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Biofeedback exercise improved the EMG activity ratio of the medial and lateral vasti muscles in subjects with patellofemoral pain syndrome

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Abstract

Patellofemoral pain syndrome (PFPS) is usually due to weakness of vastus medialis obliquus (VMO) resulting in abnormal patellar tracking. One of the objectives of rehabilitation is to strengthen the VMO so as to counterbalance the vastus lateralis (VL) action during normal activities. This study compared the effects of an 8-week exercise program with and without EMG biofeedback on the relative activations of VMO and VL. Twenty-six subjects with PFPS were randomly allocated into an "exercise" group (Group 1) and a "biofeedback + exercise" group (Group 2). Both groups performed the same exercise program but subjects in Group 2 received real time EMG biofeedback information on the relative activations of VMO and VL during the exercises. After 8 weeks of training, Group 1 had insignificant changes in their VMO/VL EMG ratio ($p = 0.355$), whereas Group 2 had significantly greater VMO/VL EMG ratio ($p = 0.017$) when performing normal activities throughout a 6-h assessment period. The present result reveals that the incorporation of an EMG biofeedback into a physiotherapy exercise program could facilitate the activation of VMO muscle such that the muscle could be preferentially recruited during daily activities.

Keywords: Patellofemoral joint; Physiotherapy; Quadriceps; Electromyography; Pain

1. Introduction

Patellofemoral pain syndrome (PFPS) is a common condition presented with diffused pain in the anterior compartment of the knee with causes other than intra-articular pathologies, peripatellar tendonitis or bursitis (Thomee et al., 1999). The incidence of PFPS ranges from 10% to 28% in the general population and people with high physical activity levels (Almeida et al., 1999; Witvrouw et al., 2000). It often affects people between 10 and 35 years of age and it occurs 2–3 times more frequently in women than in men (Lichota, 2003).

Stability of the patellofemoral joint (PFJ) is largely maintained by soft tissues, in particular, the dynamic balance of the medial and lateral quadriceps muscle. The resultant vector of the knee extensors acting on the patella is normally directed laterally because of the tibiofemoral angle (Huberti and Hayes, 1984). Previous studies (Bose et al., 1980; Goh et al., 1995) had reported that the vastus medialis obliquus (VMO) played an important role in controlling the contact area and pressure distribution in the PFJ. Atrophy of VMO is often associated with PFPS, possibly as a result of the interaction between mechanical and neuromuscular factors (Flynn and Soutas-Little, 1995).

The normal VMO/VL EMG ratio was reported to be about 1:1 (Souza and Gross, 1991) but there were controversies surrounding this ratio in subjects with PFPS. In a study with intramuscular EMG, Powers (2000) reported that the VMO/VL EMG ratio was 0.54 and 0.85 for subjects with and without PFPS, respectively. The lowering of VMO/VL EMG ratio would result in less medial pull on the patella (Davlin et al., 1999) leading to an imbalance

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of shearing and compressive forces on the PFJ during normal activities (Sikorski et al., 1979).

EMG biofeedback is a device that detects the neuromuscular contractions and provides feedback signals to the subject (Dursun et al., 2001). Because an EMG biofeedback system can provide immediate information on the muscle activation pattern, Ingersoll and Knight (1991) stated that the use of EMG biofeedback training to selectively strengthen the VMO as being essential for correcting excessive lateral tracking of the patella for patients with PFPS.

Wise et al. (1984) explored the use of EMG biofeedback coupled with a graded exercise programme and found that with 4–6 weeks of training, there was a change in the PFJ force and a concomitant decrease in pain. Therefore, they concluded that EMG biofeedback was effective for treating patients with PFPS.

It was reported that patients with PFPS had a lower VMO/VL EMG ratio than healthy subjects (Powers, 2000; Souza and Gross, 1991), and such a change in EMG ratio was a predisposing factor for the development of PFPS. An increase in the ratio of VMO/VL EMG implies that there is an increase in medial pull on the patella. Therefore, the EMG ratio of VMO/VL appears to be an important parameter in these patients.

Controversies exist in the literature regarding the altered VMO/VL EMG ratios in patients with PFPS. It is not known whether this alteration can be changed after a physiotherapy exercise program. Furthermore, the effect of exercise on the VMO/VL EMG before and after the training program in subjects with PFPS has not been well studied. Therefore this study was conducted to investigate if subjects with PFPS had differences in VMO/VL EMG ratios before and after a physiotherapy exercise program, and whether the addition of an EMG biofeedback to exercise would alter the VMO/VL EMG ratio during functional daily activities.

2. Method

Twenty-six subjects (16 female and 10 male) aged between 20 and 55 years, diagnosed with PFPS by their attending physicians were recruited for this study. The inclusion criteria were that the subjects had insidious onset of anterior knee pain for at least 6 months without receiving physiotherapy and they experienced pain in at least two of the following activities: ascending stairs, descending stairs, squatting, kneeling, prolonged sitting, hopping or jumping (Cowan et al., 2002a; Dursun et al., 2001). The study was reviewed and approved by the Human Subjects Ethics Subcommittee of the Hong Kong Polytechnic University. All subjects gave their written consent prior to the study.

2.1. Testing procedures

A pretest-posttest, randomized double-blind design was used in this study. At the initial assessment, the VMO/VL EMG values were recorded by a custom designed portable surface EMG system for 6 h, during which the subject assumed a normal daily life to establish the baseline VMO/VL EMG ratio. The custom designed portable surface EMG system was a high precision and low power design, able to operate with a 9 V battery for maximum portability. The unit comprised a main unit with three interface ports. The main unit was a microcontroller based unit with built-in software drivers for the interfaces and computation firmware. The three interface ports were:

(1) A dual channel analog interface for the electrodes,
(2) A compact flash (CF) interface for removable memory modules and
(3) A remote two-column multi-LED display unit.

The detail configuration of the system is as follows:

- Detection of EMG signals of 5 μV to 10 mV;
- Main amplification stage with amplification 1000;
- Frequency response of 20–450 Hz;
- Maximum sampling rate of 1000 Hz for each channel;
- Nominal pre-amplification stage of 4.5 V/V;
- Noise less than 2 μV r.m.s. (20–450 Hz).

In order to reduce the noise, suitable amplifiers and filters were integrated in the electrodes. Besides capturing the signals and converting them into digital format, the analog interface of the main unit also provided the power required for the electrode-side amplifier and signal conditioning unit. The analogue signals were captured and converted into 12-bit digital format for storage and subsequent analysis. Data were stored on the Compact Flash (CF) interface, which allowed any standard CF memory card of any capacity to be attached to the main unit. The CF memory module could then be removed and plugged into a computer with CF interface for data uploading. With the attachment of the remote dual column LED display module to the main unit, the system became a monitoring unit and each of the LED columns would display the real-time root mean square of the respective signals.

This study adopted a randomized double-blind design, after establishing the baseline EMG ratios, subjects were randomly assigned into two groups by a research physiotherapist, namely, 'Exercise group' (Group 1) and 'EMG biofeedback + exercise group' (Group 2) with 13 subjects in each group. The subjects were not aware that there was another group and the examiner who performed the assessments was also unaware of the grouping of the subjects. The whole study lasted for 8 weeks (Alaca et al., 2002; Cowan et al., 2002a) with 30 min of exercise daily. Standardized instructions and demonstrations were given to the subjects in the first session and an exercise leaflet was given to them to follow at home. The training protocol included warm up, knee extensors strengthening, proprioceptive training to the knee and agility drills that aimed at VMO strengthening (Hunter and Funk, 1984; Ng and Man, 1996; Witvrouw et al., 2003). An EMG biofeedback unit was given to the subjects in Group 2. These subjects performed the exercises with the help of the biofeedback unit so as to aim at achieving a selective increase in VMO activities while maintaining a constant level of activities in VL by adjusting their hip and knee positions (Lam and Ng, 2001; Ng and Man, 1996).

During the study, subjects' progress was followed up with telephone calls by the research physiotherapist on a weekly basis, and they were reminded not to change their daily activity patterns. On the final visit, the EMG of VMO and VL were assessed again for a continuous 6-h period, during which the subjects assumed their normal daily activities.

To determine the EMG ratios of VMO/VL, two channels were used. The skin along the fibers of VMO (55° to the vertical) and

VL (15° to the vertical) were shaved and cleansed with alcohol. The surface electrodes for VMO were placed at 4 cm superior and 3 cm medial to the superior-medial border of patella, whereas for VL, they were placed at 10 cm superior and 7 cm lateral to the superior border of the patella (Lam and Ng, 2001; Ng, 2005). The common reference electrode was placed on the ipsi-lateral fibula head. Electrodes were affixed to the skin with hypoallergenic tape. The electrode positions were marked on a transparent plastic sheet together with bony landmarks and any permanent skin blemishes, such as freckles and scars. The plastic sheet was used as a reference for accurate re-positioning of the electrodes during the next visit by putting it over the skin to match the skin marks on the leg (Ng and Stokes, 1992; Ng, 1993).

The amplifier of the EMG system had a bandwidth of 20–450 Hz. Raw EMG signals were digitized by an A/D converter with a sampling rate of 1000 Hz. After digitization, the EMG signals were processed for their root means square values and recorded on a CF card. To compare the EMG between muscles, the data were normalized against the values acquired during a functionally demanding knee extension exercise. This was done by asking the subjects to perform a single leg sit-to-stand activity with the affected leg in the first minute of recording. During this movement, the EMG signals of both VMO and VL were regarded as the maximum activities that one would normally produce in daily activities and these values were used as the references for the normalization process.

The relative activities of VMO/VL of each subject were analyzed by calculating the percentage of the activity of each muscle over its respective value during the single leg sit-to-stand activity. The time that each muscle contracted at greater than 20% of its maximum reference value was regarded as functionally meaningful and this value was used for the analysis.

The use of 20% maximum EMG as a cut off point was because this level of activity was achieved during normal walking by most subjects, thus it could reflect the contributions of the muscles in dynamic functional activities of daily living. The total time for VMO and VL working at their respective 20% or more was expressed as a ratio to denote the relative activity levels of the two muscles.

The reliability of EMG recording of VMO and VL was established during a 1-min walking trial and going up/down stairs in the initial assessment before and after the 6-h EMG recording. The data were analyzed with the intraclass correlation coefficient (ICC [1, 1]). The VMO/VL activity ratios between the two groups were compared with independent t-tests to determine whether the groups were comparable before the study. The final data were also compared by independent t-tests for difference between the two groups. Paired t-tests were also performed to compare the difference scores before and after the exercise program in each group. The level of significance was set at $p < 0.05$.

3. Results

All subjects completed the study. The ICC (1, 1) for the EMG VMO/VL was higher than 0.9 for both groups, which indicated that the recordings have good reliability (Portney and Watkins, 2000). The initial assessments of the two groups were not different, which indicated that the subjects in both groups were comparable.

Fig. 1 shows the changes in VMO/VL EMG ratio in both groups before and after the physiotherapy exercise program. Improvements over time of VMO/VL EMG ratio were not significant in Group 1 ($p = 0.355$) but they were significant in Group 2 ($p = 0.016$). The subjects in Group 2 demonstrated a greater change in VMO/VL EMG ratio throughout the 8 weeks of training than those in Group 1.

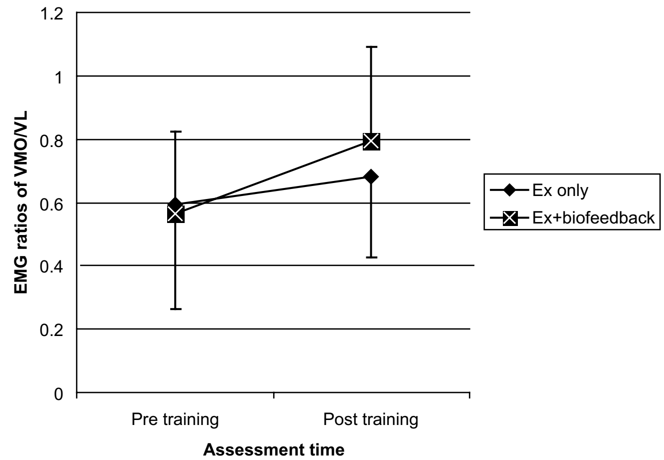

Fig. 1. Changes in the VMO/VL EMG ratio for the exercise group and the exercise + biofeedback group throughout the study. The values indicate the means and standard deviations of the EMG ratios. The difference between the pre-training and post-training assessment was not significant for the exercise group ($p = 0.355$) but statistically significant ($p = 0.016$) for the exercise + biofeedback group.

4. Discussion

This study examined the effectiveness of an exercise program on the VMO/VL EMG ratio during functional daily activities in subjects with PFPS and whether the EMG ratio would be improved using the same exercise protocol with the addition of an EMG biofeedback training. Results revealed that the VMO/VL EMG ratios in both groups had improved throughout the study but significant difference was only observed in the 'EMG biofeedback + exercise' group. This finding suggested that EMG biofeedback was an effective adjunct to therapeutic exercise for patients with PFPS for increasing their VMO/VL EMG ratios.

The mechanism underlying the change in VMO/VL EMG ratio in the EMG biofeedback + exercise group may be due to the real time feedback information provided to the subjects during the training sessions, which had facilitated the integration of sensory cues and motor recruitment of the muscles (Yip and Ng, in press).

The present study was based on the assumption that the physiotherapy exercise program was able to regulate the VMO/VL EMG activity ratio during normal daily activities and that such a change in EMG ratio was necessary for improvement of the symptoms. In a parallel study, it was found that subjects had significant improvements in the patellar tracking and a drop of 8% in pain level after the exercise training (Yip and Ng, in press). The relative magnitude of VMO/VL EMG during activities of daily living is an indication of muscle synergism of the knee. It is important for therapists to understand the knee's muscle activation pattern during functional activities, because it provides a framework within which specific pathologic processes of the knee can be determined. However, this assumption had not been tested before. The present results demonstrated that an 8-week physiotherapy exercise program might alter the VMO/VL EMG ratio for people with PFPS.

Imbalance of VMO and VL muscles is frequently reported in the literature as an etiologic factor of PFPS. Various exercise protocols including the use of EMG biofeedback had been proposed to restore the balance of activities between these muscles which could help muscular control for better PFJ stability (Ingersoll and Knight, 1991).

The specific components of the exercise program that altered VMO/VL EMG ratio and the mechanisms on how this occurred were not examined in this study. It was believed that the active stretching of the lower limb muscles, proprioceptive training and agility training of the subjects in both groups had contributed positively to the outcome of this study.

The VMO/VL EMG ratio was believed to provide an indication on the medial and lateral forces on the patella. It could also be an indicator of altered recruitment patterns and muscle dysfunction. A ratio of VMO/VL greater than one implies that VMO had higher normalized activity than VL. Exercises that elicit larger VMO/VL EMG ratios may effect a change in the activation patterns of VMO/VL muscle during the performance of functional activities.

It was reported that patients with PFPS had lower VMO/VL EMG ratios and such a lowering in the EMG ratio was believed to be a predisposing factor for the development of PFPS (Ficat and Hungerford, 1977). Its significance could be dependent on the magnitude of the lateral tracking of the patella. In a rehabilitation program, the increase in magnitude of VMO/VL EMG ratio implies an increase in medial pull on the patella. Therefore, VMO/VL EMG activity ratio appears to be an important parameter in the consideration of rehabilitation for PFPS.

Despite the precautions during the assessments, EMG activity might vary when it is measured repeatedly over a long time frame. Therefore, the data in the present study were normalized before analysis. The reference peak EMG value for this study was obtained from the activity of rising from sitting with one leg. This normalization procedure was favored by subjects who had difficulties in developing maximal extension force because of pain and discomfort. Furthermore, this activity was regarded as functionally demanding enough on the knee muscles, so that it could reflect on the maximum activity one would do in normal daily living.

Many studies had been conducted to evaluate the efficacy of physiotherapy treatment for PFPS (Cowan et al., 2002b; Dursun et al., 2001; Thomee, 1997; Witvrouw et al., 2003). Of these studies, only one had investigated an exercise program similar to that used in the present study. Although the results of all the published studies generally favored physiotherapy treatment intervention, the present study is the first to measure VMO/VL EMG ratio and to compare the effect of a physiotherapy exercise program with or without the use of biofeedback. Therefore, the finding of the present study has vital clinical implications in providing the evidence base for this physiotherapy rehabilitation programme.

The efficacy of the biofeedback to help muscle training has been investigated in two uncontrolled case studies (LeVeau and Rogers, 1980; Wise et al., 1984). Both studies found that the amplitude of VMO/VL EMG activity was improved in normal subjects.

Although there were reports on the assessment of EMG activities of VMO and VL in patients with PFPS, randomized studies on the effectiveness of EMG biofeedback with a conventional exercise program were limited and the results were controversial. Among these studies, only Dursun et al. (2001) investigated the effectiveness of EMG biofeedback in combination of conventional therapy on the balance between VMO and VL in 60 patients with PFPS. They found that the mean contraction values of VMO and VL of the biofeedback group were significantly higher than those of the control group. They also found that the combined EMG biofeedback and conventional exercise program resulted in better knee function and lower pain intensity.

Results of the present study were in agreement with the findings of Dursun et al., 2001). In the present study, VMO/VL EMG ratio was significantly improved over time in the EMG biofeedback + exercise group but not in the other group. This result suggested that the addition of biofeedback to exercise could have a beneficial effect on VMO activation.

Very few studies on EMG biofeedback were conducted in patients with PFPS, but there were studies on the effect of exercise program on VMO/VL EMG ratio in other pathologies. Krebs (1981) evaluated the effectiveness of EMG biofeedback and conventional physiotherapy in the functional recovery of quadriceps femoris muscle in 42 patients with uncomplicated meniscectomy. It was found that the average difference between pre- and post-training EMG output for the biofeedback group was 10 times higher than that of the standard therapy group. Ingersoll and Knight (1991) reported that EMG biofeedback training was superior to progressive resistive exercise for correcting patellar mal-alignment. The authors suggested that VMO muscle strengthening exercise with the assistance of EMG biofeedback as being essential in correcting patellar mal-alignment. The present study has provided further evidence based on the clinical efficacy of biofeedback as an adjunct to conventional exercise program. Patients with PFPS could benefit from EMG biofeedback for selective facilitation of the VMO muscle.

5. Conclusion

This study showed that there was significant difference in the VMO/VL EMG ratio over time in the subjects performing therapeutic exercise with the assistance of EMG biofeedback. This finding implies that EMG biofeedback is an effective adjunct to physiotherapy exercise for patients with PFPS in facilitating their VMO activity. It has a vital clinical implication in improving the rehabilitation of patients with PFPS.

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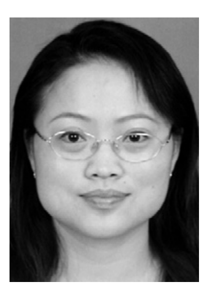

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