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Original Article

Effect of early proprioceptive training on postural balance in patients after anterior cruciate ligament reconstruction

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Abstract
After anterior cruciate ligament reconstruction, proprioceptive abilities of an individual are impaired. A decreased static and dynamic postural control between the operated and non-operated leg is observed. To improve postural stability, it is still controversial whether to start with a more aggressive protocol (so-called accelerated program) or to follow the non-accelerated program with a delayed protocol of loading. The **purpose** of this study was to estimate whether the early onset of proprioceptive exercises and early weight-bearing affected the postural balance and knee stability of patients with anterior cruciate ligament reconstruction. **Methodology:** A total of 40 patients were tested at their sixth postoperative month using a computerized posturographic system (CAT 2004 Plovdiv/Bulgaria) to assess the static unilateral postural balance, and using two dynamic functional tests (30 m straight line running for time and running in figure-8 for time) to evaluate dynamic changes in postural balance. The patients were divided into two groups, i.e. - 21 in the control group and 19 in the experimental group. Each patient was placed in a group according to the start with proprioceptive closed kinetic chain exercises and weight-bearing activities. **Results:** Compared to the patients from the control group, during the test of unilateral stance on a stable surface, the patients from the EG showed a significantly lower postural sway both in mean amplitude oscillation and in the sway of mean velocity, similarly with the operated and non-operated leg when eyes were closed. The other posturographic test (i.e. unilateral stance on a foam surface), showed even bigger discrepancies between the groups, especially in the values of mean velocity, and postural oscillations were significantly lower in both directions, for both conditions, and for both tested limbs. Both dynamic functional tests showed that – only running in figure-8 for time revealed significantly better performance by the patients from the experimental group compared to those from the control group. Based on the obtained results, we can **summarize** that subjects who started with early training using proprioceptive exercises in closed kinetic chain and immediate weight-bearing of the operated leg had better static and dynamic postural balance in the quantitative and qualitative way in their sixth postoperative month after isolated anterior cruciate ligament reconstruction. These patients were ready for a safe return to more vigorous activities, while the patients who started to execute these specific proprioceptive exercises a month later had more precautious and uncertain performance in more challenging tasks.
Key Words: anterior cruciate ligament reconstruction, proprioception, instability

Introduction

The postural balance is important for human motor abilities, and its control after knee impairments is an essential requirement for physical activities in daily life (Zouita Ben Moussa et al, 2009; Popova-Dobreva, 2020). One of the reasons for a ligamentous knee injury and repetitive trauma in the joint is a decreased static and dynamic postural control of the lower limb (Dargo et al, 2017). The integration of information from the three sensory systems (visual, vestibular, and proprioceptive) has a considerable role in maintaining a standing balance (Riva et al. 2016). If one of the components is reduced or changed, there is a modulation in the balance abilities (Mohammadi et al., 2012). The authors stated that following anterior cruciate ligament reconstruction (ACLR), an individual's proprioceptive abilities were impaired (Van Melik et al, 2016; Filbay & Grindem, 2019). Some claimed that there was a difference in postural stability between the operated and non-operated leg (Paterno et al 2007; Mohammadi et al., 2012). Most patients build a compensatory mechanism to the non-affected leg in order to perform the given functional task with the lower limbs (Dauty et al, 2010)

Most often researchers estimate the level of postural balance with the help of a computer-based posturography platform system for quiet postural stance (Mohammadi et al., 2012; Stambolieva, 2011, Lehmann et al, 2017) and with dynamic functional tests for the dynamic postural task (Ortiz et al, 2008; Padua et al, 2009).

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By testing different conditions, it is possible to determine increased postural instability under selected conditions. That is how it is possible to identify sensory interaction problems such as loss of somatosensory feedback and respectively a proprioceptive deficit (Zouita Ben Moussa et al., 2009; Howells et al, 2011). Eye closure eliminates vision and some vestibular information, thereby taxing the somatosensory system (Alonso et al. 2009; Page et al, 2010, Chiba et al 2016). According to Riva et al (2016) when test trials are performed with eyes open, it is an indicator of postural control, as all sensory systems are in use. When the tests are performed with eyes closed, it is considered an indicator of proprioceptive control, since mainly the proprioceptive input is provoked. Changing the stable surface with an unstable one makes reorganization in the proprioceptive input mechanism, mainly through the foot receptors. The afferent part of the somatosensory system works harder in order to keep the body center of mass over the base of support and maintain efficient postural balance (Aman et al, 2015; Page et al, 2010).

To enhance postural balance, different exercises from an upright standing position, with both eyes open and closed are needed to be trained (Norris, 2004; Tasheva, 2018). Training on the uneven or giving surface provides additional training to the balance system. Exercises on a rocker board and foam pad are excellent to progress in joint proprioception improvement (Norris, 2004; Grueva-Pancheva, 2016). Plyometrics and agility training, which are part of complex proprioceptive training, are often included in late-stage rehabilitation (Co, 2015; Grueva-Pancheva, 2018; Tasheva, 2019). Often on the early postoperative days, the postural balance can be trained with some proprioceptive exercises in close kinetic chain (CKC) in unloaded (horizontal position) or semi-loaded position (sitting or standing with hands support) (Grueva-Pancheva, 2016). It is still controversial whether to start with a more aggressive protocol so-called accelerated program or to follow the non-accelerated program with a delayed protocol of loading after ACLR. The authors who support the idea of the accelerated rehabilitation program assume that there is a minimal risk of complications with the early start of weight-bearing to tolerance and CKC exercises. They believe that it is possible to start with the proprioceptive exercises and weight-bearing immediately postoperatively or within a week without compromising the autograft site (Arden et al, 2018; Wilk et al, 2003;Van Grinsven et al, 2010; Janssen et al, 2017 & 2018). The other team of authors considers that stressing the new graft tissue too soon will risk the detachment of the graft site, bone tunnel enlargement can be increased and this can render the joint stability (Hoglum, 2001; Vadalà et al, 2007). The delayed protocol includes touchdown with weight-bearing not early than 4th postoperative week, refraining from the CKC exercises for the first 4-6 weeks and limited extension by a locked brace at 15° of flexion, restricting as well a full range of motion. There are researchers who did not found a difference between the accelerated and non-accelerated programs. They pointed out that with advancing the exercises and increasing the activity level the increase in knee laxity was the same (Beynnon et al, 2011; Christensen et al, 2013).

Therefore the purpose of this report is to estimate whether the early onset of proprioceptive exercises and early weight-bearing influence the postural balance and knee stability of patients with anterior cruciate ligament reconstruction.

Materials and Methods

Participants

A total of 40 patients were tested in the sixth month postoperatively after isolated reconstruction of the anterior cruciate ligament. Both Bone Tendon Bone (BTB) and Hamstring (HAM) autograft operative techniques were applied. The patients were divided into two groups, i.e. – 21 in the control group and 19 in the experimental group. A patient was placed in a group according to the start with proprioceptive close kinetic chain (CKC) exercises and weight-bearing activities. On the first postoperative days the patients from the EG started to perform these specific exercises: From the back lying position, the exercises consisted of: foot slide or push on a wall; active flexion and extension of the knee, rolling on a fitball; heel slide on a table/floor – later with theraband resistance. As weight-bearing of the operated leg was allowed to tolerance immediately post-reconstruction, some simple balance exercises were performed on stable and unstable surfaces. In contrast, the patients from the CG started to execute this type of exercise around the 30th-45th postoperative day, when the weight-bearing of the reconstructed knee was already allowed.

Meanwhile, they followed the standard postoperative protocol for alleviating the postoperative symptoms and improving the mobility in the limb: cryotherapy and anti-swelling position to reduce pain and edema; active movements only for the adjacent joints, hip and ankle; continuous passive movement through artromot machine for the knee. The locomotion was performed with two crutches without stepping on the operated leg which eliminated the opportunity to practice any kind of balance exercises. The progression with proprioceptive exercise resumed with individual speed, according to the possibilities of the subjects. Detailed data information about the type of reconstruction procedure and the start with proprioceptive training for each subject are presented in figure 1.

The subjects were young and active, received their trauma during sports activity and none of them was a professional athlete. The male gender prevailed in both groups, 16 out of 19 for the EG and 20 out of 21 for the CG. All participants gave their signed informed consent to participate in the study in accordance with the ethical standards of the local Ethics Committee and the Helsinki declaration and were free to withdraw from the study at any time.

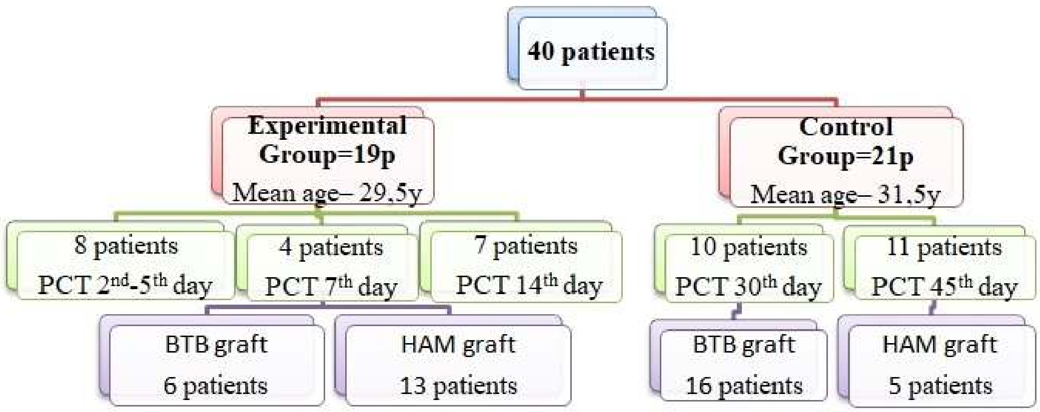

Figure 1. Subjects autograft reconstruction technique (BTB – bone tendon bone; HAM – hamstring) and onset of proprioceptive training (PCT)

Measurement procedure

To assess the changes of the static unilateral postural balance a computerized posturographic system - "CAT 2004" Plovdiv/Bulgaria was used, which consists of a stable platform, modulator and adapted software (Stambolieva, 2011). The displacements of the foot pressure center in both medio-lateral (ML) and anterior-posterior (AP) directions were registered. The postural stability parameters mean amplitude (MA) and mean velocity (MV) were detected. Two analog signals were digitized with a sampling interval of 10 ms and filtered with a digital Hamming low-pass filter with a cut-off frequency of 10 Hz in order to remove the high-frequency noise and sampling error.

The measurement for all subjects included two tests. In the first test, the subject was directly positioned on the stable posturographic surface, barefooted in a quiet unilateral stance (fig. 2). And the second test was done on a foam block, which was situated onto the posturographic platform (fig. 3). Both tests were performed in two conditions: with eyes open (EO) and with eyes closed (EC), with a 30 seconds time duration.

Figure 2. Test 1 – unilateral stance on a stable surface

Figure 3. Test 2 – unilateral stance on a foam surface

Additionally, to assess the dynamic changes of the postural balance two dynamic functional tests were executed to evaluate the possibilities of the patients to react to more vigorous cutting and rapid deceleration activities. On the one hand, the patients were tested with a 30 m straight line running for time and on the other hand, the same running distance was covered but in a figure-of-eight. The second functional dynamic test is considered the most provoking cutting maneuver after ACL proprioceptive deficiency (McGee, 2006). Each dynamic functional test was repeated 3 times with a minute rest between the repetitions, and the mean score was calculated and taken for further statistical analysis. Apart from quantitative data, we collected qualitative information about the performance. The patients from both groups were tested in their 6th postoperative month.

Statistical analysis

The data for the descriptive analysis were expressed by mean values ± standard deviations (SD). The results did not have a normal distribution, so non-parametric methods were used. Differences between groups were tested by the Mann-Whitney U-test for independent variables and a t-test for dependent variables was used for calculating the differences between the conditions within a group. The accepted level of statistical significance was $p < 0.05$. All statistical analyses were performed with Statistics 7.0 (Stat Soft Inc., USA, 2004).

Results

Test 1 – Stable Surface

The mean amplitude of postural sway on a stable surface for both conditions is presented in figure 4A, and that for the operated leg (OL) and non-operated leg (NOL). During the easiest task, unilateral standing on a stable surface with eyes open, the patients from both groups presented similar amplitude values of postural sway in both orthogonal axes and for both legs. When the eyes were closed the patients from the experimental group (EG) compared to the ones in the control group (CG) showed significantly lower amplitude postural sway in anterior-posterior (AP) and medio-lateral (ML) direction for the OL, and in AP direction for the NOL. Only the CG revealed a statistically significant raise of the amplitude oscillation when the vision was eliminated for the OL in both orthogonal axes and for the NOL in AP direction only.

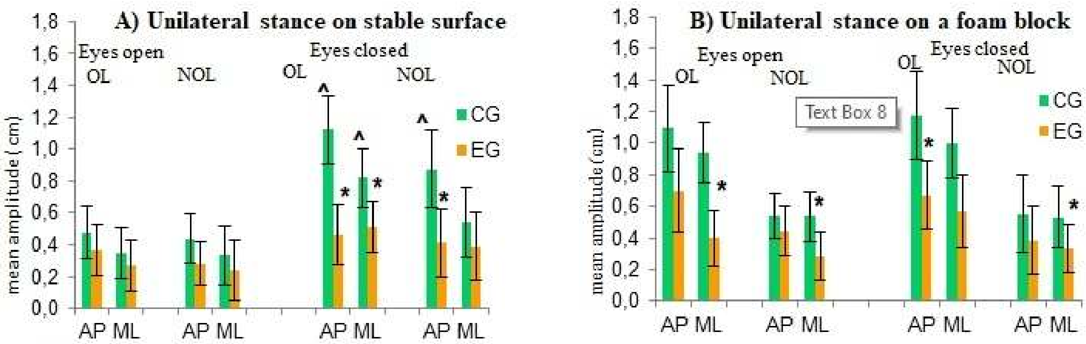

Figure 4.
A) Mean amplitude on a stable surface B) Mean amplitude on a foam surface
* St. Significance between groups (p<0.05); ^ St. Significance between the conditions within a group (p<0.05)

The mean velocity of postural sway on the stable surface did not differ statistically between the groups when performed with eyes open, except for the OL in AP direction the patient from the EG showed significantly lower values. When the vision was eliminated the patients from the EG showed significantly lower mean velocity than those of CG in AP direction for OL and NOL, and in ML direction only for the NOL. Comparing the values between the conditions only the CG showed a statistically significant raise in AP direction for the OL when eyes were closed (Figure 5A).

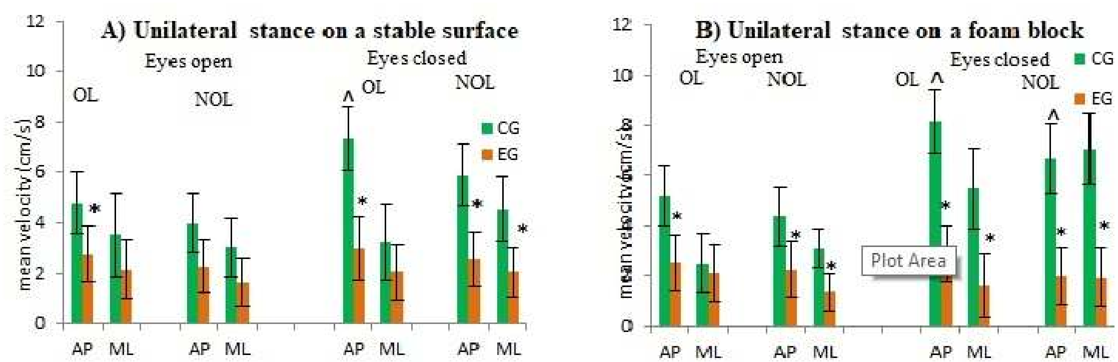

Figure 5.
A) Mean velocity on a stable surface B) Mean velocity on a foam surface
* St. Significance between groups (p<0.05); ^ St. Significance between the conditions within a group (p<0.05)

In this test, unilateral stance on a stable surface, the patients from the EG showed lower postural sway both in mean amplitude oscillation and in the sway of mean velocity, similarly with the OL and NOL. The values remained almost the same when the test was performed with eyes closed. Compared to them the patients from the CG significantly raised the amplitude and velocity sway when the test was performed with eyes closed and that specifically for the operated leg.

Test 2 – Foam surface

When the proprioceptive input was provoked during unilateral stance on a foam block in the eyes open condition the EG showed significantly lower mean amplitude sways in ML direction and that for both legs, operated and non-operated, compared to the controls. With closing the eyes the mean amplitude sway for the NOL was still significantly lower for the EG in ML direction, but for the OL a significant difference was observed for the AP direction. Comparing the values between the conditions no statistical significance was found for the EG and for the CG (Figure 4B).

The mean velocity postural sway during unilateral stance on foam block revealed great discrepancies between the groups in both conditions. When maintaining a quiet unilateral stance with eyes open, the patients from the EG had significantly lower velocity sway in AP direction for the OL and in both directions for the NOL. With the elimination of the vision, lower significant values were observed again for the subjects from the EG, in both orthogonal axes for both legs. The sensory deficit was confirmed with visual dependence for the patients from the CG as a statistically significant raise in velocity sway was seen in AP direction for OL and for NOL (Figure 5B).

This experimental test, quite unilateral stance on a foam surface, revealed even bigger discrepancies between the groups, especially concerning the values of mean velocity. While the mean amplitude values for the EG were lower predominantly in the ML direction for both conditions and that for OL and NOL. The mean velocity postural sway was lower in both directions, for both conditions, and for both tested limbs.

It seems that with the sensory provocation of the postural task the control group demonstrated poor static postural balance in comparison to the patients from the experimental group.

Functional test - Straight line running

This dynamic postural balance test did not present any differences in performance between the groups in their sixth postoperative month (Figure 6). But the subjective feeling during the task performance differed between the subjects. From the EG only one subject (5.3 %) informed about weak pain and uncertainty while doing the speed running, while fifteen subjects from the CG (71.4 %) complained. During the speed forward running the shear forces in anterior-posterior direction acted mainly on the lower leg and did not seem to affect the quantitative parameters but did so on the quality of movement.

Functional test – running in figure-8

Running in figure-8 gives stress and more torsion forces acting on the knee joint while taking the curves. The patients from the EG performed it significantly faster than the subjects from the CG (Figure 7). Compared to the straight line running test, more patients from the EG (5 out of 19, or 26.3 %) complained of subjective feelings like pain and discomfort. But the percentage of the subjects in CG was bigger (12 out of 21, or 57.1 %). This test, provoking more the agility of the lower limb, revealed better performance in a quantitative and qualitative way for the subjects from the EG.

Figure 6. Mean values for straight line running test

Figure 7. Mean values for figure-of-8 running test
St. Significance between groups (p<0.05)

Discussion

Our most important finding was that subjects who started with early training of proprioceptive exercises in close kinetic chain (CKC) and immediate weight-bearing of the operated leg had a better static and dynamic postural balance at their sixth postoperative month after ACLR. This finding is in correspondence with a statement of Janssen et al (2018), who revealed in a systematic review that accelerated rehabilitation, defined as early unrestricted motion, immediate weight-bearing and eliminating the use of immobilizing braces, is appropriate after ACLR. Although "unrestricted motion" is not a very clear and complete definition for the type of exercises on the first postoperative days, there are some precautions that should be obeyed. It is well known that in order to build a new capillary system for good blood supply which is well incorporated in the bony system the new autograft should not be mechanically overstressed and yet early loading is necessary (Tomberlin, 2007). Open kinetic chain exercises are a type of exercises that put the laxity of the graft site at risk, as the lower leg is hanging on the soft tissues around the joint and the quadriceps muscle is the only one in action, which at that moment is weak and inhibited (Norris, 2004). Besides, isolated contraction of the quadriceps leads to ventral displacement of the tibia to the femur, causing even bigger mechanical stress on the newly fixed ACL. Great shear forces are acting on the newly implemented ligamentous implant, causing it a possible elongation or increase bony tunnel enlargements (Vadalà et al 2007). Isolated hamstring contraction can diminish this ventral translation of the tibia, but it is not a functional outcome to strengthen separately the hamstring group. That is why we consider that the involvement of OKC on the first postoperative days is not so appropriate and the use of CKC exercise is more of an option. Probably that was the reason why Janssen et al (2018) underlined that OKC exercises should be started around the 4th postoperative week in a specific range (90° to 45°). A lot of positives are shown during CKC exercise performance: the opposing hamstring action and its co-activation together with the quadriceps help to minimize the anterior displacement of the tibia; helps for evenly distributed articular surface pressure in the knee and improves joint stability (Norris, 2004). In their study, a group of authors explained how knee joint stability depended on the interaction of articular soft tissue resistance, bodyweight and applied muscle load. They underlined how compressive forces (resulting from body weight and muscle activity) provided additional strength and prevented ligament overload when the knee was subjected to excessive loads during more aggressive activities (Williams et al, 2001). In that statement and their own results Zouita Ben Moussa and his colleagues (2009) summarized that difference in postural stability in patients after ACLR could be explained by the specific nature of the exercise performed postoperatively and possibly, by compensation by other lower extremity muscle groups. That is why we assume that the difference in static and dynamic postural balance between the ACLR patients in both groups, with lower sway values for the ones in the experimental group, was due to the early start of proprioceptive CKC exercise and loading with the bodyweight of the operated leg. Early proprioceptive involvement in the physiotherapy program helped the subject from the EG to return safely to their daily functional activities already at the end of the first postoperative month without any complaints about knee laxity. This was not a question of the present report but meanwhile organizing the control test trials we figured out that patients from CG could not hold the 30 seconds test trial in a quiet unilateral stance at the end of their first postoperative month.

The results from the posturografic tests at the sixth postoperative month showed predominantly better performance of unilateral static postural balance of patients from the EG. When the simplest task, standing on firm support with eyes open, was executed, the postural sway did not differ significantly between the groups. According to Riva et al (2016), when vision is present, all channels are open, which is an indicator for postural balance. It seems that patients from both groups were dealing merely equal regardless of the type of exercises they performed during the early postoperative period. Whereas during the most difficult task, standing on a foam block with eyes closed, a major discrepancy between the patients' groups was observed. Closing eyes trials became an indicator of proprioceptive control as the received information from the CNS was narrowed mainly to the proprioceptive input. Reducing the vision and changing the support with unstable one increased the sway values of the parameters to the patients from the CG, while the ones from the EG managed to keep them almost unchanged. This is another proof that early proprioceptive training post ACL reconstruction helped to refine the proprioceptive input and in that way to improve the presence of proprioceptive deficit. The interesting fact was that these findings of better proprioceptive control in EG patients were observed both for the operated leg and for the non-operated leg. This led us to think that early proprioceptive training prepared well and symmetrically the lower limb functioning in general, not only the reconstructed side.

The dynamic functional tests also revealed the better postural balance performance of the subjects from the experimental group. Especially when more pivoting maneuvers were done the results were even better in a quantitative and qualitative way. Most researchers stop their attention on exploring the one-leg hop for a time test as they compare the differences between the involved and uninvolved leg (Mohammadi et al, 2012; Zouita Ben Mousa 2009). There are researchers who point out that there was the importance of the appropriate selection of motion tasks as an integral factor in dynamic stability testing which evoked different kinematic outcomes in relation to the different stages of ACLR recovery. According to them running and pivoting were recommended 6 months after ACLR surgery before letting the subjects engage in sports practice (Chua et al, 2016). We did not meet any similar results concerning running and pivoting. One reason could be the method of assessment. But this makes our finding even more valuable for the present moment.

Conclusion

Based on the obtained results we can summarize that early start with proprioceptive close kinetic chain exercises and early weight-bearing of the operated leg in the first postoperative days after ACL reconstruction did not compromise the operative technique and did not provoke any laxity in the knee joint. What is more important, these specific exercises which were started a few days after the operation shortened the period to functional return to the daily activities of the subjects. In their sixth postoperative month, the patients with ACLR knee demonstrated better static and dynamic postural balance in a quantitative and qualitative way compared to subjects who started to execute these specific proprioceptive exercises a month later. The patients from the experimental group were ready for safe return to more challenging sports activities, while the ones from the control group had more precautious and uncertain sports performance.

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