ORIGINAL ARTICLE

Combining isometric knee extension exercises with hip adduction or abduction does not increase quadriceps EMG activity

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Br J Sports Med 2004;**38**:210–213. doi: 10.1136/bjsm.2002.003277

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Accepted 15 April 2003

Objective: To determine if the combined isometric contractions of knee extension/hip adduction and knee extension/hip abduction will elicit a different quadriceps and gluteus medius electromyographic (EMG) pattern as compared to isometric contraction of a uniplanar knee extension exercise.
Methods: Eight healthy young adult volunteers without history of knee or quadriceps injury participated. Surface EMG data were collected from the vastus medialis oblique (VMO), vastus lateralis (VL), and gluteus medius (Gmed) muscles of the dominant leg of each subject during three single leg, weight bearing, isometric exercises (uniplanar knee extension, knee extension/hip adduction, knee extension/hip abduction). All exercises were performed at a position of 60° knee flexion. Three trials lasting 5 s each were performed for each of the three exercises. EMG data from each muscle were integrated and the maximum root mean square activity over a 0.5 s window for each trial was averaged. Analyses of variance were performed with exercise (straight extension, extension/adduction, extension/abduction) as the independent variable and VMO, VL, and Gmed activity and VMO:VL ratio as dependent variables.
Results: A significant main effect for exercise was found for the VMO ($p = 0.006$) and VL ($p = 0.02$), but not the Gmed ($p = 0.25$) or the VMO:VL ratio ($p = 0.13$). For the VMO and VL, the uniplanar knee extension task produced significantly more EMG activity than the extension/adduction or extension/abduction tasks.
Conclusions: Uniplanar knee extension exercises may be more appropriate than combining isometric knee extension exercises with hip adduction or abduction when eliciting maximal VMO and VL contractions.

Dysfunction of the quadriceps muscle has been hypothesised as a cause of patellofemoral pain syndrome (PFPS) with great emphasis placed on the role of the vastus medialis oblique muscle (VMO). Quadriceps dysfunction in PFPS patients has been assessed in various ways including decreased magnitude of electromyographic (EMG) activity of the quadriceps,[1 2] diminished EMG activity of the VMO in relation to that of the vastus lateralis (VL),[3–7] and delayed onset of VMO activation in relation to the VL.[8–13] Consequently, there have been numerous studies that have sought to identify exercises to selectively recruit the VMO in an effort to retrain this muscle.[3 4 14–24]

Because fibres of the VMO attach to the adductor magnus muscle, it has been hypothesised that activation of the VMO may be enhanced by combining active knee extension with volitional hip adduction.[14 19] Open kinetic chain knee extension exercises performed concurrently with hip adduction have not been shown to selectively increase VMO activity.[15–17 19] Conversely, squatting exercises that incorporate simultaneous hip adduction and knee extension have been associated with increased VMO activity.[4 19 23]

It has been speculated that VMO activity may also be enhanced by combining knee extension exercises with hip abduction.[25] The gluteus medius (GMed) is a prime mover of hip abduction and is also critical to controlling internal rotation of the femur during closed kinetic chain activities. Inability of the GMed to eccentrically control femoral internal rotation and VMO inhibition may both lead to excessive lateral tracking of the patella within the trochlea of the femur. Co-contraction of the GMed and VMO may be advantageous in subjects with PFPS; however, only anecdotal reports of this phenomenon may be found in the literature.[25 26] Lam and Ng[24] reported increased VMO activity with closed chain knee extension exercises performed in a position of medial rotation of the hip compared to neutral or laterally rotated positions. They did not, however, report measures of GMed activity.

We are unaware of previous investigations that have assessed muscle activation of the quadriceps and gluteus medius muscles with combined knee and hip motions during single leg, weight bearing exercises. Therefore, the purpose of this study was to determine if combined single leg isometric contractions of knee extension/hip adduction and knee extension/hip abduction altered VMO, VL, and GMed EMG activity compared to uniplanar knee extension isometric contractions.

METHODS

Subjects

Eight healthy young adult volunteers (five males, three females, age = 24 ± 2.5 years, mass = 67.2 ± 10.3 kg, height = 169.5 ± 4.7 cm) without history of knee or quadriceps injury participated. All subjects read and signed an informed consent form approved by the Pennsylvania State University Institutional Review Board prior to participation in the study.

Instrumentation

Surface electromyography (EMG) was used to quantify muscle activation of the VMO, VL, and GMed muscles. EMG hardware and software was manufactured by Biopac (Santa Barbara, CA). The EMG signals were analysed using Acknowledge Software version 3.5 (Biopac Systems, Santa Barbara, CA). The data was high pass filtered at 75 Hz. The following parameters were used: band width 10–500 Hz,

Abbreviations: EMG, electromyographic; Gmed, gluteus medius; PFPS, patellofemoral pain syndrome; VL, vastus lateralis; VMO, vastus medialis oblique input impedance 2 MΩ (differential), common mode rejection ratio 110 dB, maximum input voltage ±10 V, sampling rate 1000 Hz, gain 1000.

Procedures

Prior to electrode placement, the skin was prepared by shaving and vigorously cleaning the appropriate areas with alcohol wipes. The VMO electrodes were placed at an angle of approximately 55° to the long axis of the femur at a location that was over the muscle belly when the knee was in 60° of flexion.[20] The VL electrodes were placed proximal to the distal tendon over the area of greatest muscle bulk. The Gmed electrodes were placed over the proximal third of the line between the iliac crest and the greater trochanter. The interelectrode distance for all three muscles was 2 cm. A ground electrode was placed on the tibial crest of the test leg. The same experienced researcher (JEE) applied the electrodes in a consistent manner to all subjects.

Subjects performed three types of weight bearing, isometric exercises with their dominant limbs: uniplanar knee extension, knee extension/hip adduction, and knee extension/hip abduction. Three trials of 5 s each were performed for each of the exercises. Each trial was separated by 2 min of rest. Verbal encouragement to perform maximally was given to subjects for all trials. Supramaximal electrical stimulation was purposefully not used because we wanted to study maximal ''voluntary'' isometric contractions, not absolute maximal muscle capacity.

For the uniplanar knee extension exercises, a custom-made testing apparatus was used. This consisted of a 30° angled platform covered with a non-slip surface. Participants stood with their back against the wall and their test leg on the platform in front of them with their knee positioned in 60° of flexion (fig 1). This position was chosen because it has been previously shown that greatest activation of the VMO is achieved at 60° of knee flexion during the weight bearing exercise.[6] Knee joint angle was measured with a standard goniometer prior to the start of each trial to ensure consistent positioning across the trials of all subjects. The distance of the platform from the wall was adjustable to account for differences in subject height and leg length. A heavy rubber mat was placed in front of the platform to prevent it from sliding. Shoulder straps ensured that subjects did not move their trunk, hip, or knee when they performed the isometric contractions. Subjects were instructed to lift their contralateral foot and to maximally push up and back into the wall with their test leg.

The knee extension/hip adduction task used the same set-up with the addition of a towel roll between subjects' knees (fig 2). Subjects were instructed to maximally contract their test leg and simultaneously squeeze both knees together (hip adduction). For the knee extension/hip abduction task subjects were positioned with their test leg on the angled platform and their non-test side against the wall. Subjects were instructed to drive their non-test hip into the wall (causing hip abduction contralaterally) with maximal effort as they performed maximal isometric knee extension on their test leg (fig 3).

Data processing

EMG data for each muscle were integrated and the maximum root mean square (RMS) activity over a 0.5 s window for each trial was calculated and used as the dependent variables. The data were not normalised because all comparisons made in this study were within-day comparisons of single muscles and the electrodes were left in place for all tests.[27]

Figure 1 Straight knee extension exercise.

Statistical analysis

Four separate analyses of variance with repeated measures were performed with exercise (uniplanar knee extension, knee extension/hip adduction, knee extension/hip abduction) as the independent variable and normalised maximal RMS activity of the VMO, VL, and GMed, and the VMO:VL ratio as the dependent variables. Tukey's post hoc tests were used to identify specific significant differences in the presence of a significant ANOVA. The level of significance was preset at $p<0.05$ for all analyses.

RESULTS

Muscle activation patterns were significantly different between the three exercises for the VMO ($F_{2,14} = 7.38$, $p = 0.006$) and the VL ($F_{2,14} = 5.17$, $p = 0.02$). Post hoc

Figure 2 Knee extension/hip adduction exercise.

Figure 3 Knee extension/hip abduction exercise.

analysis revealed that for the VMO and VL both the knee extension/hip adduction task and the knee extension/hip abduction task produced significantly less EMG activity than the uniplanar knee extension task ($p<0.03$). There were no significant differences between the knee extension/hip adduction and knee extension/hip abduction exercises for either the VMO or VL. There were no significant differences for GMed activity ($F_{2,14} = 1.53$, $p = 0.25$) or VMO:VL ratio between exercises ($F_{2,14} = 2.39$, $p = 0.13$). Means and standard deviations for all dependent measures may be seen in table 1.

DISCUSSION

Our primary finding was that maximal surface EMG activity of the VMO and VL was greater when performing weight bearing, isometric, uniplanar knee extension exercises compared to exercises combining knee extension with hip abduction or adduction. The VMO and VL responded similarly in our study as the VMO:VL ratio was not significantly different between the three exercises.

Our findings are inconsistent with previous literature that identified enhanced VMO activity with combined knee extension and hip adduction during weight bearing.[4 19 23] We had subjects perform the knee extension/hip adduction in single leg stance whereas previous studies have utilised bilateral squatting exercises.[4 19 23] We chose single leg knee extension/hip adduction because our knee extension/hip abduction exercise required single leg stance. It could be that these novel, single leg stance exercises required volunteers to focus on maintaining their balance and they thus were concentrating more on recruiting postural stabilisers than the quadriceps. Another explanation could be that concentration on producing horizontally directed force (hip abduction and adduction) may have diminished the ability to produce vertically directed force (knee extension). Previously, Yamashita[28] suggested that VMO activity is enhanced by combining knee extension with hip extension. This is most likely more easily accomplished in the closed kinetic chain with a pure sagittal plane exercise than with multiplanar exercises.

Previous studies demonstrating increased VMO activity with knee extension/hip adduction activities used isotonic exercises[4 19 23] while we studied isometric exercises. Isotonic squatting exercises may lead to increased VMO activity because the VMO must be more active in the dynamic stabilisation of the patella during knee movement. While more dynamic activities are certainly a necessity in advanced rehabilitation, uniplanar knee extension isometric exercise may be more appropriate during early rehabilitation where retraining of the VMO is critical to restoring normal patellofemoral mechanics.

Patellofemoral dysfunction may also be related to inadequate control of femoral rotation.[25 26] Excessive internal rotation of the femur may contribute to increased lateral tracking of the patella. During weight bearing activities, the GMed eccentrically controls femoral internal rotation.[29] The GMed has also been shown to be an important contributor to pelvic stability during weight bearing.[30] Inadequate strength or recruitment of the GMed alone, or in combination with VMO dysfunction, may lead to PFPS. While we did not find significant differences in GMed activity during our three exercises, the knee extension/hip abduction task was associated with the greatest amount of GMed activity. Because this task was isometric and did not involve dynamic hip and knee flexion (and associated femoral internal rotation), it may not have caused maximal GMed activity.

Our study was not without limitations. We only examined variables of EMG amplitude and did not measure timing variables. Onset of muscle activation has been shown to be altered in PFPS patients[7 10–13] and clinicians should be mindful of these changes when implementing neuromuscular rehabilitation programs. Another limitation is that our comparisons were of non-normalised EMG signals. While using non-normalised signals allowed us to answer our research question, it may limit the ability to compare our results to those of others who analysed normalised EMG signals. Lastly, our sample size was not large ($n = 8$) and the generalisability of our findings to more diverse populations may be limited. These data provide preliminary answers to our research questions, however a larger study utilising more subjects both with and without PFPS would better control for the considerable intersubject variability of surface EMG, provide for increased statistical power, and expand the generalisability of the results.

CONCLUSION

We found that there was significantly greater surface EMG activity of the VMO and VL during weight bearing, isometric

Table 1 Mean maximum iEMG activity (±SD) of the three muscles during the different exercises

	Straight knee extension	Knee extension/ hip adduction	Knee extension/ hip abduction
Vastus medialis oblique (mv)	1.25* (0.53)	0.96 (0.40)	0.89 (0.31)
Vastus lateralis (mv)	0.42* (0.15)	0.37 (0.13)	0.35 (0.13)
Gluteus medius (mv)	0.15 (0.10)	0.13 (0.007)	0.16 (0.008)
VMO:VL ratio	3.00 (1.04)	2.58 (0.58)	2.58 (0.43)

*Measures significantly greater ($p<0.05$) with straight knee extension exercise compared to the other exercises.

Take home message

If eliciting maximal activity of the VMO and VL during weight bearing isometric exercise is a clinician's rehabilitation goal, a uniplanar knee extension exercise appears to be more appropriate than combining hip abduction or adduction with knee extension.

uniplanar knee extension exercises than with either combined knee extension/hip adduction or knee extension/hip abduction exercises. Further research investigating the muscle activation patterns during various isometric and isotonic exercises commonly prescribed for PFPS is warranted.

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Conflict of interest: none declared.

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