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Original Article

Visual biofeedback exercises for improving body balance control after anterior cruciate ligament reconstruction

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Abstract. [Purpose] To evaluate the effects of balance training after arthroscopic anterior cruciate ligament reconstruction. [Subjects and Methods] Sixteen patients (mean 33 ± 8 years old) who underwent anterior cruciate ligament reconstruction three months prior to participating in a one-month rehabilitation program. The control group included 15 people aged 34 ± 4 years. Patients' functional level was evaluated according to the Lysholm knee score, and balance quality was ascertained by static and dynamic tests. A balance platform was used to measure the center of foot pressure deflection. Two dynamic balance tests evaluated time of task execution. [Results] Lysholm knee score improved significantly after rehabilitation. Balance in the sagittal plane with eyes closed improved significantly after rehabilitation. The average velocity of center of foot pressure swing in both the frontal and sagittal planes with eyes closed differed significantly from those of controls. Execution time required for the two dynamic tests decreased significantly after rehabilitation and were significantly better than those in the controls. [Conclusion] Maintaining static balance with eyes closed is very challenging after anterior cruciate ligament reconstruction. Maintaining balance in the sagittal plane is particularly difficult. A one-month rehabilitation program partially improves static and dynamic balance.
Key words: Balance training, Anterior cruciate ligament, Reconstruction

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INTRODUCTION

The anterior cruciate ligament (ACL) stabilizes the knee in the sagittal plane, especially when the knee is flexed, which prevents the tibia from slipping forward. It simultaneously allows physical activities, which incur shear, rotational, and compressive forces. ACL injury is the most common ligament injury of the knee joint; it causes mechanical dysfunction of the compactness of the joint, disturbing the flow of afferent information from ligament mechanoreceptors.

These disorders change the activities of individual muscle groups and impair motor coordination[1–4)]. Both kinematic and neuromuscular factors such as muscle activation, recruitment, and firing patterns must be taken into consideration to accurately characterize complex knee stability[5)]. This eventually leads to reduced muscle strength and even muscle atrophy. Knee pain accompanying trauma and inefficient lower-extremity loading disturb the biomechanics of the entire system; thus, affected patients may also have problems maintaining balance[2)]. Handicapped proprioception of the knee negatively impacts patient satisfaction with treatment outcome. Treating postural balance and proprioception allows the patient to achieve the desired results of surgical treatment and helps prevent further injury[2)].

Accordingly, this study evaluated the impact of rehabilitation on balance improvement in patients after arthroscopic anterior cruciate ligament reconstruction.

SUBJECTS AND METHODS

A total of 31 people participated and were divided into two groups: the control group consisted of 15 healthy volunteers (9 females and 6 males, mean age 34 ± 4 years) without any knee disorder or history of knee injuries, while the rehabilitation group consisted of 16 patients (6 females and 10 males, 33 ± 8 years) who had undergone arthroscopic reconstruction of the ACL and participated in a four-week rehabilitation program a mean of 3 months postoperatively.

All procedures were performed using arthroscopic anatomical single-bundle reconstruction. Four strand autogenous semitendinosus tendons were harvested. The graft was placed in the center of ACL anatomical insertion. A femoral tunnel was drilled through the anteromedial portal, and the tibial tunnel was placed in the center of the anteromedial and posterolateral bundles. For femoral tunnel fixation, an EndoButton TightRope (Arthrex, Naples, FL, USA) was used. For tibial fixation, a bioabsorbable RetroScrew (Arthrex,

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Table 1. Lysholm knee scores

Lysholm knee score	Groups				
	Intervention group before rehabilitation (B)	Intervention group after rehabilitation (A)	Change (A − B)	Controls (C)	Difference (C − A)
Mean ± SD	79.3 ± 10.1	89.7 ± 10.0	10.4 ± 6.4*	100	10.2 ± 9.6*

*p < 0.05

Naples, FL, USA) was inserted.

The rehabilitation process was decided on a case-by-case basis but was based on the same scheme. Rehabilitation included low-magnetic-field therapy, laser therapy, warming therapy, connective tissue lengthening by deep-tissue massage and myofascial release, and exercises aiming to increase range of motion and muscle strength. Biofeedback-based balance exercises were the main aspect of treatment; these exercises were performed on unstable ground (i.e., a rubber plate), with visual self-control of body posture through a mirror in front.

Patients were examined on the first day of the rehabilitation process. After four weeks of the rehabilitation program, patients were re-examined using the same procedure. Patients' functional levels were measured according to the Lysholm knee score[3, 4], which evaluates patients after knee ligament reconstruction[5–7]. The patient reports the stability of the knee joint, pain, locking, swelling, and the ability to perform everyday activities such as climbing stairs and squatting. This scale is commonly used to evaluate the damage of the knee ligaments pre- and postoperatively[8–13]. Balance was examined by static and dynamic tests on the Good Balance platform (Metitur Company, Jyväskylä, Finland). The dynamic test on the balance platform was performed on three boards (including "paths"), with the same platform sensitivity for all paths. Each board showed different paths to the displacement of the center of foot pressure (COP). The patient's position during dynamic tests was identical to that in normal standing tests. Patients could observe the position of the COP as a cursor on the recorder's monitor. The patient attempted to reach the targets shown in succession on the screen during body displacement. On the basis of the force signals, the system produces a dimensional curve showing the amount and characteristics of postural sway throughout the measurement period. The software also calculates several variables quantifying the patient's test behavior, such as the amounts and velocities of anteroposterior and mediolateral sway, and the amplitude of sway.

Static balance examination consisted of four measurements in the following positions: (1) eyes open position: upright posture with feet hip-width apart, upper limbs along the body, head facing forward, and eyes focused on one point; (2) eyes closed position: upright posture with feet hip-width apart, upper limbs along the body, and eyes closed; (3) tandem right leg forward position: right leg forward, left toes at the same level as the right heel, arms along the body, head facing forward, and eyes open; (4) tandem left leg forward position: same as the tandem right leg forward but with the left leg in front.

The patient attempted to maintain balance in the eyes open and closed positions for 30 second and the tandem right and left leg forward positions for 20 seconds. The dynamic balance test was based on biofeedback. The patient was instructed to precisely manipulate his or her COP position to complete the task. Each patient was given the same task with the same level of difficulty and was allowed two test runs to become familiar with the procedure.

This study complied with ethical principles of the Declaration of Helsinki (1975, revised 1983). This study was approved by the Bioethical Committee of the University of Medical Sciences, Poznań, Poland. Written informed consent was obtained from all participants.

All numerical data are expressed as mean ± standard deviation. The paired t-test was used to determine the differences between the first and second examinations in order to determine if the rehabilitation significantly affected balance performance. In addition, post-rehabilitation results were compared to those of the control group. The level of statistical significance was set at $p < 0.05$.

RESULTS

The subjective Lysholm knee score increased significantly from 79 ± 10 before rehabilitation to 90 ± 10 after the four-week program (14%, $p = 0.0004$). The main problems reported in the first examination were sensations of instability and pain in the knee; however, these problems were unnoticeable after rehabilitation. Moreover, there was a significantly difference between the total scores of the rehabilitation and control groups ($p = 0.0016$) (Table 1).

During examinations in normal standing with eyes open, recordings performed in the sagittal plane differed significantly between patients after rehabilitation and the controls ($p = 0.05$). The results of the same static balance examination performed in the position with eyes closed differed significantly after rehabilitation ($p = 0.0004$). However, after rehabilitation, the patients were less stable in both the sagittal and frontal planes than controls ($p = 0.04$ and 0.05, respectively). There were no significant differences in other positions (Table 2).

Test execution time on the balance platform improved significantly after rehabilitation ($p = 0.00002$). Patients undergoing rehabilitation achieved better results than the control group in both examinations (Table 3).

DISCUSSION

ACL injury not only causes mechanical instability of the joint, but also disturbs the transmission of afferent proprioceptive impulses. In the present study, the Lysholm knee scores of all patients improved after rehabilitation. The mean score of the patients (<90) is evaluated as excel-

Table 2. Mean velocity of COP swing in the frontal and sagittal planes in all test positions

Mean velocity of COP swing	Examined groups of subjects				
	Intervention group before rehabilitation (B)	Intervention group after rehabilitation (A)	Change (A − B)	Controls (C)	Difference (C − A)
Normal standing, eyes open					
Vx	3.85 ± 1.90	3.85 ± 1.46	0.00 ± 2.39	3.62 ± 1.49	−0.23 ± 2.13
Vy	5.68 ± 1.55	4.93 ± 1.46	−0.75 ± 2.05	3.85 ± 0.70	−1.08 ± 1.81*
Normal standing, eyes closed					
Vx	4.05 ± 1.73	4.32 ± 1.81	0.27 ± 2.37	2.6 ± 1.38	−1.72 ± 2.65*
Vy	7.82 ± 2.53	5.17 ± 1.40	−2.65 ± 1.98*	4.32 ± 1.79	0.85 ± 2.29*
Tandem position, right leg forward					
Vx	11.22 ± 2.78	11.72 ± 3.07	0.49 ± 2.76	11.62 ± 1.91	−0.09 ± 3.67
Vy	10.44 ± 2.60	9.46 ± 3.10	−0.98 ± 4.01	11.59 ± 2.00	2.13 ± 3.91
Tandem position, left leg forward					
Vx	11.00 ± 3.72	10.6 ± 1.36	−0.4 ± 4.32	11.11 ± 1.91	0.51 ± 2.28
Vy	10.02 ± 3.91	9.82 ± 1.90	−0.2 ± 4.50	10.37 ± 2.92	0.55 ± 2.92

Data are mean ± SD. COP: center of foot pressure; Vx: frontal plane; Vy: sagittal plane. *p < 0.05

Table 3. Execution times for dynamic tests on the balance platform

Execution time (s)	Examined groups of subjects				
	Intervention group before rehabilitation	Intervention group after rehabilitation	Change	Controls	Difference
		First examination			
	20.3 ± 4.03	12.1 ± 2.6	8.3 ± 4.4*	15.6 ± 2.1	3.6 ± 3.4*
		Second examination			
	18.2 ± 3.3	11.6 ± 2.6	6.6 ± 3.8*	16.3 ± 2.4	4.7 ± 3.2*

Data are mean ± SD. *p < 0.05

lent[14]. Moreover, the improvement after rehabilitation was significant. Patients showed improvement in overall body balance. Fremerey et al.[15] evaluated patients three months postoperatively according to the Lysholm knee scale and report similar findings. Moreover, they report an association between proprioception and patient functional level, i.e., patients with high scores in subjective tests exhibited improved proprioception, whereas patients with worse outcomes exhibited showed worse results in functional tests and reduced proprioception despite good joint mobility and mechanical stability. This is corroborated by Risberg and Ekeland[16], who studied patients in the late postoperative period (18 months after arthroscopic ACL reconstruction). In their studies, the mean Lysholm knee score was 89.1. They also report a strong correlation between Lysholm knee score and functional test results. Karasel et al.[13] compared patients before and after ACL reconstruction and found significant improvement in postoperative Lysholm knee scores; however, they point out the influence of the patients' motivation on the obtained scores. Most patients played recreational sports. Some did not return to the level of performance before their injury; despite this, they did not declare wanting to improve their skills or return to sports because of the risk of further injury.

Biofeedback-based balance studies reveal improvements as a result of treatment. Moreover, they help patients overcome psychological barriers before returning to full physical activity. Analysis of the sway of the COP on the balance platform in static positions showed a significant change after rehabilitation in the position with eyes closed. The mean velocity of the COP sway in the sagittal plane was significantly slower after rehabilitation. Dauty et al.[17] compared postural stability in static conditions in patients 15 days after ACL reconstruction with healthy controls; they found all parameters increased, particularly the length of the COP path in the sagittal plane, when subjects had their eyes closed. These results are consistent with those obtained in the present study. After ACL reconstruction, patients compensate for impaired balance control by greater involvement of visual perception. This impairment is only evident after excluding eye control (Table 2). O'Connell et al.[18] found subjects showed the lowest values of selected parameters (i.e., length and velocity) while standing on both legs with eyes open and the highest values while standing on one leg with eyes closed.

The reduced mean velocity of the COP sway in the sagittal plane in healthy controls indicates the role of the ACL in the anteroposterior stabilization (Table 2). From a biomechanical perspective, the ACL, together with the posterior cruciate ligament, is the major stabilizer of the knee in the sagittal plane[1, 19, 20]. It provides stability and normal kinematics, acting in coordination with the muscular system. Couillandre et al.[21] emphasize that the muscular system is the important factor in maintaining balance and stabilizing joints. Strengthening the quadriceps and hamstrings muscles is an integral component of rehabilitation after ACL reconstruction; these muscles stabilize sagittal plane movements. Therefore, it can be concluded that strengthening muscles in addition to proprioception training played a clinically significant role in the observed balance improvements. Akima et al.[22] also highlight the importance of strengthening the muscles in the rehabilitation process in order to obtain satisfactory treatment outcomes. Biofeedback-based balance training is widely used in neurological rehabilitation[23–26]. However, there are no reports about the usefulness of biofeedback in patients undergoing ACL reconstruction. The present results show such rehabilitation significantly decreased the time required to accomplish the dynamic balance test (Table 3), indicating a faster response and adaptation of the COP position to the desired position. The time improved significantly on both treatment boards. Thus, patients improved their dynamic balance, which prevents future injuries[27].

In conclusion, ACL injury treated with arthroscopic reconstruction results in the disturbance of proprioception and balance; this is especially evident during static balance with eyes closed. Maintaining the balance in a sagittal plane incurs the greatest difficulties. However, one month of biofeedback-based rehabilitation can partially improve static and dynamic balance.

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