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Original Article

Effects of neuromuscular training on knee joint stability after anterior cruciate ligament reconstruction

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Abstract. [Purpose] This study examined the effects of neuromuscular training on knee joint stability after anterior cruciate ligament reconstruction. [Subjects and Methods] The subjects were 16 adults who underwent arthroscopic anterior cruciate reconstruction and neuromuscular training. The Lysholm scale was used to assess functional disorders on the affected knee joint. A KT-2000 arthrometer was used to measure anterior displacement of the tibia against the femur. Surface electromyography was used to detect the muscle activation of the vastus medialis oblique, vastus lateralis, biceps femoris, and semitendinosus before and after neuromuscular training. [Results] There was significant relaxation in tibial anterior displacement of the affected and sound sides in the supine position before neuromuscular training. Furthermore, the difference in the tibial anterior displacement of the affected knee joints in the standing position was reduced after neuromuscular training. Moreover, the variation of the muscle activation evoked higher muscle activation of the vastus medialis oblique, vastus lateralis, biceps femoris, and semitendinosus. [Conclusion] Neuromuscular training may improve functional joint stability in patients with orthopedic musculoskeletal injuries in the postoperative period.
Key words: Arthrometer, Anterior cruciate ligament reconstruction, Neuromuscular training

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INTRODUCTION

The prevalence of knee joint injuries and disease has been increasing as a result of the increasing numbers of patients injured in various leisure, industrial, and traffic accidents. As ligament injuries account for a significant proportion of knee injuries, the importance of the anterior cruciate ligament (ACL) has been increasing[1)]. Examining ligaments is necessary, because knee joint function depends on ligaments. Dynamic joint stability involves the control of passive (i.e., ligament) and active (i.e., muscle) elements as well as sensory-motor coordination. As passive structures, ligaments play an important role in joint stability, limiting joint movement. They also confer primary functional stability by providing sensory feedback, enabling the control of muscle stability and sensing of joint position[2)]. Proprioception, functional performance ability, and the strength of the quadriceps femoris decrease significantly on the side of the injured knee joint after ACL injury[3)]. Regarding gait, the activity of the hamstrings increases to compensate for the excessive forward movement of the tibia, decreasing the activity of the quadriceps femoris[4)]. Intra-articular ACL reconstruction using autografts or allografts is used to restore knee functional stability in ACL injuries.

However, significant instability can occur due to altered muscle activity pattern and proprioception deficiency for joint movement control after reconstruction. These instabilities can cause degenerative changes by increasing the risk of re-injury as well as the loads on articular cartilage and other soft tissues. Thus, the importance of postoperative therapeutic exercise rehabilitation has been increasing because of the need for effective interventions to restore knee joint stability after ACL reconstruction.

Therapeutic exercises are an important component of physical therapy. Therapeutic exercises in the treatment process should be initiated as early as possible, and all patients must perform exercise programs as tasks[5)]. Neuromuscular training aims not only to restore the functions of injured joints, but also to improve the patient's body to a state even better than that before their injury. Accordingly, improved movement patterns, coordination, increased muscle strength, endurance, and agility are helpful for preventing recurrence

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and future injuries[6].

Studies in the fields of sports medicine and physical therapy continue to investigate exercise tools and programs targeting the knee joint and its rehabilitation. Exercise type and intensity should be controlled during rehabilitation.

Several studies have investigated various exercise programs and evaluation tools for rehabilitation after ACL reconstruction. However, few studies have investigated the effects of neuromuscular training on knee joint stability by using both direct and subjective methods. Therefore, the present study objectively evaluated the effects of individualized neuromuscular training as a rehabilitation exercise program. This study investigated how neuromuscular training affects knee stability and muscle strength by using an arthrometer and surface electromyography (EMG). The hypotheses of this study are as follows: (1) the arthrometer measurements will not differ before and after non-weight-bearing neuromuscular training; (2) when 100% weight bearing is required, the lower-extremity muscles will be functionally contracted and the anterior drawer movement of the tibia against the femur will be smaller after neuromuscular training during arthrometer measurement; (3) the muscle activity of the lower-extremity muscles will be higher after neuromuscular training.

SUBJECTS AND METHODS

This study recruited patients who underwent arthroscopic ACL reconstruction in hospitals in Daejeon, Cheongju, Cheonan, and Busan, Korea between May 2013 and May 2014. Patients performed rehabilitation exercises for at least 3 months at the Exercise Prescription Center (weeks 1–3: reconstruction home program, weeks 4–6: intermuscular coordination improvement, weeks 7–9: partial muscle-endurance improvement, weeks 10–12: muscle strength improvement). After providing an explanation of the study's purpose as well as the experimental method and processes, written informed consent was obtained from all patients. Patients who were available for follow-up tests and agreed to participate in the experiment aged 19–50 years were included. There were a total of 16 patients (11 males and 5 females). Before the experiment, the Lysholm scale was used to determine the level of rehabilitation after ACL reconstruction; this scale evaluates the following items: limping (5 points), support (5 points), stair climbing (10 points), and squatting (5 points). Instability (30 points), swelling (30 points), and pain (30 points) experienced when a patient walked, ran, and jumped as well as atrophy of the thigh (5 points) were evaluated. The maximum score is 100 points; scores from 98–100, 93–97, 82–92, 66–81, and ≤65 are classified as excellent, good to excellent, fair to good, fair, and poor, respectively. Accordingly, 5 (31.25%), 4 (25%), and 7 (43.75%) patients were classified as excellent, good to excellent, and fair to good, respectively, with an average of 82.75 points (fair to good). Knee joint instability evaluation relied on the subjective feelings of the patients. This study was approved by the Daejeon University Institutional Review Board.

Meanwhile, an arthrometer (KT-2000, MEDmetric Corp, USA) objectively measures knee joint instability. When anteroposterior force is placed on the tibia, the displacement between the two assisting pads, which are placed on the patella and tibia, is shown in millimeters. Many studies have evaluated the KT-2000 arthrometer in patients with ACL injuries, confirming its reliability[7].

For EMG, a non-invasive 8-channel wireless surface electromyograph (WEMG-8, LAXTHA, USA) with disposable electrodes was used. Surface electrodes (Ag/AgCl 2223, 3M, Korea) were placed on the vastus medialis oblique, vastus lateralis, biceps femoris, and semitendinosus muscles. The distance between the reference electrode and activity electrode was 3 cm. The ground electrode was placed on the sacrum. Before the electrodes were attached, the skin was shaved, and dead skin was removed by gel and alcohol[8].

The maximum voluntary isometric contraction of the vastus medialis oblique and vastus lateralis muscles was measured with the subjects in a sitting position, while that of the biceps femoris and semitendinosus muscles was measured in a prone position, with the knee of the affected side fixed at 30° flexion. The measurements were repeated three times for 3 seconds each time, and the greatest value was used for analysis. The muscle activities before and after neuromuscular training were measured while the patients stood and put 100% of their weight on the affected side knee at 30° flexion, maintaining this posture for 20 seconds. Measurements were repeated three times. The EMG sampling rate was 1,000 Hz and band-pass filtered from 13–430 Hz, notch filtered at 60 Hz, and reduction filtered. Filtered signals were chosen from 10–20 seconds, and EMG signals were quantified as the root mean square[9, 10].

The neuromuscular training, KT-2000 arthrometer, and surface EMG measurements were made at 30° knee flexion of the affected side[11]. While the subjects were in the supine position, the anterior displacement of both knees was measured with the KT-2000 arthrometer; the measurement was subsequently repeated on the affected side in a standing position. After resting for 3 minutes, maximum voluntary isometric contraction of each muscle was performed in the sitting or prone positions as appropriate. Patients rested for another 3 minutes, and the muscle activities of the vastus medialis oblique, vastus lateralis, biceps femoris, and semitendinosus muscles were measured with the lower extremities of affected side bearing 100% of body weight in a standing position.

A balance ball (DYNAIR, TOGU, Germany) exercise was selected as a neuromuscular training exercise. The balance ball exercise requires intense concentration, lower extremity strength, and knee joint stability. The weight of the balance ball was always kept at 0.9 kg in order to quantify the amount of air inside. After a warm-up and sufficient rest, the affected side was placed on the balance ball (bearing 100% of body weight) and held still for 15–20 seconds. The exercise was repeated three times, with a 3-minute rest between repetitions.

Patients rested for 3 minutes after the neuromuscular training. Muscle activities were reexamined in a standing position with the lower extremity of the affected side bearing 100% of body weight. The anterior displacement of tibia was recorded in the same position with the KT-2000 arthrometer. Finally, the tibial anterior displacement of the affected-side knee was measured in the supine position.

SPSS version 18.0 for Windows was used for statistical analysis. The nonparametric Wilcoxon test was used to compare the affected sides in the supine and standing positions before and after neuromuscular training. The difference between the knees of the affected and unaffected sides in the supine position measured by the KT-2000 arthrometer before neuromuscular training was analyzed.

Repeated-measures ANOVA was performed to determine the changes in muscle activities (determined by surface EMG) before and after neuromuscular training. The level of significance was set at $p < 0.05$.

RESULTS

Eleven men and five women participated. Their mean age, height, weight, and body mass index (BMI) were 33.0 years, 167.87 cm, 67.93 kg, and 24.06 kg/m^2, respectively (Table 1). The differences in tibial anterior displacement between the affected and unaffected sides at 15, 20, and 30 lbs. were 1.31 ± 1.25, 2.13 ± 1.63, and 2.94 ± 1.77 mm, respectively. The maximum passive displacement was 3.44 ± 2.22 mm, indicating clear relaxation of the affected side ($p < 0.05$).

The arthrometer measurements in the supine position showed tibial anterior displacement between the affected sides of 0.06 ± 0.68, 0.13 ± 0.89, and 0.13 ± 0.96 mm at 15, 20, and 30 lbs., respectively. There were no significant differences in displacement between before and after neuromuscular training ($p > 0.05$). The arthrometer measurements in the standing position showed tibial anterior displacement between the affected sides was 1.31 ± 1.25, 2.13 ± 1.63, and 2.94 ± 1.77 mm at 15, 20, and 30 lbs. respectively. There were significant differences in displacement of the vastus medialis oblique, vastus lateralis, biceps femoris, and semitendinosus muscles before and after neuromuscular training ($p < 0.05$) (Table 2).

The changes in the muscle activities of the vastus medialis oblique, vastus lateralis, biceps femoris, and semitendinosus before and after neuromuscular training measured by surface EMG were 8.87 ± 6.18%, 7.41 ± 6.11%, 2.30 ± 2.53%, and 2.25 ± 2.63%, respectively. Hence, muscle strength increased significantly after neuromuscular training ($p < 0.05$); the vastus medialis oblique showed the greatest activity among them (Table 3).

DISCUSSION

The ligaments and muscles around the knee joint play important roles in supporting the joint's stability. The ACL provides a wide range of resistance to any movement, providing stability, because the ligament's direction line is oblique[12]. However, because of this characteristic, the ACL is prone to being damaged. In particular, the ACL is damaged when the knee joint is fixed on the ground and the knee joint is extended excessively. In addition, the force generated by the quadriceps femoris can exacerbate the damage[13]. The quadriceps femoris plays a very important role as a dynamic stabilizer of the knee joint. Meanwhile, the hamstrings act as a dynamic agonist of the ACL and play the most important role in the prevention of anterior subluxation of the knee joint. Therefore, atrophy of these two muscles causes severe

Table 1. General characteristics (*N* = 16)

Age (years)	33.1 ± 10.6	(19.0–50.0)
Height (cm)	167.9 ± 5.6	(158.0–176.0)
Body mass (kg)	67.9 ± 8.4	(53.0–81.0)
BMI (kg/m^2)	24.1 ± 2.3	(20.1–27.6)

Values are mean ± SD (range).
BMI: body mass index

Table 3. Change in muscle activation (*N* = 16)

	Pre-intervention	Post-intervention training	Change
VMO	21.93 ± 14.88	30.80 ± 19.38	8.87 ± 6.18*
VL	22.93 ± 11.80	30.35 ± 15.85	7.41 ± 6.11*
BF	7.42 ± 4.64	9.72 ± 5.91	2.30 ± 2.53*
ST	8.08 ± 9.27	10.33 ± 9.81	2.25 ± 2.63*

Values are the mean ± SD % maximum voluntary isometric contraction. *p < 0.5.
VMO: vastus medialis oblique; VL: vastus lateralis; BF: biceps femoris; ST: semitendinosus

Table 2. Comparison of tibial anterior displacement between the affected and unaffected sides in the supine and standing positions before neuromuscular training (*N* = 16)

		Affect side	Unaffected side	Difference
Standing ATD	(15 lbs.)	3.94 ± 1.44	2.63 ± 0.81	1.31 ± 1.25
	(20 lbs.)	6.13 ± 1.93	4.00 ± 1.10	2.13 ± 1.63*
	(30 lbs.)	8.94 ± 2.24	6.00 ± 1.86	2.94 ± 1.77*
Supine ATD	(15 lbs.)	3.94 ± 1.44	3.88 ± 1.20	0.06 ± 0.68
	(20 lbs.)	6.13 ± 1.93	6.00 ± 1.63	0.13 ± 0.89
	(30 lbs.)	8.94 ± 2.24	8.81 ± 2.10	0.13 ± 0.96
Standing	MMD	14.13 ± 2.36	10.69 ± 2.77	3.44 ± 2.22*
Supine	MMD	7.44 ± 1.97	5.43 ± 1.09	2.00 ± 1.75*

Values are mean ± SD in mm, *p < 0.5.
ATD: anterior tibial displacement, MMD: manual maximum displacement.

symptoms, thus exacerbating the functional disability. The ACL is an important structure for the anterior stability of the knee joint. Damage, including tearing, can cause knee joint instability and pain.

Joint proprioception is related to kinesthesis and joint position sense, which determines the movements and locations of body parts. Peripheral mechanoreceptors, which contribute to proprioception, are abundantly distributed in the joints, muscles, connective tissue, and ligaments; they play an important role in joint stability by providing neuromuscular and muscle control[14]. In particular, type I, II, and III receptors are abundantly distributed in the ACL where they contribute to proprioception of the knee joint[15]. Mechanoreceptors located in joint capsules and ligaments were previously thought to play the main role in kinesthesis and joint position sense[16]. However, a recent study emphasizes the importance of the sensory roles of tendons and afferent fibers, which are combined with muscle spindle and joints[17]. Another study reports proprioception gradually increases 9 months after ACL reconstruction and that increased joint stability facilitates proprioception recovery[18].

The present study was conducted on patients who underwent arthroscopic ACL reconstruction. All patients underwent at least 3 months of personalized rehabilitation exercise at the Exercise Prescription Center in order to improve knee joint stability. Three to six months after the standard rehabilitation exercise program was applied, proprioception was evaluated; the results showed proprioception increased on both the affected and unaffected sides[19].

In the present study, neuromuscular training was selected among various rehabilitation exercise programs. This exercise requires intense concentration, lower extremity strength, and mechanoreceptors in the knee joint. This exercise was performed with the knee joint flexed at 30° and 100% of body weight on a balance ball.

Exercise performed on a balance ball, which provides an air cushion, stimulates several mechanoreceptors and effectively increases the strength of the quadriceps femoris and hamstrings by increasing muscular mobilization. Unconscious motor responses manifest owing to the stimulation of afferent inputs and central mechanisms to control dynamic joint stability. In one study of 50 patients who underwent ACL reconstruction and received balance training for proprioception as well as dynamic stability training, the Lysholm score and hamstring contraction latency increased significantly compared to those who performed non-weight-bearing training[20].

The present study used an arthrometer to measure knee joint instability before and after neuromuscular training; for measurement, a constant force was applied by mechanical compression around the joint in order to evaluate the degree of ligament relaxation around the examined area. This test has higher reproducibility than the manual stress test, which produces results owing to the examiner's instantaneous power.

Wroble et al. report no significant differences in test measurements after repeatedly measuring normal knee joints on different days; they used different types of commercial arthrometers on the same participants and found no differences among them[21, 22]. Several studies suggest anterior displacement due to ACL rupture can be best observed in the knee joint at a flexion angle from 15–45°. To measure the displacement of both knee joints, it is important to place both knees at the same flexion angle, because the knee joint flexion angle can change the anteroposterior displacement[23]. In the present study, both knee joints were placed at a flexion angle of 30° using a thigh support. In both the affected and unaffected knee joints, the anteroposterior displacement of the lateral tibial plateau was larger than that of the medial tibial plateau. When an anteroposterior load is placed on the knee joint, displacement and rotation occur simultaneously. Anterior and posterior displacement of the tibia occurs with internal and external rotation, respectively[24]. If knee joint rotation occurs, anterior displacement of the tibia can be reduced by approximately 30%[25]. In the present study, internal rotation was not limited by the foot support during the load test by providing 15° of external rotation of both knee joints. When the muscles are not fully relaxed, the displacement test result can decrease to 25–50%. Therefore, subjects should be in a comfortable position, and the examiner should check if the muscles are fully relaxed. Doing this can reduce errors due to muscle contraction[26]. An arthrometer measures the displacement between the patellar and tibial tubercle sensor pads. To precisely measure the displacement between the tibia and femur, the patellar sensor pad should be firmly placed on the patella; therefore, the patella should be placed on the femoral trochlea in place in order to reduce the error.

Before neuromuscular training, the difference in tibial anterior displacement between the affected and unaffected sides measured by the KT-2000 arthrometer with the patients in the supine position showed clear displacement of the affected side.

Several studies have investigated ACL damage and methods to resolve it. In particular, ACL injury can cause a loss of the range of terminal active extension, insufficient gait, and abrasion of joint cartilage; moreover, it can lead to losses in joint proprioception, quadriceps femoris of strength, and active extension. Therefore, muscle strength recovery, improved proprioception for functional activities, and pain reduction are required. Thus, exercises that can facilitate recovery and minimize contusion of the ACL by considering its biomechanics must be selected[27]. Weight-bearing exercises provide postural stability as well as dynamic stability of the joint by increasing joint congruity and muscle coordination. In a functional position with a progressive mechanical pressure, such exercises promote soft tissue healing and provide stimulation for proprioception[3]. The results of the present study indicate neuromuscular training is effective for improving all of these elements. Therefore, if a proper initial rehabilitation exercise program is administered after ACL reconstruction, neuromuscular training should be encouraged in order to increase functional ability, increase the strength of the flexor and extensor muscles of the knee joint, and minimize the joint shearing force.

Major limitations of this study are the small number of patients and lack of a control group. Therefore, the results cannot be generalized to all patients who have undergone ACL reconstruction. Furthermore, we selected only one method among neuromuscular training methods. Moreover, the KT-2000 arthrometer evaluation was performed by one examiner, so the possibility of errors cannot be excluded. Nevertheless, the present results are meaningful, because this study aimed to determine the functional stability of the knee joint through an objective test based on subjective symptoms rather than focusing on the results of knee joint stability after ACL reconstruction.

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