Acta of Bioengineering and Biomechanics Original paper
Vol. 20, No. 4, 2018 DOI: 10.5277/ABB-01204-2018-02

Assessment of postural stability in patients after reconstruction of the anterior cruciate ligament with LARS and autogenous graft

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Purpose: The aim of the study was to assess static balance after reconstruction of the anterior cruciate ligament (ACL), using gracialis tendons graft (GR) or semi-tendinosus (ST), compared to patients treated with the Ligament Advanced Reinforcement System (LARS). The study was performed within 36 to 48 months after the surgery. *Methods*: The study included 96 patients. The LARS group consisted of 44 patients, control group operated with ST/GR tendons included 52 patients. The stabilometric platform Alpha was used to assess the static balance. Two 30-second trials in the double-leg stance position with eyes opened and closed were performed. The distribution of loads in a free standing was also assessed. *Results*: In the test with open eyes the subjects from the LARS group had a significantly longer center of pressure (COP) path, a higher mean velocity, a greater mean COP sway in foot in the lateral direction and a larger path area occupied by the COP graph. During the tests with eyes closed, a significant difference occurred in the mean displacement of COP in lateral direction – greater in the LARS group. In addition, all parameters deteriorated during the tests with eyes closed in both groups. *Conclusions*: In static balance assessed with eyes closed, more proprioceptive deficits may appear in the LARS group.

Key words: *postural stability, knee, ACL reconstruction, LARS, knee function*

1. Introduction

Direct result of an injury of the structures of the musculoskeletal apparatus is joint instability [5]. The anterior cruciate ligament (ACL) stabilizes the tibia against excessive anterior translation relative to the femur. It also plays an important role in controlling the axis of rotation, primarily internal, and thus contributes to the rotational stabilization of the knee joint [30].

In addition to the surface of the femur and tibia, there are also mechanical receptors at the site of the ACL insertion, such as: Paccini bodies, Ruffini endings, and Golgi tendon organs, which play an important role in proprioception [27]. Therefore, ACL injury causes not only mechanical instability, but also affects the deterioration of deep sensation [27]. Previous studies confirmed the association between ACL injury and disturbed information from deep sensory receptors [11]. The consequence of disrupted information flow from the ligament mechanoreceptors to the central nervous system may be disorders of postural stability [23].

Stability of body posture depends on various factors, including age, level of physical activity, muscle strength and the incidence of previous injuries in the lower limbs [26]. Information about the relationship between pro-

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Received: September 11th, 2018
Accepted for publication: October 16th, 2018

prioception and postural stability are inconsistent. Lee et al. [14] showed a significant positive correlation between threshold for the detection of passive motion proprioception and the dynamic balance for the lower limb after ACL injury. In subsequent studies [13], the authors did not confirm this relationship.

Impaired proprioception of the knee joint and abnormal postural stability may adversely affect patient satisfaction with treatment outcomes [18]. Obtaining optimal stability and efficiency of the knee joint is a challenge for surgeons during ACL reconstruction [4] and physiotherapists planning effective rehabilitation after the surgery [12]. In the process of comprehensive treatment of patients after ACL injuries, it is important to use the appropriate method and technique of reconstruction and individual physiotherapy protocol [12].

One of the methods of ACL reconstruction is the use of synthetic ligaments, the Ligament Advanced Reinforcement System (LARS). Synthetic LARS fibres are made of terephthalic polyethylene polyester fibres [29]. The internal part of the ligament consists of many parallel fibres twisted at an angle of 90 degrees, which ensures an even distribution of tension along its entire length. The porous structure of the weave provides better ability to ingrow into biological tissues and reduces fibre wearing [10]. The advantage of using this technique of reconstruction is minimization of soft tissues injuries in the knee joint. The ACL stump is anchored to the meshwork of the LARS to support the optimization of the primary ACL tissue regeneration and helps to preserve some vascularization and deep sensory receptors [7].

Only few reports are available on the return of full function of the knee joint after the LARS reconstruction, therefore, the aim of our paper is to compare the postural stability in patients after ACL reconstruction with LARS and autogenous graft.

2. Materials and methods

In compliance with the Declaration of Helsinki, all participants were informed about the purpose and course before entering the study and they gave their informed consent to participate in it. The Bioethics Committee of the Faculty of Health Sciences at Jan Kochanowski University in Kielce gave the consent No. 7/2015 to conduct the study.

2.1. Seeting

The tests were performed in the Physiotherapy Laboratory at the Holy Family Specialist Hospital in Rudna Mała near Rzeszów, Podkarpackie Province, Poland. All examined patients performed tests at the same time, in the morning, in a specially prepared place. The tests were carried out from January 2015 to June 2015.

2.2. Participants

The patients were enrolled by a call at the Holy Family Specialist Hospital in Rudna Mała. After the initial qualification, patients aged 27 to 50 years who underwent ACL reconstruction in 2010–2012 were included to the study.

The inclusion criteria for the study were: reconstruction of the ACL with two types of grafts: synthetic LARS and autogenous from the semitendinosus or gracialis ST/GR muscle, the period after the surgery between 36 and 48 months, age from 27 to 50 years of age.

Exclusion criteria were: bilateral ACL injury, revision ACL reconstruction, multi-ligament lesions, surgical treatment of trauma to lower limb joints, congenital malformations of lower limbs, disturbed balance of neurological background, lack of consent for participation in the study.

Patients after the reconstruction were subjected to comprehensive rehabilitation. According to the guidelines from the literature, it is an important element in restoring both active and passive stability of the knee joint [21]. Depending on the existing structural and functional deficits and indications, it lasted from 8 to 16 weeks (14 weeks on average).

The main goal of rehabilitation in the initial period was to reduce exudate, edema and pain, and then gradually restore full function of the joint: mobility, proprioception, strength and coordination. The post--surgery rehabilitation program consisted of protocol including the PRICE principle (in the initial period), progressive weight-bearing walking, progressive range of motion (ROM) exercise, progressive strengthening exercise of the knee muscles, stretching exercises,

Table 1. Characteristics of the studied groups

Variable	LARS Group ($N = 44$)		ST/GR Group ($N = 52$)	
Sex	N	%	N	%
Woman	7	15.9	13	25.0
Man	37	84.1	39	75.0
Age	$\bar{x}$	s	$\bar{x}$	s
	38.8	8.0	34.6	7.3

N – number of observations, % – percent, $\bar{x}$ – arithmetic mean, s – standard deviation.

proprioception exercises and stabilization of the knee as well as the educational program focused on the potential post-surgical complications and limitations.

After considering inclusion and exclusion criteria, 96 patients were included in the study. They were divided into two groups: LARS group (n = 44) and ST/GR group (n = 52). The characteristics of the studied groups are presented in Table 1.

2.3. Assessment of Static Balance and load distribution

Assessment of postural stability and load distribution was carried out using the ALFA stabilometric platform. Three tests were performed in the double-leg stance position: the Romberg test with open eyes and the Romberg test with eyes closed to assess postural stability and the test to assess the distribution of loads with eyes open. The tests lasted 30 seconds. The subjects performed two trials of each test, separated by a minute rest, which allowed to eliminate the discomfort associated with longer standing in a still position. The results were averaged for further analysis. Each of the tests on the platform was preceded by performing one complete activity in order to minimize the learning effect. In the analysis, this trial was not taken into account. The subject adopted and maintained the position with the arms alongside the body and the head in an intermediate position. During the tests, the patients were asked to direct their sight to a fixed point placed on the wall at a distance of 1 meter from the subject. The feet setting on the platform was determined by fixed lines placed on the plate of the posturographic platform. The tests were performed barefoot, in conditions not interfering with its course [28].

A set of parameters was chosen to the analysis of the results, based on the Romberg test:

- COP path length, i.e., the total path travelled by the Center of pressure (COP) tested within 30 s, expressed in cm: with eyes open (LcopOe) and with eyes closed (LcopCe);
- Mean COP deviation in the anterio-posterior (AP) direction, expressed in cm: with eyes open ($MAPS_{COP}Oe$) and with eyes closed ($MAPS_{COP}Ce$);
- Mean COP deviation in the lateral (L) direction expressed in cm: with eyes open (MLSCOPOe) and eyes closed (MLSCOPCe);
- Mean COP velocity in AP direction expressed in cm/s: with eyes open ($MVAPS_{COP}Oe$) and eyes closed ($MVAPS_{COP}Ce$);
- Mean COP velocity in the L direction expressed in cm/s: with eyes open ($MVLS_{COP}$ Oe) and eyes closed ($MVLS_{COP}Ce$);
- COP path area plotted during the test, expressed in cm^2: with eyes open ($F_{COP}Oe$) and with eyes closed ($F_{COP}Ce$).

A set of parameters was chosen to the analysis of the results based on the load distribution test:

- Distribution of load for a healthy lower limb, expressed as a percentage (DTH – Distribution Test Health),
- Distribution of load for a lower limb after reconstruction, expressed as a percentage (DTAR – Distribution Test After Reconstruction).

2.4. Data analysis

The parameters analysed did not have a normal distribution in the analysed groups (p from the Shapiro–Wilk test below 0.05). Mann–Whitney U-test was used to evaluate the significance of the differences in the selected stabilometric parameters between LARS group and ST/GR group. Wilcoxon matched-pairs test was used to check the intra-group variability that occurs in the tests with open and closed eyes.

The statistical analysis of the collected material was carried out in the SPSS Statistics 13.1. The level of statistical significance was adopted at p <0.05.

3. Results

In the tests with open eyes, the LARS group showed a significantly longer COP path covered within 30 s, greater mean COP deviation in the L direction, higher mean COP velocity towards AP and L direction, and larger COP area plotted within 30 seconds. In both groups, COP tended to have more posterior (P) deviations than anterior (A) ones, the trend was more pronounced in the ST/GR group.

In tests with eyes closed, statistically significant difference between the compared groups occurred only at the parameter of the mean COP deviation in the L direction (greater deviations in the LARS group) (Table 2).

In the tests with eyes closed, all assessed parameters deteriorated in both groups. In the LARS group, statistically significant differences were found in all analysed parameters between the trial performed with open and closed eyes. However, in the ST/GR group, significant differences did not occur in two analysed

Table 2. Comparison of the results of the Romberg test with open and closed eyes in the LARS group and the ST/GR group

Variable	LARS Group ($N = 44$)					ST/GR Group ($N = 52$)					p
	$\bar{x}$	Me	Min.	Max.	s	$\bar{x}$	Me	Min.	Max.	s	
L_{COP}Oe	27.89	25.35	9.40	112.50	16.35	21.49	20.10	1.40	49.00	9.24	0.007
$MAPS_{COP}$Oe	–0.03	0.00	–1.10	0.50	0.30	–0.09	0.00	–1.60	0.80	0.44	0.405
MLS_{COP}Oe	0.19	0.10	–0.90	2.00	0.54	–0.16	0.00	–4.80	1.30	0.15	0.021
$MVAPS_{COP}$Oe	0.59	0.50	0.20	2.20	0.32	0.47	0.40	0.20	1.10	0.18	0.010
$MVLS_{COP}$Oe	0.68	0.60	0.20	2.60	0.40	0.56	0.50	0.20	1.10	0.22	0.050
F_{COP}Oe	1.84	1.25	0.20	11.10	1.93	1.21	0.90	0.20	9.30	1.42	0.007
L_{COP}Ce	42.09	36.00	16.10	167.80	27.49	38.12	36.45	12.20	81.70	15.46	0.918
$MAPS_{COP}$Oe	–0.18	–0.10	–3.20	1.70	0.68	–0.15	–0.10	–1.40	0.80	0.46	0.886
MLS_{COP}Ce	0.34	0.25	–1.00	2.10	0.73	–0.19	–0.10	–4.10	2.10	1.02	0.007
$MVAPS_{COP}$Ce	0.79	0.70	0.30	2.90	0.50	0.76	0.70	0.30	1.60	0.28	0.419
$MVLS_{COP}$Ce	1.05	0.90	0.40	4.30	0.68	1.00	1.00	0.30	1.90	0.41	0.668
F_{COP}Ce	3.42	1.75	0.20	29.30	5.36	2.18	1.65	0.30	9.40	1.69	0.702

N – number of observations, $\bar{x}$ – arithmetic mean, Me – median, Min – minimum, Max – maximum, s – standard deviation, p – Mann–Whitney U-test.

parameters – in the mean COP deviation in the AP direction ($MAPS_{COP}$) and in the mean COP deviation in the L direction (MLS_{COP}) (Table 3).

Table 3. Differences in the stabilometric parameters between the tests with eyes closed and eyes opened in LARS group and ST/GR group

Variable	LARS Group ($N = 44$)		ST/GR Group ($N = 52$)	
	$\bar{x}$	p	$\bar{x}$	p
L_{COP}Oe	27.89	<0.001	21.49	<0.001
L_{COP}Ce	42.09		38.12	
$MAPS_{COP}$Oe	–0.03	0.044	–0.09	0.146
$MAPS_{COP}$Ce	–0.18		–0.15	
MLS_{COP}Oe	0.19	0.018	–0.16	0.873
MLS_{COP}Ce	0.34		–0.19	
$MVAPS_{COP}$Oe	0.59	<0.001	0.47	<0.001
$MVAPS_{COP}$Ce	0.79		0.76	
$MVLS_{COP}$Oe	0.68	<0.001	0.56	<0.001
$MVLS_{COP}$Ce	1.05		1.00	
F_{COP}Oe	1.84	0.005	1.21	<0.001
F_{COP}Ce	3.42		2.18	

N – number of observations, $\bar{x}$ – arithmetic mean, p – Wilcoxon test.

In the ST/GR group, load distribution was distributed on average by 50% on both limbs, while in the LARS group, healthy leg took on an average slightly more load of 50.8%. At the same time, the analysis did not show statistically significant differences in the results between the groups regarding load distribution (Table 4).

Table 4. Comparison of load distribution results in the LARS group and in the ST/GR group

Variable	LARS Group ($N = 44$)		ST/GR Group ($N = 52$)		p
	$\bar{x}$	s	$\bar{x}$	s	
DTH	50.8	2.1	50.0	2.1	0.164
DTAR	49.3	2.1	50.0	2.1	0.164
Difference	–1.5	4.1	–0.0	4.2	0.164

N – number of observations, $\bar{x}$ – arithmetic mean, s – standard deviation, p – Mann–Whitney U-test.

4. Discussion

Reconstruction of ACL is a standard procedure for people who want to return to an active lifestyle [17]. LARS ligament under arthroscopy is a minimally invasive, safe and effective method used especially in people who require a quick return to high levels of sport activity [10]. Ardern et al. [1] show that only 55% of athletes return to competitive sport, and only 65% of them return to their pre-injury level of performance after ACL reconstruction. However, the type of reconstruction was not considered in the studies. Paterno et al. [24] indicate that athletes who returned to sport show an increased risk of ACL re-injury. A distant consequence of such damage may be a faster development of a degenerative disease limiting physical fitness [15]. Different results presented Gao et al. [8], who published data from the 50-month observation concerning 159 patients after ACL reconstruction with the LARS. All respondents returned to sport before the end of the six months, and the re-rapture occurred only in 1.9% of people. Nau et al. [20] observed 27 people after ACL reconstruction using autogenous graft from the patellar ligament and 26 people after reconstruction with LARS ligament for 27 months. They did not notice differences between the groups in terms of re-injury and other complications, and the only difference in favour of the LARS group was a faster rehabilitation protocol and earlier return to sport.

The injury followed by reconstruction and rehabilitation result in temporary absence of a person from work and require large financial spending [17]. Therefore, it is extremely important to indicate and eliminate modifiable risk factors for injury or re-injury of the ACL ligament. Paterno et al. [25] indicate that abnormal postural stability after ACL reconstruction can lead to re-injury. It is related to coordinated integration of sensory input from the vestibular and visual systems and on somatosensory information from the extremities, which gives the position and the movement of the joints and body [6].

This paper attempts to answer whether postural stability is at a similar level in patients after ACL reconstruction, regardless of the type of graft used. All subjects performed a stabilometric test on a force platform in both visual conditions – with eyes opened and closed as well as load distribution test. Objective measurements of static balance and postural control using computerized force platforms are considered to be "gold standards" for clinical and scientific practice [16].

According to Overmoyer et al. [22], the smaller the amplitude, the deviation length and mean velocity of COP, the better the postural stability. In our studies, differences in the absolute values of the mean COP deviations in the L direction were found in the Romberg test. Larger deviations in this plane occurred in the LARS group, which may indicate worse proprioception from the knee joint in this group. Research conducted by Baloha et al. [3] indicated that the measurements in the frontal plane are a more sensitive indicator of balance disorders than measurements in the sagittal plane. At the same time, in our subjects, these deviations increased their amplitude in both groups during the trial with closed eyes, however, they increased significantly in the LARS group. This may indicate that the lack of visual input during the eyes closed test emphasize greater persisting proprioceptive deficits in the group of LARS patients. A systematic review by Howells et al. [9] presented the results from the studies in which a total of 644 subjects were assessed, on average in the period of 29 months after the reconstruction. In static balance tasks, there was a trend towards improved postural control in the group for eyes-open but not in the eyes-closed conditions. There was also evidence suggesting impaired postural control in patients following surgery, compared to controls, especially for more challenging tasks.

However, visual control is also important in healthy people in maintaining body balance. Asseman et al. [2] tested young athletes on the platform in three static test positions. Deprivation of the sense of sight resulted not only in increased COP oscillation, but also in an increase in the mean velocity of its deviations in the assessed planes.

Analysing the COP deviations in the sagittal plane, no significant differences were found between the groups. In both groups, COP tended to be more deviated posteriorly than anteriorly, a trend was more pronounced in the subjects from the ST/GR group. At the same time, the LARS group was characterized by on average greater COP deviation velocity in both planes (sagittal and frontal) then the ST/GR group. However, they were statistically significant only for MVAPS index in the eyes open test.

Mostafaee et al. [19] examined 54 Iranian patients on the platform after ACL reconstruction before and after a 4-week rehabilitation period. They performed both static and dynamic postural tests. The results of static postural measures indicate the mean and the SD of velocity in AP and ML directions as the most responsive COP parameters for discriminating between improved and unimproved patients.

There are some limitations of our study. One of them is the fact that only static balance was assessed in our study and we did not assess the patient's dynamic balance. Static postural control is also assessed in the early period after reconstruction. It gives information on the current asymmetry in loading the lower limbs. This result can be taken into account as an early indicator of the load asymmetry appearing later. In the case of distant studies of knee joints after ACL reconstruction, dynamic tests are also used.

5. Conclusions

In static balance assessed with eyes open, more proprioceptive deficits tests may appear in the LARS group. The mean COP deviation in the lateral direction with the eyes open and closed, which is significantly higher in the LARS group, seems to be an important parameter to detect proprioceptive deficits in patients after ACL reconstruction. Static lateral balance is worse in patients treated with LARS. Assessment of postural stability should be an integral part of the comprehensive assessment of patients after ACL reconstruction to monitor re-education of knee function and prevention of re-injury.

References

[1] ARDERN C.L., TAYLOR N.F., FELLER J.A., WEBSTER K.E., *Fifty-five per cent return to competitive sport following anterior cruciate ligament reconstruction surgery: An updated systematic review and meta-analysis including aspects of physical functioning and contextual factors*, Brit. J. Sport Med., 2014, 48, 1543–1552.

[2] ASSEMAN F., CARON O., CRE´MIEUX J., *Effects of the removal of vision on body sway during different postures in elite gymnasts*, Int. J. Sports Med., 2005, 26, 116–119.

[3] BALOH R.W., YING S.H., JACOBSON K.M., *A Longitudinal Study of gait and balance dysfunction in normal older people*, Arch. Neurol-Chicago, 2003, 60, 835–839.

[4] COLOMBET P., JENNY J.Y., MENETREY J., PLAWESKI S., ZAFFAGNINI S., *Current concept in rotational laxity control and evaluation in ACL reconstruction*, Ortop. Traumatol. Sur., 2012, 98(8), 201–210.

[5] CROSS M., *Clinical terminology for describing knee instability*, Sports Med. Arthrosc. Rev., 1996, 4, 313–318.

[6] DAUTY M., COLLON S., DUBOIS C., *Change in posture control after recent knee anterior cruciate ligament reconstruction?*, Clin. Physiol. Funct. I., 2010, 30, 187–191.

[7] DERICKS G., *Ligament Advanced Reinforcement system anterior cruciate ligament reconstruction*, Oper. Techn. Sport Med., 1995, 3(3), 187–205.

[8] GAO K., CHEN S., WANG L., ZHANG W., KANG Y., DONG Q., ZHOU H., LI L., *Anterior cruciate ligament reconstruction with LARS artificial ligament: a multicenter study with 3- to 5-year follow-up*, Arthroscopy, 2010, 26, 515–523.

[9] HOWELLS B.E., ARDERN C.L., WEBSTER K.E., *Is postural control restored following anterior cruciate ligament reconstruction? A systematic review*, Knee Surg. Sport Tr. A., 2011, 19, 1168–1177.

[10] HUANG J.M., WANG Q., SHEN F., WANG Z.M., KANG Y.F., *Cruciate ligament reconstruction using LARS artificial ligament under arthroscopy: 81 cases report*, Chin. Med. J. (Engl.)., 2010, 123(2), 160–164.

[11] KO M.S., YANG S.J., HA J.K., CHOI J.Y., KIM J.G., *Correlation between Hamstring Flexor Power Restoration and Functional Performance Test: 2-Year Follow-Up after ACL Reconstruction Using Hamstring Autograft*, Knee Surg. Relat. Res., 2012, 24, 113–119.

[12] KRUSE M.L., GRAY B.,WRIGHT R.W., *Rehabilitation After Anterior Cruciate Ligament Reconstruction*, J. Bone Joint Surg. Am. Title., 2012, 94(19), 1737–1748.

[13] LE D.H., LEE J.H., AHN S.E., PARK M.J., *Effect of Time after Anterior Cruciate Ligament Tears on Proprioception and Postural Stability*, Plos One, doi.org/10.1371/journal.pone.0139038.2015.

[14] LEE H.M., CHENG C.K., LIAU J.J., *Correlation between proprioception, muscle strength, knee laxity, and dynamic standing balance in patients with chronic anterior cruciate ligament deficiency*, Knee, 2009, 16(5), 387–391.

[15] LOHMIER L.S., STENBERG A., ENGLUND M., ROOS H., *High prevalence of knee osteoarthritis, pain and functional limitations in female soccer players twelve years after anterior cruciate ligament injury*, Arthritis Rheumatol., 2004, 50, 3145–3152.

[16] MANCINI M., HORAK F.B., *The relevance of clinical balance assessment tools to differentiate balance deficits*, Eur. J. Phys. Rehab. Med., 2010, 46(2), 239–248.

[17] MATHER R.C., KOENIG L., KOCHER M.S., DALL T.M., GALLO P., SCOTT D.J., BACH B.R., SPINDLER K.P., *Societal and economic impact of anterior cruciate ligament tears*, J. Bone Joint Surg. Am., 2013, 95, 1751–1759.

[18] MOLKA A.Z., LISINSKI P., HUBER J., *Visual biofeedback exercises for improving body balance control after anterior cruciate ligament reconstruction*, J. Phys. Ther. Sci., 2015, 27(7), 2357–2360.

[19] MOSTAFAEE N., YAZDI M.J.S., NEGAHBAN H., GOHARPEY S., MEHRAVAR M., PIRAYEH N., *Responsiveness of Static and Dynamic Postural Balance Measures in Patients with Anterior Cruciate Ligament Reconstruction Following Physiotherapy Intervention*, Arch. Bone Jt. Surg., 2017, 5(3), 153–167.

[20] NAU T., LAVOIE P., DUVAL N., *A new generation of artificial ligaments in reconstruction of the anterior cruciate ligament. Two-year follow-up of a randomised trial*, J. Bone Joint Surg. Br., 2002, 84, 356–360.

[21] OGRODZKA-CIECHANOWICZ K., CZECHOWSKA D., CHWAŁA W., ŚLUSARSKI J., GĄDEK A., *Stabilometric indicators as an element of verifying rehabilitation of patients before and after reconstruction of anterior cruciate ligament*, Acta Bioeng. Biomech., 2018, 20, 1, DOI: 10.5277/ABB-01005-2017-02.

[22] OVERMOYER G.V., REISER R.F., *Relationships between lower-extremity flexibility, asymmetries, and the Y balance test*, J. Strenght Cond. Res., 2015, 29(5), 1240–1247.

[23] PARK J.H., JEONG W.K., LEE J.H., CHO J.J., LEE D.H., *Postural stability in patients with anterior cruciate ligament tears with and without medial meniscus tears*, Knee Surg. Sport Tr. A., 2015, 23(1), 240–245.

[24] PATERNO M.V., RAUH M.J., SCHMITT L.C., FORD K.R., HEWETT T.E., *Incidence of contralateral and ipsilateral anterior cruciate ligament (ACL) injury after primary ACL reconstruction and return to sport*, Clin. J. Sport Med., 2012, 22, 116–121.

[25] PATERNO M.V., SCHMITT L.C., FORD K.R., RAUH M.J., MYER G.D., HUANG B. et al., *Biomechanical measures during landing and postural stability predict second anterior cruciate ligament injury after anterior cruciate ligament reconstruction and return to sport*, Am. J. Sport Med., 2010, 38, 1968–1978.

[26] RELPH N., HERRINGTON L., TYSON S., *The effects of ACL injury on knee proprioception: a meta-analysis*, Physiotherapy, 2014, 100(3), 187–195.

[27] SCHUTTE M.J., DABEZIES E.J., ZIMNY M.L., HAPPEL L.T., *Neural anatomy of the human anterior cruciate ligament*, J. Bone Joint Surg. Am. Title.,1987, 9, 243–247.

[28] SCOPPA F., CAPRA R., GALLAMINI M., SHIFFER R., *Clinical stabilometry standardization Basic definitions – Acquisition interval – Sampling frequency*, Gait Posture., 2013, 37(2), 290–292.

[29] TRIEB K., BLAHOVEC H., BRAND G., SABETI M., DOMINKUS M., KOTZ R., *In vivo and in vitro cellular in growth into a new generation of artificial ligaments*, Eur. Surg. Res., 2004, 36, 148–151.

[30] ZANTOP T., HERBORT M., RASCHKE M.J., FU F.H., PETERSEN W., *The role of the anteromedial and posterolateral bundles of the anterior cruciate ligament in anterior tibial translation and internal rotation*, Am. J. Sports Med., 2007, 35(2), 223–227.