Effects of open and closed kinetic-chain exercises on the muscle strength and muscle activity of the ankle joint in young healthy women

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Abstract. [Purpose] The purpose of this study was to analyze the effects of open and closed chain exercise on the muscle strength and muscle activity of the ankle joint. [Subjects and Methods] Twenty women in their 20s were randomly assigned to two groups: the open kinetic-chain group and the closed kinetic-chain group. Each group performed 5 sets 3 times per week for 4 weeks. Exercise intensity was increased once after two weeks. The muscle activity of the tibialis anterior, gastrocnemius, tibialis posterior, and peroneus longus muscles were measured. The collected data were analyzed with two-way repeated measures ANOVA. [Results] In the results for muscle strength, both groups showed significant differences in dorsiflexion and plantar flexion between the pre-test and post-test. In the results for muscle activity, no significant differences were noted for either group. [Conclusion] Open and closed kinetic-chain exercises can help to improve muscle strength.

Key words: Open and closed kinetic-chain exercise, Muscle strength, Muscle activity

INTRODUCTION

An increase of initial muscle strength can result from the mechanism of nerve training, as muscle activity is increased due to the improvement in the recruiting motor unit, and then muscle strength increases as a result of muscle hypertrophy1). Understanding the effect of a change in muscle length on the electromyographic (EMG) activity recorded in a muscle is essential in the functional interpretation of EMG data during different activities2). There is considerable debate regarding the relative efficacy of open kinetic-chain (OKC) and closed kinetic-chain (CKC) exercise for increasing the strength and control of knee muscles3). OKC exercise is performed in a state of free distal and fixed proximal extremities4). The OKC exercises isolate specific muscle groups for strengthening and evaluation purposes5).

The use of axial-load exercises, which are known as CKC exercises, has grown considerably in recent years. Biomechanically, the function of each segment of the body is considered in relation to other interconnected segments. The whole body is considered as a chain; the movement of one part affects the others6). A study performed the OKC flexion and extension exercise for non-operative or post-operative joint-disorder management; the results indicated that in the post-anterior cruciate ligament reconstruction or injury period, the exercise could be safely employed to strengthen the hamstring muscles without risk to the anterior cruciate ligament. In contrast, post-posterior cruciate or lateral collateral ligament reconstruction or injury, the OKC flexion exercise should be avoided under moderate to large flexion angles and resistant forces7). A study evaluated the EMG activities of the vastus medialis obliquus (VMO) and vastus lateralis (VL) muscles in open and closed kinetic-chain exercises in subjects with patellofemoral pain syndrome...
SUBJECTS AND METHODS

Twenty women in their early 20s participated in this study. None of the subjects had impaired musculoskeletal or neurological systems, and none had a history of athletics or had received any training in muscle strengthening within the past 6 months. The procedures of the experiment were explained to the students; no problems with the experiment were indicated, and all subjects voluntarily agreed to participate. They were each randomly assigned to one of two groups: the 10 OKC exercise group and the 10 CKC exercise group. This study was approved by the Institutional Review Board of Namseoul University.

To measure the physical characteristics of the subjects, body composition analyzers (Inbody 720, Biospace Co. Ltd., Seoul, Republic of Korea) were used before each exercise. To determine muscle activity, the Free EMG system (Free EMG, BTS Inc., Seoul, Republic of Korea) were used before each exercise. To determine muscle strength, a functional rehab system (PRI MUS RS, BTE Tech., Hanover, USA) was used. To determine muscle activity, the Free EMG system (Free EMG, BTS Inc., Milan, Italy) was used.

Before the exercises, the physical characteristics of the subjects were measured. The exercises were performed to non-dominant exercise. They kicked a ball to determine their dominant lower extremity. The exercise protocols, which were modified in reference to a previous study, included the performance of OKC and CKC exercise for 60 minutes. The exercise was performed on the non-dominant side. The protocol consisted of a warm-up exercise for 10 minutes, the main OKC or CKC exercises for 40 minutes, and then a cool-down exercise for 10 minutes (Table 2). They had a 1-minute rest period between sets to avoid the fatigue effect.

To measure the movement of the plantar flexion (PF) and dorsiflexion (DF), the subjects were positioned in the physical rehabilitation equipment with their knees fully, and the hip joints and the knee joints on both sides were fixed into a neutral position using a strap to prevent compensation. The subject was allowed to sit with knee flexion 90° and to use tool number 701 to measure the movement of the inversion (IV) and eversion (EV). The pelvic and knee joints were fixed in order to prevent compensation. The equipment was calibrated before each exercise was performed. The isometric exercises were performed three times by each subject to induce muscle fatigue for maximal voluntary isometric contraction (MVIC).

For surface EMG, electrodes were attached to the muscles at maximum static contraction to prevent any technical difficulties from influencing the experiment. The skin was abraded with sandpaper, shaved, and then cleaned with an alcohol-soaked cotton swab in order to reduce the electrical impedance of the skin to less than 5 kΩ. Active electrodes (Carbon electrode, 3M, USA) were placed 2 cm apart in parallel with the muscle fibers on the tibialis anterior (TA), gastrocnemius (GM), tibialis posterior (TP), and peroneus longus (PL) in the state of maximal static contraction of the muscles in each actions dorsiflexion, plantar flexion, inversion, and eversion.

For the TA, the electrode was placed 33% of the way from the tip of the muscles in each actions dorsiflexion, plantar flexion, inversion, and eversion.

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| Table 2. Exercise protocol (for 4 weeks) |
|-----------------------------------------|
| Exercise | OKC | CKC |
| Warm-up (Ankle stretching) (10 minutes) | Dorsiflexion and pull the towel on the mat | Dorsiflexion and push the wall |
| Main (40 minutes) | | |
| Weeks 1–2 (20 times 5 sets) | Dorsiflexion and inversion | Lunge |
| Dorsiflexion and inversion | Roll the towel with extended toes |
| Plantar flexion and inversion | Roll the towel with ankle inversion |
| Plantar flexion (with red Thera-band) | |
| Weeks 3–4 (20 times 7 sets) | Dorsiflexion and inversion | Lunge |
| Dorsiflexion and inversion | Roll the towel with extended toes |
| Plantar flexion and inversion | Roll the towel with ankle inversion |
| Plantar flexion (with green Thera-band) | |
| Cool-down (Ankle stretching) (10 minutes) | Dorsiflexion and pull the towel on the mat | Dorsiflexion and push the wall |

| Table 1. General characteristics of the subjects (N=20) |
|-----------------------------------------------|
| Group | OKC (n=10) | CKC (n=10) |
| Age (years) | 22.2 ± 5.1 | 21.6 ± 2.6 |
| Height (cm) | 161.2 ± 4.1 | 161.7 ± 5.0 |
| Weight (kg) | 57.8 ± 13.4 | 56.5 ± 5.6 |
| BMI (kg/m²) | 22.2 ± 5.1 | 21.6 ± 2.6 |

Variables are expressed as mean ± SD; OKC: open kinetic chain exercise; CKC: closed kinetic chain exercise; BMI: Body mass index.
of the fibula to the medial malleolus. For the GM, the electrode was placed 17% of the way medially from the distal midline of the knee joint and 2 cm above this part. For the TP, the intramuscular electrode was inserted approximately 50% of the way from the popliteus cavity to the medial malleolus. For the PL, the electrode was placed 25% of the way from the fibula head to the lateral malleolus. All electrodes were attached at maximal static contraction by the same physiotherapist. The EMG signal that was measured was analyzed using MyoLab software (BTS Inc., Milan, Italy). The MVIC was measured for 5-second with each movement and used 3-second in this study excepted for the first and the last one second. The root mean square (RMS) value of the EMG of the muscles was measured for 10-second.

Statistical analyses were performed using SPSS for Windows v. 22.0. The physical characteristics are reported as mean ± SD. The dependent variables were tested for normality using the Kolmogorov-Smirnov test and for homogeneity of variance using Levene’s test. Two-way repeated measures ANOVA was used to examine the significance of the differences in balance and to compare the muscle strength and the EMG of the muscles between the groups (OKC and CKC exercise groups) and time (pre- and post-exercise). The statistical significance level was α=0.05. This study was approved by the Institutional Review Board of Namseoul University.

RESULTS

Twenty young adult women participated in this study (Table 1). In the results for muscle strength, there were significant differences in PF and DF between the pre- and post-tests for both the OKC and CKC exercise groups. There was no significant difference between the groups (Table 2). In the results for muscle activity, there was no significant between the pre- and post-tests, nor was there a significant difference between the groups (Table 3, 4).

DISCUSSION

The OKC and CKC exercises generated, as expected, different patterns of muscle activity and ligament forces. The CKC exercise activated antagonistic muscle groups across multiple joints; as a result, it cannot be used to isolate or examine a single muscle group. The OKC exercise isolated specific muscle groups for strengthening and evaluation purposes. Resistance exercise using the Thera-band is simple, economical, and safety. It is often used for rehabilitation purposes because the training can be selected and adapted case by case due to the control of the loading intensity.

This study aimed to analyze the effects of the OKC and CKC exercises with a Thera-Band and towel so that the exercises can be performed easily in daily life on muscle strength and muscle activity.

In a previous study, the femoral quadriceps muscle was activated in isolation during the OKC exercise, thus increasing the...
force of patellofemoral compression\textsuperscript{21}. A previous study examined the effects of the CKC exercise and OKC exercise on muscle activation in the patellar lower limbs of chronic stroke subjects. The muscle activation of the GM and TA increased significantly only in the CKC exercise group. These findings indicate that the CKC exercise can improve lower-limb muscle strength in chronic stroke patients, and this may carry over into an improvement in functional performance\textsuperscript{22}. A previous study analyzed the effects of a stable versus an unstable base of support on shoulder muscle activity during CKC exercise; the CKC exercise with an unstable base of support did not increase the muscle activity in comparison to the CKC exercises with a stable base of support\textsuperscript{9}.

In the current study, there were significant differences in PF and DF in the muscle strength between the pre- and post-tests for both the OKC and CKC exercise groups. There was no significant difference in the muscle activity. The OKC and CKC exercises led to muscle-strength improvement because they stimulated mechanoreceptors in the joint and increased muscle fiber, and the number of motor units increased during these resistance exercises. There were significant differences in PF and DF, rather than inversion and eversion, because the OKC and CKC exercises in this study were focused on PF and DF exercise. The intensity and duration of the OKC and CKC exercises was not high enough or long enough, respectively, to change the muscle activity of young adult women.

In conclusion, this study aimed to analyze the effect of the OKC and CKC exercises on the muscle strength and muscle activity of the lower extremity in young women. The OKC and CKC exercises had a positive effect on the muscle strength of the TA and GM. These results can help in devising an exercise protocol to improve muscle strength that can be used not only at home but also in a clinical. Further studies are required in order to determine the appropriate intensity and duration for individual participants.

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