THE ANALYSIS OF PROPRIOCEPTION ALTERATION DURING FIRST FIVE MONTHS AFTER ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION

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ABSTRACT

Research background and hypothesis. Proprioception is important in the prevention of injuries as reduced proprioception is one of the factors contributing to injury in the knee joint, particularly the ACL. Therefore, proprioception appears not only important for the prevention of ACL injuries, but also for regaining full function after ACL reconstruction.

Research aim. The aim of this study was to understand how proprioception is recovered four and five months after anterior cruciate ligament (ACL) reconstruction.

Research methods. The study included 15 male subjects (age – 33.7 ± 2.49 years) who had undergone unilateral ACL reconstruction with a semitendinosus/gracilis (STG) graft in Kaunas Clinical Hospital. For proprioceptive assessment, joint position sense (JPS) was measured on both legs using an isokinetic dynamometer (Biodex), at knee flexion of 60° and 70°, and at different knee angular velocities of 2°/s and 10°/s. The patients were assessed preoperatively and after 4 and 5 months, postoperatively.

Research results. Our study has shown that the JPS's (joint position sense) error scores to a controlled active movement is significantly higher in injured ACL-deficient knee than in the contralateral knee (normal knee) before surgery and after four and five months of rehabilitation.

After 4 and 5 months of rehabilitation we found significantly lower values in injured knees compared to the preoperative data. Our study has shown that in injured knee active angle reproduction errors after 4 and 5 months of rehabilitation were higher compared with the ones of the uninjured knee. Proprioceptive ability on the both legs was independent of all differences angles for target and starting position for movement. The knee joint position sense on both legs depends upon the rate of two different angular velocities and the mean active angle reproduction errors at the test of angular velocity slow speed was the highest compared with the fast angular velocity.

Discussion and conclusions. In conclusion, our study shows that there was improvement in mean JPS 4 and 5 months after ACL reconstruction, but it did not return to normal indices.

Keywords: knee joint, joint position sense, angular velocity, starting position for movement.

INTRODUCTION

Proprioception is the sum of kinaesthesia and joint position sense. Kinaesthesia is defined as the awareness of joint movement and it is dynamic. Joint position sense (JPS) is restricted to the awareness of the position of a joint in space and is a static phenomenon. Proprioception can also be defined as the cumulative neural input to the central nervous system from specialized nerve endings called mechanoreceptors (Grob et al., 2002). These are located in the joint capsules, ligaments, muscles, tendons, and skin (Lephart et al., 1998; Kavounoudias et al., 2001). Some of these receptors (for example, Pacinian corpuscles) are stimulated in the initial and terminal stages of the

range of movement of joints as well as during rapid changes in velocity and direction (kinaesthesia). On the other hand the Ruffini end organ-like receptors and Golgi tendon organ-like receptors have been associated with a response to the relative position of muscles and joints (joint position sense). However, in the literature the terms kinaesthesia, joint position sense (JPS) and proprioception are often used synonymously (Grob et al., 2002). Histologically, it has been demonstrated that the human anterior cruciate ligament (ACL) contains mechanoreceptors that can detect changes in tension, speed, acceleration, direction of movement, and the position of the knee joint (Borsa et al., 1997). Proprioception is assessed by measuring kinesthetic sensibility and joint position sensibility which are perception of joint motion and joint position, respectively (Dhillon et al., 2011). Proprioception is important in the prevention of injuries as reduced proprioception is one of the factors contributing to injury in the knee, particularly the ACL. Although the causes of ACL injury are multi-factorial, poor proprioception is one of the key causative factors (Griffin et al., 2000). Therefore, proprioception appears not only important for the prevention of ACL injuries, but also for regaining full function after ACL reconstruction. Injury to the anterior cruciate ligament not only causes mechanical instability but also leads to a functional deficit in the form of diminished proprioception of the knee joint (1992; Pap et al., 1999; Fischer-Rasmussen, Jensen, 2000; Dhillon et al., 2011). Proprioception is emerging as an important factor determining post operative results of ACL reconstruction (Dhillon et al., 2011). Although reconstruction is successful in regaining joint stability, the recovery of proprioceptive function remains debatable (Henriksson et al., 2001). P. B. MacDonald et al. (1996) reported no significant improvement in proprioceptive deficits in patients 31 months after ACL reconstruction by measuring kinesthesia. Furthermore, D. M. Hopper et al. (2003) reported no significant difference in knee proprioception after 12 and 16 months of ACL reconstruction by measuring JPS. However, B. Reider et al. (2003); and S. Karasel et al. (2010) reported a significantly improved level of proprioception by measuring JPS in an ACL reconstructed knee after six months of rehabilitation when compared with the contralateral limb. The aims of this study was to understand how proprioception is recovered four and five months after ACL reconstruction. Perhaps proprioception can return to normal within 4–5 months of ACL reconstruction. Secondly, we hypothesized that proprioceptive ability in the knee depends upon the rate at all different angles for the target and the starting position for movement. Lastly, the purpose of this study was to analyze the knee joint position sense in different knee angular velocities and to compare the results.

RESEARCH METHODS

Subjects. The group of patients included 15 male (age = 33.7 ± 2.49 years, body weight = 78.93 ± 4.31 kg, height = 177.93 ± 3.37 cm (mean ± SD)) subjects who had undergone unilateral ACL reconstruction with a semitendinosus/ gracilis (STG) graft in Kaunas Clinical Hospital. Individuals were eligible for inclusion in the experiment if they had no previous ACL surgery normal contralateral hip and ankle joint function.

Each subject read and signed a written informed consent form, consistent with the principles outlined in the Declaration of Helsinki. All subjects gave informed consent according to the requirements of the Kaunas Regional Ethical Committee of Biomedical Research (the Protocol No. BE-230). The patients were assessed preoperatively and after four and five months, postoperatively. The uninjured contralateral knee of these patients was used as an internal control.

The logic of the research. Proprioception was evaluated at the knee with the passive extension active replication method using the isokinetic dynamometer „*Biodex System* PRO 3“ (ISO 9001 EN 46001, New York). The subjects sat upright in the dynamometer chair and were tied up with chest, waist and thigh straps. The axis of rotation of the dynamometer was visually aligned with the axis of rotation of the subject's knee joint. The ankle pads were placed just above the subject's lateral malleoli. The subjects were instructed to keep their hands crossed in front of their chest during all testing sessions.

I Assessment of joint position sense. The subjects were with a blindfold. They sat in the dynamometer chair and began the test in the position with the leg flexed at 90 degrees. The subjects had a handheld device with a red button. The persons leg was passively extended by the technician, at a rate of approximately 2- and 10- degrees per second, to an index angle of 60 degrees flexion. The angle was maintained for 10 seconds and the subject was asked to concentrate on its position. The knee was returned passively to the starting position and then

moved again by the motor at a speed of 2- and 10- degrees per second. When the subject thought that the leg was in the same position as before, he pressed the red button on the handheld device. The difference in degrees between the starting index angle and the reproduced angle reflected the subject's ability to estimate angular motion accurately (lower number = better proprioceptive acuity). The subjects underwent 3 repetitions at each angle and the results were evaluated as the mean absolute error of the trials. Improvements in proprioception were calculated as the difference between baseline and follow-up measures.

II Assessment of joint position sense. The subjects were with a blindfold. They sat upright in the dynamometer chair and began in the position with the leg flexed at 10 degrees. The subject's leg was passively flexed by the technician, at a rate of approximately 2- and 10- degrees per second, to an index angle of 70 degrees flexion. The angle was maintained for 10 seconds and the subject was asked to concentrate on its position. The knee was returned passively to the starting position and then moved again by the motor at a speed of 2- and 10- degrees per second. Subjects had a handheld device with a red button. When the subject thought that the leg was in the same position as before, he pressed the red button on the handheld device. Assessment of joint position sense was performed in the same way as before-mentioned.

Statistical analysis. Descriptive data are presented as means ± standard deviation (SD). Data were analyzed using a repeated measures analysis of variance (ANOVA) with time as the repeated measures factor for the outcome measures at the 4- and 5-month follow-ups. SPSS (SPSS Inc., Version 10.0, Chicago, IL) was used to calculate the ICC. The difference between the injured and uninjured knees was analyzed using one way ANOVA. The t-test for paired samples was used to determine whether there was a difference between the mean values for the same measurements on the operated and normal knee joints. The difference of $p < 0.05$ between the means of the same measurements for the operated and normal knees was considered to be statistically significant.

RESEARCH RESULTS

Joint position senses (JPS) of the knees were determined by measuring the ability of the patient to reproduce active position at two different target angles and movement start angles from 90° flexion to 60° flexion and at 10° flexion to 70° flexion, and at two different angular velocities 2°/s and 10°/s. The results of this study indicated, that there was a significant difference ($p < 0.001$) between the injured and the healthy legs before surgery and after four months, and five months $p < 0.05$ of rehabilitation (Table 1). Both the knee tests extension and flexion data showed that there was JPS error scores higher on the injured knee compared with the uninjured knee. We found that before surgery there was higher difference for JPS errors scores between the legs compared with the values four and five months after surgery. After four and five months of rehabilitation we found significantly lower ($p < 0.05$) values in the injured knees compared with the preoperative data (Table 2). In injured knee

Table 1. **Differences of degrees in JPS for mean error scores between injured and uninjured knees**

Test	Injured and uninjured knees			
	Extension		Flexion	
	Angular velocity 2°/s	Angular velocity 10°/s	Angular velocity 2°/s	Angular velocity 10°/s
Before surgery, %	56.2#	56.9#	53.9#	48.6#
After 4 months, %	40.4#	42.3#	30.8*	33.9*
After 5 months, %	30.8*	32.2*	21.1*	29.4*

Note. * – $p < 0.05$; # – $p < 0.001$.

Table 2. **The effects of improvement of degree in JPS for mean error scores on the injured knee after four and five months of rehabilitation compared with the preoperative data**

Improvement of degree	Injured knee			
	Extension		Flexion	
	Angular velocity 2°/s	Angular velocity 10°/s	Angular velocity 2°/s	Angular velocity 10°/s
After 4 months, %	23.1*	20.7*	30.3*	19.2*
After 5 months, %	37.8*	35.6*	43.9*	30.1*

Note. * – $p < 0.05$.

active angle reproduction errors after five months of rehabilitation, were significantly ($p < 0.05$) higher compared with uninjured knee. On both legs significant differences ($p < 0.05$) between two different angular velocities 2°/s and 10°/s (Figures 1, 2) were measured. It should be noted, that the mean active angle reproduction errors the test of angular velocity of 2°/s were the highest compared with the angular velocity of 10°/s (Table 3). There were no significant differences in both legs at all different angles for the target and the starting position of the movement.

DISCUSSION

Our study has shown that the JPS (joint position sense) error scores to a controlled active movement are significantly higher in injured ACL-deficient knee than in the contralateral knee (normal knee) before surgery and after four and five months of rehabilitation.

Before surgery we found that there were higher differences for JPS errors scores between injured ACL-deficient knee and the contralateral knee (normal knee). Many authors have demonstrated significant proprioceptive deficits in ACL-deficient knees (Pap et al., 1999; Fischer-Rasmussen, Jensen, 2000; Anders et al., 2008; Dhillon et al., 2011). Significant data have come to light demonstrating proprioceptive differences between normal and injured knees, and often between injured and reconstructed knees (Dhillon et al., 2011). R. L. Barrack et al. (1989) found that proprioception was virtually identical in the two knees of the control group. The test group, however, showed a significantly lower proprioceptive activity in injured knees as compared to the uninjured knees.

Table 3. **Differences of degrees in JPS for mean error scores (averages ± SD) between two different angular velocities of 2°/s and of 10°/s**

Angular velocity	Injured knee			Uninjured knee		
	Before surgery (averages ± SD)	After 4 months (averages ± SD)	After 5 months (averages ± SD)	Before surgery (averages ± SD)	After 4 months (averages ± SD)	After 5 months (averages ± SD)
Extension of 2°/s	16.7 ± 2.8	12.9 ± 3.3	10.4 ± 2.1	7.3 ± 1.3	7.7 ± 1.4	7.2 ± 1.3
Extension of 10°/s	12.5 ± 2.5	9.9 ± 2.2	8.1 ± 2.4	5.4 ± 1.8	5.7 ± 1.2	5.5 ± 1.4
Difference of degrees, %	25.1*	22.7*	22.4*	26.4*	25.2*	24.1*
Flexion of 2°/s	15.2 ± 5.5	10.6 ± 1.9	8.5 ± 1.9	7 ± 1.6	7.3 ± 1.2	6.7 ± 1.1
Flexion of 10°/s	9.7 ± 2.8	7.9 ± 1.5	6.8 ± 0.9	5 ± 1.6	5.2 ± 1.3	4.8 ± 0.9
Difference of degrees, %	36*	25.8*	20.3*	28.6*	29.1*	28.7*

Note. * – $p < 0.05$.

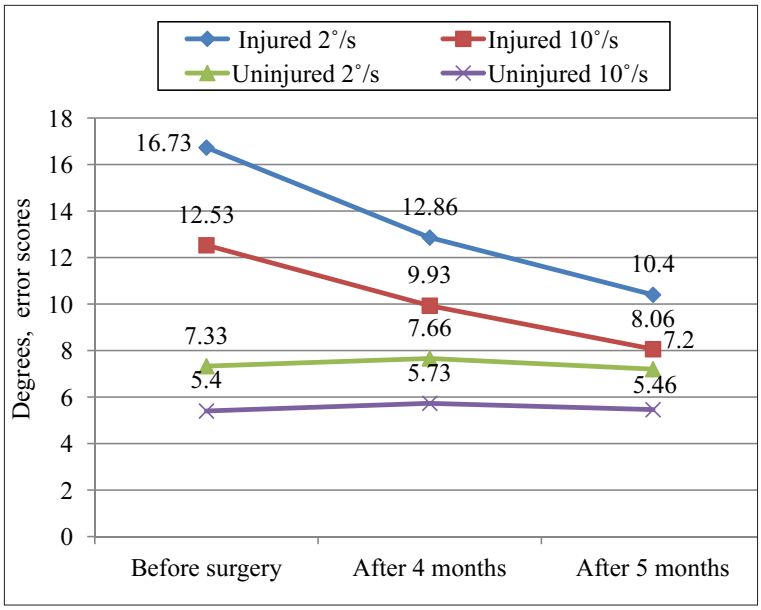
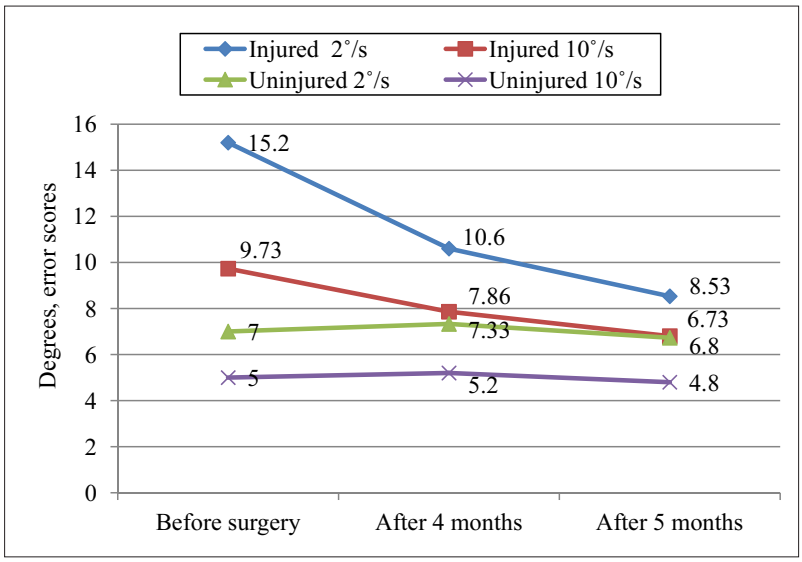


Figure 1. **Mean values of uninjured and injured knee extension at different velocities ($p < 0.05$)**

Figure 2. **Mean values of uninjured and injured knee flexion at different velocities ($p < 0.05$)**



After four and five months of rehabilitation we found significantly lower values in injured knees compared with the preoperative data. Some studies concluded that proprioception might be restored to an equal level compared to the uninjured contralateral limb or controls (Reider et al., 2003; Karasel et al., 2010). ACL reconstruction alters proprioception of the knee to a certain extent; many authors have demonstrated that reconstruction of ACL restores proprioception and kinesthesia equivalent to that of ACL intact knees (Reider et al., 2003; Mir et al., 2008; Muaidi et al., 2009; Angoules et al., 2011).

In a recent study, A. G. Angoules et al. (2011) prospectively studied knee proprioception following ACL reconstruction in 40 patients, allocated into two equal groups based on reconstruction using hamstring or bone-patellar tendon-bone autograft. Joint position sense at various knee angles and threshold to detection of passive motion at 15° and 45° were used as measures of proprioception. The patients were assessed preoperatively and at 3, 6 and 12 months, postoperatively. The uninjured contralateral knee of these patients was used as an internal control. At 6 and 12 months, no statistical difference was found in the proprioceptive acuity of the reconstructed knee and uninjured knee, or in the two graft groups. The authors concluded that knee proprioception returned to normal within 6 months of ACL reconstruction, without statistically significant differences between types of autograft used. Our study has shown that in injured knee active angle reproduction errors after 4 and 5 months of rehabilitation, were significantly ($p < 0.05$) higher compared with uninjured knee.

We chose to measure JPS with the knee positioned at 10° of flexion because the ACL, as well as the posterior aspect of the joint capsule, acts as limit detectors for the neuromuscular system. This is based on the fact that neurophysiological experiments have shown increased afferent impulse generation from mechanoreceptors with joint movement into extension and that proprioception is improved at the limit of joint motion (Lephart et al., 1992). There were no significant differences of both legs at all different angles for the target and the starting position for movement.

G. Pap et al. (1999) have suggested that the analysis of failure of JPS is essential since differences between damaged and undamaged knees can be seen in a wide range at different angular velocities. Therefore, in this study we analyzed failure of JPS at each of the two different angular velocities used. We used reproduction active position (RAP) to assess the proprioceptive function in ACL- reconstructed and normal knees. We preferred this method because reproductions are done actively using muscular contractions of muscle groups during RAP, thus enabling elicitation of input from the musculotendinous receptors as well (Borsa et al., 1997). Although it is usually performed at slow speeds, RAP stimulates both joint and muscle receptors and provides a more functional assessment of the afferent pathways (Lephart et al., 1992). Our study has shown that significant differences between two different angular velocities 2°/s and 10°/s were measured on both legs. It should be noted that the mean active angle reproduction errors in the test of angular

velocity of 2°/s were highest compared with the angular velocity of 10°/s. This is in accordance with previous studies in which proprioceptive acuity was found to improve with increasing velocities of joint movement (Pap et al., 1997). G. Pap et al. (1997) found increasing rates of failure for the detection of both the start and the end of movement with slower angular velocities. Two explanations may account for this: 1) separated populations of mechanoreceptors in the ACL are stimulated at different rates of extension of the knee, providing different proprioceptive information; or 2) periarticular receptors (including muscle spindles) may be selectively activated at higher speeds (Wright et al., 1994).

CONCLUSIONS AND PERSPECTIVES

In conclusion, our study shows that there was improvement in the mean JPS four and five months after ACL reconstruction, but it did not return to normal. Proprioceptive ability on both legs was independent of all different angles for the target and the starting position for movement. The knee joint position sense on both legs depends upon the rate between two different angular velocities, and the mean active angle reproduction errors at the test of angular velocity at slow speed were the highest compared with the fast angular velocity.

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PROPRIORECEPCIJOS POKYČIAI PER PIRMUOSIUS PENKIS MĖNESIUS PO KOJŲ PRIEKINIŲ KRYŽMINIŲ RAIŠČIŲ REKONSTRUKCIJOS

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SANTRAUKA

Tyrimo pagrindimas ir hipotezė. Proprioreceptija yra svarbi traumų prevencijai. Pablogėjusi proprioreceptija yra vienas iš veiksnių, kuris gali sukelti kelio sąnario traumą, ypač priekinio kryžminio raiščio (PKR). Proprioreceptija yra svarbi ne tik traumų prevencijai, bet ir visaverčiam kelio funkcijos atgavimui įvertinti po atliktos PKR rekonstrukcijos.

Tyrimo tikslas – nustatyti proprioreceptijos pokyčius praėjus 4 ir 5 mėnesiams po atliktos PKR rekonstrukcijos.

Metodai. Buvo tiriama 15 vyrų (amžius – 33,7 ± 2,49 m.), kuriems Kauno klinikinėje ligoninėje buvo atlikta vieno kelio PKR rekonstrukcija panaudojant pusgyslinio/grakščiojo raumens sausgyslės transplantą. Tiriant proprioreceptiją, kelio sąnario pozicijos nustatymas buvo matuojamas izokinetiniu dinamometru (*Biodex*), tiriamajam lenkiant kelio sąnarį skirtingais kampais (60° ir 70°) ir skirtingais kampiniais greičiais (2 ir 10°/s). Tiriamieji buvo testuojami prieš operaciją ir praėjus 4 ir 5 mėnesiams po jos.

Rezultatai. Tyrimas parodė, kad prieš operaciją bei po 4 ir 5 mėnesius trukusios reabilitacijos kelio sąnario pozicijos nustatymo daromų klaidų reikšmės yra didesnės tos kojos, kurios nutrauktas priekinis kryžminis raištis, lyginant su sveiko kelio reikšmėmis. Po 4 ir 5 mėnesių reabilitacijos nustatytas sumažėjęs pažeistos kojos daromų klaidų vidurkis, lyginant su duomenimis prieš operaciją, bet jie vis dar liko didesni nei sveikos kojos. Abiejų kojų proprioreceptija nepriklausė nuo skirtingų kelio sąnario sulenkimo kampų ir skirtingos judesio pradžios, priklausė – nuo skirtingų kampinių greičių. Sąnario kampo nustatymo klaidų buvo daroma mažiau testuojant dideliu kampiniu greičiu nei mažu.

Aptarimas ir išvados. Atlikus PKR rekonstrukciją, po 4 ir 5 mėnesių reabilitacijos kelio sąnario pozicijos nustatymas pagerėjo, bet negrįžo iki normos rodiklių.

Raktažodžiai: kelio sąnarys, sąnario pozicijos nustatymas, kampinis greitis, judesio pradžios pozicija.

Gauta 2012 m. sausio 19 d.
Received on January 19, 2012

Priimta 2012 m. kovo 13 d.
Accepted on March 13, 2012

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