in VMO is more significant after endurance exercise training [21].

Conclusion

In this study, moderate sustained isometric exercise at level of 20% and 30% MVC resulted in a greater EMG rate of changes in VMO compared with VML muscle, probably due to higher activity of the VMO muscle to stabilize the patella during fatiguing contractions. These results suggested that isometric exercise at this force level is effective in activating medial stabilizer of the patella, and, therefore, it may be used at the early phase of rehabilitation program to establish patella control as stable base for knee rehabilitation.

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