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Original Article

Effects of isometric exercise using biofeedback on maximum voluntary isometric contraction, pain, and muscle thickness in patients with knee osteoarthritis

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Abstract. [Purpose] The purpose of our study was to investigate the effects of isometric exercises using electromyographic biofeedback (EMGBF) and ultrasound biofeedback (USBF) on maximum voluntary isometric contraction (MVIC), pain assessed by the Visual Analogue Scale (VAS), and vastus medialis oblique (VMO) thickness in patients with knee osteoarthritis (OA). [Subjects and Methods] Thirty females over 65 years of age who had been diagnosed with knee osteoarthritis were recruited and randomly assigned to three groups, each comprising of 10 subjects. The Subjects in the EMGBF training and USBF training groups were trained with the corresponding physical training exercise program targeting the vastus medialis oblique, whereas the subjects in the control group were treated with conventional physical therapies, such as a hot pack, ultrasound, and transcutaneous electrical nerve stimulation. Subjects in each group were trained or treated for 20 min, 3 times a week for 8 weeks. [Results] The MVIC in the EMGBF and USBF training groups was significantly increased compared with that in the control group, and the VAS score (for measurement of pain) in the EMGBF and USBF training groups was significantly decreased compared with that in the control group. Only the EMGBF training group showed a significantly increased VMO thickness compared with before training. [Conclusion] These results suggest that USBF training is similar to EMGBF training in terms of its effectiveness and is helpful for treating patients with knee OA.

Key words: Conventional physical therapy, Electromyographic biofeedback, Ultrasound biofeedback

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INTRODUCTION

Osteoarthritis (OA) is a prevalent musculoskeletal disease in the elderly[1], and it is estimated that the prevalence rate of this disease in the population over 65 years of age is 38.1% in South Korea and that the percentage of women affected by this disease is three times higher than that of men affected by this disease[2]. A recent survey in India reported that the prevalence of OA in the elderly over 65 years of age was 60.3% in urban populations and 32.6% in rural populations[3], and knee OA affects approximately 9.3 million Americans[4]. Knee OA is accompanied by pain and weakening of the quadriceps in general[5], and it affects a person's walking ability[6]. The weakening of the quadriceps in particular makes the knee joint unstable, thereby resulting in less frequent use of the knee joint, and as a result, weakening of the muscle worsens[7]. The weakness of the vastus medialis oblique (VMO) causes an increase in joint pain, and it is related to the lower knee extension strength and range of joint motion[8]. According to animal studies, degenerative arthritis is associated with the muscle volume in the infiltrated joints and decreased strength of the antigravity muscles[9]. Quadriceps volume rather than quadriceps activation is a far more reliable prognostic factor[10]. An increase in the VMO size after treatment of knee OA was reported to ameliorate pain in the afflicted joint and to be good for compensating for structural changes[11].

The maximum voluntary isometric contraction (MVIC) of the quadriceps muscle in patients with knee OA was found to be lower than that of the quadriceps muscle in a normal person[12]. The reduced MVIC of patients with knee OA can be improved by voluntary quadriceps activation[13, 14], and this is considered an adequate and reliable method for assessment of the effect of therapeutic exercise[15, 16]. Isometric exercise was found to be easily applicable in the elderly suffering from knee OA for improving

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the MVIC of the quadriceps[17].

Recently, isometric exercise employing biofeedback has been introduced for treatment of patients with OA. The EMG biofeedback device transforms the action potential of the muscle into visual or audible signals[18] so that it can increase or decrease the level of voluntary activity, and it is effective in generating active participation of patients during treatment[19]. The real-time information obtained from electromyographic biofeedback (EMGBF) can lead to adequate muscle contraction, thus maintaining body alignment and normal body movement[20]. It was reported that selective strengthening of the VMO with this type of the treatment resolved malalignment of the patellofemoral joint[21]. Ultrasound biofeedback (USBF) has been used to measure cross-sectional area and thickness by visualizing real-time muscle activity and contraction[22, 23], and it can detect and measure specific muscle activity during isometric contraction[24]. It has been recognized that ultrasound is useful for differentiating between the type of muscle contraction and the timing of muscle activation, and it could be an important part of rehabilitation[25–27]. Callaghan et al.[28] employed ultrasound to quantify the contraction of the quadriceps and suggested that physical therapy and rehabilitation programs using ultrasound would be feasible.

USBF training has been used for abdominal muscle training or for studying the effect of pelvic floor muscle training for managing urinary incontinence[23, 25]. However, there are apparently no other studies employing USBF for knee OA. In addition, a comparative study between the effects of EMGBF training and USBF training on knee OA has not yet been reported. In this study, we investigated the effects of EMGBF training or USBF training on the MVIC of the quadriceps, pain, and VMO thickness in patients with knee OA.

SUBJECTS AND METHODS

Subjects

This study was performed in elderly women who visited welfare facilities for the aged in Jinju City, Gyeongsangnam-do. Fifty subjects diagnosed with knee OA were selected through a survey. Ultimately, 30 subjects, in whom the disease had been diagnosed radiographically and the inside of the affected side of the knee had been viewed by anteroposterior radiographs, participated in this study. Subjects who had a BMI of more than 38, who were being treated with steroid injections, who had rheumatoid arthritis, or who had had surgery on the knee joint in the last 6 months were excluded. The mean age of the subjects was 72.8±8.8 years, mean height of the subjects was 158.2±6.0 cm, mean body weight of subjects was 60.7±7.5 kg, and mean BMI of the subjects was 24.3±2.5. We classified the cartilage defects in the patella according to the Outerbridge classification[29]. The mean Outerbridge osteoarthritis grade was 2.5±0.9, and tests for homogeneity of variances using Levene's F statistics showed that there was no inconsistency in the equal variance hypothesis in the medial, lateral tibiofemoral, and patellofemoral joints ($p>0.05$). In the subjects who suffered from OA on both sides of the knee joints, the severe side was selected for therapeutic intervention. Every subject provided written informed consent for participation in the study. This study was approved by the IRB of the International University of Korea.

Methods

This study was a prospective, randomized, and single-blind clinical investigation. The subjects were assigned randomly to three groups by computerized number generators, and each group comprised of 10 subjects. The first group was the electromyographic biofeedback (EMGBF) training group, the second group was the ultrasound biofeedback (USBF) training group, and the third was the control group, CPT group, which received a hot pack, ultrasound, and TENS.

The Myomed 932 (Enraf-Nonius, Rotterdam, The Netherlands) was used for EMGBF training. This device is a complete unit for EMG feedback, and the EMG signal when the muslces contract is graphically reproduced. Electromyographic electrodes were attached as suggested in the Surface Electromyography for the Non-Invasive Assessment of SENIAM protocol[30]. Prior to placing the electrodes, the skin area was shaved, and if necessary, it was cleaned and disinfected with alcohol to reduce skin impedance. A skin adherent surface electrode was used to record the muscle activity. Two electrodes were attached 4 cm above and 3 cm medial to the superior medial border of the patella to record the recruitment of the VMO. The ground electrode was attached 2–3 cm below the patella on the same side. The subjects laid down on the floor by straightening their knees, propping a rolled hand towel behind the knee, and bending the knee joint naturally. They were then instructed to straighten the knee ("extend the knee and pull the patella towards themselves") maximally for 5 sec beyond the threshold level to monitor the VMO activity[31]. During the actual training session, the subjects were allowed to relax for 10 sec after at least 5 sec of contracting the VMO beyond the threshold level. The contracting and relaxing exercise was repeated during 20 min sessions, 3 sessions a week, for 8 weeks.

A Mylab™One ultrasound system (Esaote, Genoa, Italy) was used for USBF training. This device is a dedicated ultrasound system and has up-to-date image and data management capabilities. A linear probe was placed 4 cm above and 3 cm medial to the upper edge of the patella in this group. Minimal pressure just adequate enough to attach the whole surface of the probe to the skin was applied, and the patients were provided with audible signals for 5 seconds. During the first session, the participants were trained for the muscle contraction mode using manual palpation and feedback to optimize the VMO contraction quality. The training included the mode of muscle contraction devoid of a disturbed posture affecting muscle contraction[32]. During subsequent sessions, the physical therapist encouraged the subjects to keep practicing while reviewing and reinforcing the VMO contraction technique adequately[33]. Articles describing training of the pelvic floor muscles were referenced, since a training technique for VMO contraction could not be found. The training period, exercise time, and session numbers were the same as those in the EMGBF training schedule.

For the control group, a conventional physical therapy, including a hot pack (Daewha Medipia, Busan, Republic of Korea; 15 min), ultrasound (Ito, Tokyo, Japan; 1 MHz continuous at 1.2 W/cm^2 for 5 min), and TENS (Homerlon, Tokyo, Japan; auto lower soft program for 15 min), was carried out as per the same schedule used in the experimental groups[34–36].

A strength dynamometer (TSD121C, Biopac Systems Inc., Holliston, MA, USA) was used to acquire the MVIC of the VMO muscle under isometric constraints. The MVIC of the quadriceps was recorded at a knee flexion angle of 70° while the subject exerted MVIC of the knee extensor muscles of the affected side. The subject was tested on a leg extension machine set at 120° by leaning backwards. Straps were applied to the waist and chest to stabilize the body. The arms were crossed across the chest. The strength dynamometer was attached to the frame of the machine to record the MVIC. Measured data were converted to 13.2 μV/kg by a software program and recorded. Three measurements were obtained, and the largest values were averaged and used as the MVIC[12]. Pain was scored on a 10 cm long VAS; 0 was no pain, and 10 was the maximum tolerable pain. The pain felt by the subjects at rest was scored on the scale through self-reporting.

The Mylab^{TM}One ultrasound system, the device used for the USBF training, was used to acquire ultrasound images for measuring the thickness of the VMO. The ultrasonic transducer used to assess the ultrasound images was a 7.5 MHz linear transducer. Values in the gain (G55) and dynamic range (C04) were fixed and applied to every examination. Scanning was performed in the supine position by propping a rolled towel up against the popliteal fossa to relax the upper thigh. Prior to measuring the muscle thickness, all subjects rested for 15 min, and the arms and legs were extended in the supine position. The probe was coated with water-soluble transmission gel to provide acoustic contact without depressing the skin surface. During scanning, the least amount of pressure possible was applied to reduce the pressure on the muscle. The site of muscle thickness measurement was mapped using a transparent paper to ensure that measurement was performed at the same site during the next session. All of the images were digitalized and analyzed with Mylab^{TM}Desk3 (Esaote, Genoa, Italy) after each training session. The interfaces between the muscle and subcutaneous fat and between the muscle and bone could be identified on the images, and the distance between the structures was considered the muscle thickness. One day later, all of the measurements were repeated with the assessor blinded to the former values.

The data were analyzed with the SPSS 18.0 statistical program. A 3 (groups) × 2 (times) ANOVA was used to evaluate the difference between the groups, and Bonferroni correction was applied to the post hoc analysis. A paired sample t-test was conducted to measure changes within each group. The significance level was set at $\alpha = 0.05$.

RESULTS

The demographic details of the subjects, including age, height, weight, and body mass index, were recorded. These variables showed no significant difference among the three groups. The baseline measurement of the MVIC of the quadriceps, VAS, and VMO thickness were not statistically significantly different among the three groups (Table 1).

The MVIC showed statistically significant improvement in the EMGBF training and USBF training groups compared with the control group ($p<0.05$). Upon comparing the MVIC between the EMGBF training and USBF training groups, an insignificant difference was observed ($p>0.05$).

On comparing the MVIC between before and after training, significant improvement was noted in the EMGBF training and USBF training ($p<0.05$) groups, whereas the MVIC was decreased in the CPT group ($p>0.05$). The mean improvement in the MVIC was 1.4±0.5 in the EMGBF training group, 1.7±0.5 in the USBF training group, and −4.5±1.9 in the CPT group.

The VAS score showed a statistically significant reduction in the EMGBF training and USBF training groups compared with the control group ($p<0.05$). Upon comparing the VAS score between the EMGBF training and USBF training groups, an insignificant difference was observed ($p>0.05$). Comparison of the VAS score between before and after training revealed a significant reduction in the VAS score of the EMGBF training and USBF training groups ($p<0.05$), whereas an insignificant reduction in the VAS score was noted in the CPT group ($p>0.05$). The mean re-

Table 1. Comparison of the mean values of maximum voluntary isometric contraction, visual analogue scale, vastus medialis oblique among groups and within groups

Variables	Electromyographic biofeedback		Ultrasound biofeedback		Conventional physical therapy	
	Before	After	Before	After	Before	After
MVIC (kg)	8.5±1.6	9.8±1.6*	8.2±1.4	9.9±1.4*	7.9±1.7	7.5±2.2†‡
VAS	6.3±2.0	4.4±1.6*	6.3±1.6	4.8±1.7*	6.4±1.7	6.0±1.2†‡
VMO (mm)	37.2±1.4	39.1±2.5*	37.5±1.6	38.2±1.0	37.1±2.0	37.4±2.1

The values were expressed as the mean±SD.
MVIC: maximum voluntary isometric contraction, VAS: visual analogue scale, VMO: vastus medialis oblique
* $p<0.05$ for the change within the group between before and after treatment
†Significant difference between electromyographic biofeedback and conventional physical therapy ($p<0.05$).
‡Significant difference between ultrasound biofeedback and conventional physical therapy ($p<0.05$).

duction in the VAS score was 2.0±0.7 in the EMGBF training group, 2.0±0.4 in the USBF training group, and 0.4±0.9 in the CPT group.

The VMO thickness showed a statistically insignificant improvement in the EMGBF training and USBF training groups compared with the control group ($p<0.05$). Upon comparing the VMO thickness between the EMGBF training and USBF training groups, an insignificant difference was observed ($p>0.05$).

On comparing the VMO thickness between before and after training, significant improvement was noted in the EMGBF training group ($p<0.05$), whereas insignificant improvement was noted in both the USBF training and CPT groups ($p>0.05$). The mean improvement in VMO thickness was found to be 1.8±1.3 in the EMGBF training group, 0.7±1.8 in the USBF training group, and 0.3±0.7 in the CPT group.

DISCUSSION

The purpose of this study was to investigate whether EMGBF and USBF training would affect the MVIC of the quadriceps, pain, and VMO thickness in patients with knee OA. While EMGBF and USBF training significantly increased the MVIC of the VMO and reduced pain in the affected side, the control treatment, conventional physical therapy, did not cause any significant change in the MVIC of the quadriceps. Interestingly, only the EMGBF training group showed a significant increase in the VMO thickness, whereas the other two groups did not show any change in the VMO thickness.

Wasielewski[37] and Lepley[38] reported that EMGBF training improved the MVIC of the quadriceps in patients with knee OA. The results of this study showed that EMGBF training of the VMO increased the MVIC of the quadriceps, and this finding is consistent with that in the earlier studies. EMGBF training during isometric exercise provided the subjects with visual and auditory stimulation, which might have encouraged them to participate actively, resulting in improvement in the MVIC[39]. USBF training also improved the MVIC of the quadriceps in patients with knee OA, but we were unable to find any studies reporting the effects of USBF training on knee OA that could be compared with this study. Auditory and visual biofeedback in USBF training has been used to increase motor performance[40]. The sensory biofeedback in this study might have enhanced muscle activation during the early training period. USBF training has been used to perform muscle training for reducing back pain[41] and urinary incontinence[33] and to detect changes in the size of the quadriceps[42, 43]. There are very few studies assessing the effect of USBF on MVIC of the quadriceps for treatment of knee OA. Therefore, the finding of this study that USBF training enhanced the MVIC of the knee quadriceps could be considered meaningful, as it provides an alternative treatment in patients with knee OA.

Weakening of the VMO in patients with knee OA leads to functional disorders[44], which in turn have been reported to increase pain[45]. The reason the EMGBF and USBF training groups in this study showed significantly reduced pain compared with the control group, in which a simple modality was applied, appears to be that these two training techniques enhanced the MVIC of the quadriceps, resulting in improvement of the functional disorder and subsequently breaking of the vicious cycle of pain.

EMGBF training significantly increased the MVIC of the quadriceps as well as the VMO thickness. This finding could be due to an increase in the muscle strength through muscle hypertrophy[46, 47], improved motor learning abilities[48], or both. USBF training significantly increased the MVIC of the quadriceps but did not increase the VMO thickness. In this regard, Lucca[48] reported that muscle strength was enhanced without muscle hypertrophy when there was an increase in motor learning abilities. That is, even though the size of the muscle remains unchanged, continuous training promotes the speed of motor unit recruitment and motor learning abilities, resulting in an increase in the MVIC of the quadriceps. Segal[49] reported that neuromuscular activation of the knee extensor rather than the muscle mass should be the target to prevent the occurrence and worsening of knee OA, which is consistent with our observation that USBF training increased the MVIC without any change in the muscle thickness. The conventional physical therapy, however, did not cause any change in the MVIC of the quadriceps and VMO thickness.

In the literature, there are a limited number of studies on the effects of USBF training on the MVIC of the quadriceps, pain, and VMO thickness in patients with knee OA. We observed that USBF training was as effective as an exercise program and had effects similar to those of EMGBF training in patients with knee OA. We not only observed an increase in the MVIC of the quadriceps but also a decrease in pain and improvement in the VMO thickness. Therefore, we can recommend USBF training for treatment of knee OA. A limitation of our study is the lack of long-term training and observation. Because we evaluated the patients with knee OA only at the end of training, it is not clear whether the improvements were maintained in the long term. Further studies are needed to clarify the long-term effects of USBF training and the clinical significance of continuation of training.

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