Acta of Bioengineering and Biomechanics
Vol. 23, No. 3, 2021

Original paper
DOI: 10.37190/ABB-01868-2021-03

Hamstring weakness at 90° flexion of involved knee as an indicator of the function deficit in males after anterior cruciate ligament reconstruction (ACLR)

SELVIN BALKI*, SEFA ELDEMIR

Department of Physiotherapy and Rehabilitation, Faculty of Health Sciences,
Sivas Cumhuriyet University, Sivas, Turkey.

Purpose: The aim of this study was to elucidate predictors on knee function following anterior cruciate ligament reconstruction with hamstring tendon graft or allograft and to detect the differences between it and the healthy controls. *Methods*: This study comprised of 46 males, aged 18–45, being within 6–60 months following unilateral anterior cruciate ligament reconstruction and 50 healthy men. Measurements included the Tampa Scale for Kinesiophobia-17, the self-reported knee function with the Knee Injury and Osteoarthritis Outcome Score, Tegner activity scale and handheld dynamometry the hamstring/quadriceps femoris muscle testing at 90° of flexion. Regression analyses were performed to predict the knee function in the anterior cruciate ligament reconstruction group. *Results*: The anterior cruciate ligament reconstruction group showed significantly lower Tegner activity and hamstring/quadriceps femoris strength, higher kinesiophobia and worse Knee Injury and Osteoarthritis Outcome Score ($p < 0.05$). Their Knee Injury and Osteoarthritis Outcome Score-Sport/Recrection, Quality of Life and –Total values were modestly associated with the satisfaction with prior rehabilitation, activity level, graft type, kinesiophobia, time since the reconstruction and hamstring strength ($p < 0.05$). The hamstring strength was the only important predictor of the Knee Injury and Osteoarthritis Outcome Score-Total ($p < 0.01$). The involved knee handheld dynamometry-mass normalize-hamstring strength at 90° of flexion predicted 20.5% of the variance in the knee function. *Conclusions*: Presence of a decreased handheld dynamometry-mass normalized-hamstring strength result at hyper-flexion after anterior cruciate ligament reconstruction in men may indicate self-reported knee function disorder.

Key words: *Knee Injury and Osteoarthritis Outcome Score, handheld dynamometer, hamstring weakness, anterior cruciate ligament reconstruction*

1. Introduction

A complete understanding of the relationship between the muscle strength and function is important to determine the time of return to sport or prior activity level, and to find the causes for a disability that can be treated by strength training. Like the anterior cruciate ligament (ACL), the hamstring (HS) muscle group is an important stabilizer in the human knee [20]. The gracilis (G) in the medial of the HS muscle group is a muscle that can act to reinforce the HS strength during increased knee flexion [3]. A weakened HS at knee flexion over 70° has been frequently reported due to the G graft used in ACL reconstruction (ACLR) with or without semitendinosus (ST) graft [3], [6]. This HS weakness with hyper-flexion was observed even during the five years following ACLR with hamstring tendon graft (HTG) [16]. A decreased knee flexion strength may cause functional limitations, particularly with daily and sportive activities that demand an increased knee flexion. However, its functional impact is still unclear.

Knee osteoarthritis may appear in the first years following an ACLR with HTG [17]. The Knee Injury and Osteoarthritis Outcome Score (KOOS) is responsive to the findings in articular cartilage defect cases [7]. The questionnaire offers information about the ACLR patients' function [22]. Isokinetic dynamometer mass-

* Corresponding author: Selvin Balki, Department of Physiotherapy and Rehabilitation, Faculty of Health Sciences, Sivas Cumhuriyet University, Sivas, 58140 Turkey. Phone: (+90-506) 594 5067, e-mail: balkipt@hotmail.com

Received: June 3rd, 2021
Accepted for publication: August 26th, 2021

normalized (MN) knee extensor and/or flexor strength measurements were found related to the KOOS within the first five years after ACLR, however, the results with the methods using isokinetic dynamometers in previous studies are limited [4], [11]. These dynamometers are expensive and non-portable compared to handheld dynamometers (HHD) that provide reliable strength measurements [19]. However, it is not clear whether the MN-HS/quadriceps femoris (QF) muscle strengths in hyper-flexion of the knee measured with a HHD reflects the KOOS in patients who underwent ACLR with HTG (ST + G) or allografts.

The purposes of the retrospective study were to elucidate predictors on knee function in men following ACLR with HTG (ST + G) or allografts 6–60 months before and to detect the differences between it and the healthy controls. It was planned to examine the possible effects of factors such as the HHD-MN muscle strengths during 90° flexion of the involved knee, the kinesiophobia, activity level, graft types in prediction of the knee function (KOOS) of the males with ACLR. Our hypothesis was that the involved knee HHD-MN-HS strength$_{90°}$ could be an important predictor of the KOOS in the males with ACLR.

2. Materials and methods

2.1. Ethics statement

The study was approved by the University's Institutional Ethics Committee (approval number: 2018-01/35) and conducted in accordance with the Declaration of Helsinki. All participants provided a written informed consent.

2.2. Participants

In an university hospital, male patients who underwent arthroscopic ACLR to a torn ACL between January 2013 and June 2017 were reviewed. Of selected 97 men with ACLR, 21 were not reach by phone, 15 were outlying, 2 were not willing to participate, 2 had a revision surgery, 2 had a re-injury history, 1 had a total meniscectomy, and 4 had the chondral surgery. After taking into account the afore--mentioned conditions of exclusion from this study, the ACLR group were selected 50 male participants (mean age: 31.38 ± 7.16 years). The criteria for inclusion of the ACLR group were: ages of 18–45 years and having undergone an unilateral allograft-ACLR or HTG-ACLR 6 months to 5 years ago without accompanying meniscus surgery (partial meniscectomy or meniscus repair) or together. Fifty healthy volunteers (mean age: 31.42 ± 7.11 years) who were age and gender compatible with the ACLR group were received in the study as a control group. The controls were enrolled from the community. They had no complaints of any neurological, musculo-skeletal and rheumatologic disorders, or no previous knee injury/surgery history. The dominant leg was on right side in 44 of the 50 control men. The dominant leg was determined by ball kicking. No age difference was detected between the groups ($p = 0.978$).

2.3. Surgical procedure

The unilateral arthroscopic surgeries were performed by anatomic single-bundle ACLR method using autogenous four strand HTG (ST + G) or allograft alone or with concomitant meniscal surgeries. EndoButton (Smith & Nephew Richards, Memphis, Tennessee), were used for femoral fixation and a staple + a biosure screw (Smith & Nephew Richards, Memphis, Tennessee), for the tibial side. In sample of this study, HTG (ST + G) was used in 21 ACLR and allograft was used in 29 ACLR. Three ACLRs were performed with partial meniscectomy, 18 ACLRs with meniscus repair and only 29 ACLRs. The average time between injury and ACLR was 25.08 ± 29.08 months and the average time since the surgery was 35.22 ± 20.06 months. Twenty-nine ACLRs were performed on the dominant side and 18 were on the non-dominant side.

2.4. Postoperative rehabilitation procedure

The participants of the ACLR group had undergone a similar early phase rehabilitation about three to five days under the supervision of physical therapists and then received a home exercise program. Their satisfaction with the previously given rehabilitation was questioned using a 10-cm visual analog scale (VAS). The participants with ACLR had a rehabilitation satisfaction 7.99 ± 2.06 cm in the VAS.

2.5. Measurements

All clinical assessments were performed using standardized procedures by a physical therapist (SE).

The level of participation in sports/physical activities of the ACLR and control groups were detected using the Tegner activity scale [24].

The KOOS includes five subscales: KOOS-Pain (knee pain), KOOS-Symptoms (knee symptoms), KOOS-ADL (activities of daily living), KOOS-Sport/Rec (sport and recreational activities), and KOOS-QoL (knee-related quality of life). Each question of the KOOS is evaluated on a scale of 0 to 4 points. The five subscales are scored independently and the scores are transformed to 0 to 100 points with 100 indicating no problems with the knee function [22]. The KOOS is a common, reliable, valid and responsive questionnaire in ACLR, particularly in the long-term [23]. A KOOS-QoL score of ≤87.5 and the following values in two or more of the subscales, KOOS-Symptoms ≤85.7; KOOS-Pain ≤86.1; KOOS-ADL ≤ 86.8, KOOS-Sport/Rec ≤85.0, are considered clinically significant [7].

The Tampa Scale for Kinesiophobia-17 (TSK-17) contains 17 self-report items with a four-point Likert scale. The total score ranges from 17 to 68 and higher scores represent greater fear levels of re-injury or movement. The TSK-17 evaluates individuals' feelings related to movement, pain and disability [13]. The Turkish versions of both the TSK-17 and KOOS were used in the present study [21], [25].

2.6. Muscle testing with handheld dynamometry

All participants were given a few minutes to warm up with slow physical activities like walking before the muscle testing. Then, the knee strength was measured using a HHD at 90° flexion of the knee while the patients were sitting with their arms crossed over their thighs. A cotton wrap was placed on the end piece of the HHD to reduce any pressure pain derived from muscle testing (Fig. 1). The Baseline HHD (Fabrication Enterprises, Inc., Elmsford, NY, USA) was positioned toward just proximal to the lateral malleolus of the tested leg in the anterior or posterior aspect of the tibia due to tested muscles. After one practice trial, isometric "make" tests were performed as the participants were requested to build their strength gradually to a maximal voluntary effort over a two-second period, and then demonstrated a maximum effort for five seconds, in accordance with the test described by Andrews et al. [2].

The strength [kg/body mass] generated by both the HS and QF of the involved knee (the right limb in controls) was corrected for body mass, and the mean value from the three trials with 1-min rest intervals was calculated. The normalization of the muscle strength (S_n) according to the body mass (m) was done using the formula $S_n = S : m^b$, where $b = 0.67$ [12]. No participant refused the muscle testing due to pain.

2.7. Statistical analysis

The data were analyzed using the SPSS for Windows v.14.0 software (SPSS Inc., Chicago, IL, USA). Statistical significance was set at $p < 0.05$. The skewness values and the Kolmogorov–Smirnov test were used to detect whether data were normal distributed. Of the 50 participants in the ACLR group, four were excluded from these statistical analyses for having missing item in the KOOS outcomes The mean and standard deviation were presented for participant clinical characteristics. The KOOS outcomes (except for the KOOS-QoL, –Sport/Rec and –Total scores in the ACLR group) were negatively skewed, therefore,

Fig. 1. Muscle testing for (A) the hamstring and (B) the quadriceps femoris muscles using a handheld dynamometer

the medians and interquartile ranges (IQR) were computed. The ACLR and control groups were compared by using the Mann–Whitney *U*-test for the KOOS and the independent *t*-test for body mass, height, age, Tegner activity level, muscle strength and kinesiophobia.

For the KOOS-QoL (50.79 ± 21.94), -Sport/Rec (69.78 ± 22.48) and-Total (82.58 ± 11.03) scores in the ACLR group, normal distribution was observed in Lilliefors-corrected Kolmogorov–Smirnov test. After determining the relationships between these normal distributed KOOS values and the demographic/clinical variables using Pearson correlation analysis, multiple linear regression analyses were performed to detect the predictors that contribute to each of the KOOS-Sport/Rec, -QoL, and -Total scores in the ACLR group. The KOOS-Sport/Rec score correlated with the Tegner score (r = 0.325), TSK-17 score (r = –0.433), and the involved knee HHD-MN-HS strength$_{90°}$ (r = 0.421). The KOOS-QoL score correlated with the Tegner score (r = 0.301), TSK-17 score (r = –0.483), the involved knee HHD-MN-HS strength$_{90°}$ (r = 0.323), time since the ACLR (r = 0.376), and graft type (r = –0.326). The KOOS-Total score correlated with the Tegner score (r = 0.414), TSK-17 score (r = –0.423), the involved knee HHD-MNHS strength$_{90°}$ (r = 0.453), time since the ACLR (r = 0.323), and the satisfaction with prior rehabilitation (r = 0.298). The Pearson r values were interpreted accordingly to Cohen: 0.0 to 0.3 indicated a weak correlation, while 0.31 to 0.5 indicated a moderate one, and >0.51 indicated a strong one [5]. These related factors were considered as potential explanatory variables if their p value was <0.15 in the univariable linear regression models. A p value less than 0.15 is a typical entry criterion of the stepwise regression. Before model entry, the explanatory variables were assessed for multicollinearity, and strong correlation status (≥0.80). Dummy codes as yes/no; 0/1 were considered in regression analysis for the contributions of autograft, concomitant meniscus surgeries (meniscal repair or partial meniscectomy), and ACLR in the dominant side.

Post hoc analysis using multiple linear regression with three predictors in any model indicated 91% power, with an alpha level of 0.05 and an effect size of 0.35 (G*Power v.3.1; HHU Düsseldorf).

3. Results

This study was completed with 46 men with ACLR and 50 healthy men in the control group (Table 1).

Table 1. Clinical features of the men who are healthy and have a history of ACLR surgery

Variables	ACLR group (N = 46 men) X ± SD	Control group (N = 50 men) X ± SD	Between group Difference Mean (95%CI)	p
Age [years]	31.13 ± 7.10	31.42 ± 7.11	–0.29(–3,18–2.59)	p = 0.843
Body mass [kg]	84.82 ± 13.09	81.39 ± 10.62	3.43(–1.38–8.24)	p = 0.160
Height [m]	1.76 ± 0.07	1.77 ± 0.07	–0.01(–0.04–0.02)	p = 0.386
Tegner activity score	5.56 ± 2.07	6.90 ± 1.44	–1.33(–2.05– –0.61	p < 0.001
The involved knee HHD-MN-QF strength at 90°*	0.43 ± 0.11	0.56 ±0.13	–0.12(–0.18–0.08)	p < 0.001
The involved knee HHD-MN-HS strength at 90°*	0.24 ± 0.07	0.35 ± 0.08	–0.11(–0.14– –0.07	p < 0.001
TSK-17	39.56 ± 6.54	37.08 ± 5.30	2.48(0.08–4.88)	p = 0.043
	Median (25th–75th IQR)	Median (25th–75th IQR)	Z	
KOOS-Pain	88.89 (79.86–94.44)	100 (100–100)	Z = –5.890	p < 0.001
KOOS-Symptoms	85.71 (77.67–96.43)	100 (92.86–100)	Z = –4.734	p < 0.001
KOOS-ADL	94.85(85.29–98.53)	100 (99.63–100)	Z = –5.297	p < 0.001
KOOS-Sport/Rec	70.00 (58.75–86.25)	100 (95.00–100)	Z = –6.235	p < 0.001
KOOS-QoL	50.00 (37.50–68.19)	100 (98.43–100)	Z = –8.051	p < 0.001
KOOS-Total	83.90 (78.00–88.95)	99.40 (96.85–100)	Z = –7.115	p < 0.001

ACLR – Anterior Cruciate Ligament Reconstruction, SD – Standard Deviation, CI – Confidence Interval, HHD – Handheld Dynamometry, MN – Mass Normalized, QF – Quadriceps Femoris, HS – Hamstring, TSK – Tampa Scale for Kinesiophobia, IQR – Interquartile Range; KOOS – Knee Injury and Osteoarthritis Outcome Score, ADL – Activities of Daily Living, Sport/Rec – Sports and Recreational Activities, QoL – knee-related quality of life.

* The involved limb for ACLR subjects and dominant limb for controls.

Compared to the control males, a lower Tegner activity score and the involved knee HHD-MN-strength values at 90°, higher kinesiophobia, and worse KOOS outcomes were detected in male patients had a HTG or allografts ACLR performed 6–60 months ago ($p > 0.05$, Table 1). With the exception of KOOS--Pain and-ADL, the ACLR group had lower scores at levels considered clinically significant across all KOOS subscales [7]. No differences were found between the groups in term of age and anthropometric characteristics ($p > 0.05$, Table 1).

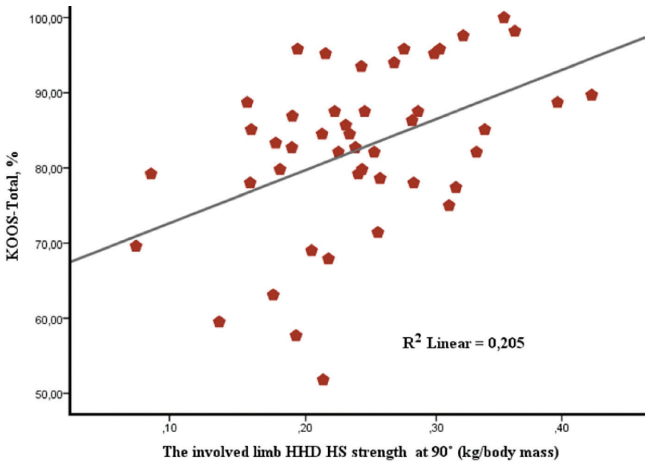

Fig. 2. Regression analysis of the Knee Injury and Osteoarthritis Outcome Score-Total (KOOS-Total) and the handheld dynamometry hamstring strength (HHD HS) at 90° flexion of the involved knee (kg/body mass) in men who underwent ACLR using hamstring tendon graft or allograft

Multiple regression results of the ACLR group for each KOOS-Sport/Rec, -QoL and -Total scores are presented in Table 2. The involved knee HHD-MN-HS strength$_{90°}$ and the TSK-17 outcome predicted 22.8% of the variance in the KOOS-Sport/Rec score ($F_{2,43} = 7.6$, $p < 0.01$). The TSK-17 outcome and time since ACLR predicted 28.5% of the variance in the KOOS-QoL score ($F_{2,43} = 9.9$, $p < 0.01$). Moreover, all the variables detected for KOOS-Sport/Rec and -QoL were statistically significant predictors. The involved knee HHD-MN-HS strength$_{90°}$, Tegner score and TSK-17 outcome predicted 31.5% of the variance in the KOOS-Total score ($F_{3,42} = 7.9$, $p < 0.01$). The HHD-MNHS strength$_{90°}$ of the involved knee was found as the only statistically significant predictor of the KOOS-Total score, since it predicted 20.5% of the variance in the KOOS-Total score alone ($F_{1,44} = 11.4$, $p < 0.01$, Fig. 2.).

4. Discussion

The most important findings of this study was that male patients who underwent ACLR with HTG (ST + G) or allograft had the MN-HS weakness at 90° flexion of the involved knee, a greater kinesiophobia, and worse Tegner activity and KOOS outcomes. The involved knee HHD-MN-HS strength$_{90°}$ was the only important predictor of the KOOS-Total score. The HHD-MN-HS strength$_{90°}$ also predicted the KOOS-Sport/Rec outcome. On the other hand, the TSK-17 outcome was a statistically significant variable in prediction of the KOOS-Sport/Rec, and -QoL scores in the ACLR group. The time since ACLR was also found to be a statistically important predictor of the KOOS-QoL score. It is known that a recovery in the KOOS comes with time after ACLR [11].

Present results confirm greater activity and function deficits and kinesiophobia and thigh muscle weak-

Table 2. Multiple regression analysis with KOOS values as the dependent variable for the male with ACLR

Dependent variables	Predictor variables	Beta coefficients (95%CI)	*p*	R^2 value of the model
KOOS-Sport/Rec	Model 1: The involved knee HHD-MN-HS strength at 90° Tampa Scale for Kinesiophobia-17	 0.341 (20.50–188.0) –0.302 (–1.9– –0.09)	 $p = 0.016$ $p = 0.032$	22.8%
KOOS-QoL	Model 2: Tampa Scale for Kinesiophobia-17 Time since ACLR	 –0.427 (–2.30– –0.56) 0.295 (0.030–0.59)	 $p = 0.002$ $p = 0.027$	28.5%
KOSS-Total	Model 3: The involved knee HHD-MN-HS strength at 90° Tegner activity score Tampa Scale for Kinesiophobia-17	 0.340 (12.10–90.0) 0.259 (–0.061–2.80) –0.235 (–0.86–0.07)	 $p = 0.012$ $p = 0.060$ $p = 0.093$	31.5%

KOOS – Knee Injury and Osteoarthritis Outcome Score, ACLR – Anterior Cruciate Ligament Reconstruction, CI – Confidence Interval, Sport/Rec – Sports and Recreational Activities, HHD – Handheld Dynamometry, MN – Mass Normalized, QoL – knee--related quality of life.

ness postoperatively in individuals that underwent ACLR with HTG, as reported by previous studies [9], [15]. The ACLR technique via ST/G grafting cannot control excessive rotation of the tibia during physical activity [8]. This rotation could result in the degeneration of the knee cartilage with the effects derived from the weakness of the QF muscle, and thus, worse KOOS and lower Tegner activity scores, as can be seen in the present findings [6], [17].

The regression analysis of the present study showed that the MN-HS strength during the hyper-flexion of the involved limb appear to be more important than the QF strength in relation to the KOOS. In contrast to our study, previous studies have exhibited important associations of both the HS and QF strengths with the KOOS, but the cohorts in these studies also involved the patellar tendon graft [4], [11]. A similar study conducted with ST/G grafts showed that the KOOS was more related with the isokinetic HS strength than the QF strength in assessing the limb symmetry index in male patients [9].

Kinesiophobia is defined as an irrational fear of physical activity and movement and it effectuates up to 25% of the reasons for not returning to sports [14]. Numerous investigations have shown that the TSK-17 has an important role in determining the functional status, physical performance, daily activities, and the surgical knee strength of the persons who underwent ACLR [10], [14]. Similarly, our results demonstrated that a higher fear of movement was an indicator for worse KOOS-Sport/Rec and -QoL subscale scores.

In a more recent comparison, the diagnostic accuracy of the HHD was found on par with the isokinetic dynamometer in identification of the QF torque asymmetry via mass-normalized measurement of the ACLR-performed on patients while sitting upright and at 90° flexion of knee [1]. However, the use of HHD in limb muscle testing after ACLR is seldom. Another study reported a significant knee flexor torque asymmetry in the ST/G graft group with HHD testing in the prone position and at 90° of knee flexion compared to the allograft group and healthy controls [15]. Our results are in concordance with those from this study.

Our study had some limitations: the time interval before and after surgery was too wide, the information on previous rehabilitation were not sufficient, lack of assessments of the stability, sensation, edema and atrophy of the operated side, no other valid ACLR function questionnaire in addition to the KOOS. In addition, there were no the radiological examination showing morphological changes in the cartilage of the knee joint after ACLR, influencing the knee function and muscle strength [4], [18]. Another limitation is that muscle strength measurements were only performed on the dominant side in the control group, on the affected side with or without the dominant in the ACLR Group. On the other hand, the fact that our study was the first one to assess the relationship between the self-reported knee function and the HHD-MN-HS strength$_{90°}$ after ACLR with the participation of healthy controls renders it an important one.

5. Conclusions

This retrospective study in male participants demonstrated reduced HHD-MN-HS and -QF muscle strengths at 90° flexion of the involved knee together with lower self-reported knee function and higher kinesiophobia in the six to 60-months period after ACLR with HTG graft or allograft. The reduced involved knee HHD-MN-HS strength$_{90°}$ together with the high fear of movement may partially explain some knee function deficits including KOOS-Total, -Sport/Rec, and -QoL scores which have implications for the planning of more effective ACLR rehabilitation programs. Future comprehensive studies addressing this issue will help shed farther light on its explanatory power in functional outcomes, and possible advantages and disadvantages of using the HHD-MN-HS strength$_{90°}$ measurement in sitting position following ACLR.

References

[1] ALMEIDA G.P.L., ALBANO T.R., MELO A.K.P., *Hand-held dynamometer identifies asymmetries in torque of the quadriceps muscle after anterior cruciate ligament reconstruction*, Knee Surg. Sports Traumatol. Arthrosc., 2019, 27 (8), 2494–2501.

[2] ANDREWS A.W., THOMAS M.W., BOHANNON R.W., *Normative values for isometric muscle force measurements obtained with hand-held dynamometers*, Phys. Ther., 1996, 76 (3), 248–259.

[3] ARDERN C.L., WEBSTER K.E., *Knee flexor strength recovery following hamstring tendon harvest for anterior cruciate ligament reconstruction: A systematic review*, Orthop. Rev. (Pavia), 2009, 1 (2), e12.

[4] BODKIN S., GOETSCHIUS J., HERTEL J., HART J., *Relationships of muscle function and subjective knee function in patients after ACL reconstruction*, Orthop. J. Sports Med., 2017, 5 (7), DOI: 2325967117719041.

[5] COHEN J., *Statistical Power Analysis for the Behavioral Sciences*, 2nd ed. Mahwah, NJ, USA: Lawrence Erlbaum Associates Inc., 1988.

[6] DAUTY M., TORTELLIER L., ROCHCONGAR P., *Isokinetic and anterior cruciate ligament reconstruction with hamstrings or patella tendon graft: analysis of literature*, Int. J. Sports Med., 2005, 26 (7), 599–606.

[7] ENGLUND M., ROOS E.M., LOHMANDER L.S., *Impact of type of meniscal tear on radiographic and symptomatic knee osteoarthritis: a sixteen-year follow up of meniscectomy with matched controls*, Arthritis Rheum., 2003, 48 (8), 2178–2187.

[8] GEORGOULIS A.D., RISTANIS S., CHOULIARAS V., MORAITI C., STERQIOU N., *Tibial rotation is not restored after ACL reconstruction with a hamstring graft*, Clin. Orthop. Relat. Res., 2007, 454, 89–94.

[9] HARPUT G., OZER H., BALTACI G., RICHARDS J., *Self-reported outcomes are associated with knee strength and functional symmetry in individuals who have undergone anterior cruciate ligament reconstruction with hamstring tendon autograft*, Knee, 2018, 25 (5), 757–764.

[10] HARTIGAN E.H., LYNCH A.D., LOGERSTEDT D.S., CHMIELEWSKI T.L., SNYDER-MACKLER L., *Kinesiophobia after anterior cruciate ligament rupture and reconstruction: noncopers versus potential copers*, J. Orthop. Sports Phys. Ther., 2013, 43 (11), 821–832.

[11] ITHURBURN M.P., PATERNO M.V., THOMAS S., PENNELL M.L., EVANS K.D., MAGNUSSEN R.A., et al., *Clinical measures associated with knee function over two years in young athletes after ACL reconstruction*, Knee, 2019, 26 (2), 355–363.

[12] JARIC S., *Muscle strength testing: use of normalisation for body size*, Sports Med., 2002, 32 (10), 615–631.

[13] KORI K.S., MILLER R.P., TODD D.D., *Kinesiophobia: a new view of chronic pain behavior*, Pain Manag., 1990, 3, 35–43.

[14] KVIST J., EK A., SPORRSTEDT K., GOOD L., *Fear of re-injury: a hindrance for returning to sports after anterior cruciate ligament reconstruction*, Knee Surg. Sports Traumatol. Arthrosc., 2005, 13 (5), 393–397.

[15] LANDES S., NYLAND J., ELMLINGER B., TILLETT E., CABORN D., *Knee flexor strength after ACL reconstruction: comparison between hamstring autograft, tibialis anterior allograft, and non-injured controls*, Knee Surg. Sports Traumatol. Arthrosc., 2010, 18 (3), 317–324.

[16] LAUTAMIES R., HARILAINEN A., KETTUNEN J., SANDELIN J., KUJALA U.M., *Isokinetic quadriceps and hamstring muscle strength and knee function 5 years after anterior cruciate ligament reconstruction: comparison between bone-patellar tendon-bone and hamstring tendon autografts*, Knee Surg. Sports Traumatol. Arthrosc., 2008, 16 (11), 1009–1016.

[17] LEE D.W., YEOM C.H., KIM D.H., KIM T.M., KIM J.G., *Prevalence and predictors of patellofemoral osteoarthritis after anterior cruciate ligament reconstruction with hamstring tendon autograft*, Clin. Orthop. Surg., 2018, 10 (2), 181–190.

[18] LENTZ T.A., TILLMAN S.M., INDELICATO P.A., MOSER M.W., GEORGE S.Z., CHMIELEWSKI T.L., *Factors associated with function after anterior cruciate ligament reconstruction*, Sports Health, 2009, 1 (1), 47–53.

[19] MAFFIULETTI N.A., *Assessment of hip and knee muscle function in orthopedic practice and research*, J. Bone Joint Surg. Am., 2010, 92 (1), 220–229.

[20] MORE R.C., KARRAS B.T., NEIMAN R., FRITSCHY D., WOO S.L., DANIEL D.M., *Hamstrings-an anterior cruciate ligament protagonist. An in vitro study*, Am. J. Sports Med., 1993, 21 (2), 231–237.

[21] PAKER N., BUĞDAYCI D., SABIRLI F., ÖZEL S., ERSOY S., *Knee Injury and Osteoarthritis Outcome Score: Reliability and Validation of the Turkish Version*, Turkiye Klinikleri J. Med. Sci., 2007, 27 (3), 350–356.

[22] ROOS E.M., ROOS H.P., LOHMANDER L.S., EKDAHL C., BEYNNON B.D., *Knee Injury and Osteoarthritis Outcome Score (KOOS)-development of a self-administered outcome measure*, J. Orthop. Sports Phys. Ther., 1998, 28 (2), 88–96.

[23] SALAVATI M., AKHBARI B., MOHAMMADI F., MAZAHERI M., KHORRAMI M., *Knee Injury and Osteoarthritis Outcome Score (KOOS); reliability and validity in competitive athletes after anterior cruciate ligament reconstruction*, Osteoarthr. Cartilage, 2011, 19 (4), 406–410.

[24] TEGNER Y., LYSHOLM J., *Rating systems in the evaluation of knee ligament injuries*, Clin. Orthop. Relat. Res., 1985, 198, 43–49.

[25] YILMAZ O.T., YAKUT Y., UYGUR F., ULUG N., *Turkish Version of the Tampa Scale for Kinesiophobia and its test-retest reliability*, [Article in Turkish] Turk. J. Physiother. Rehabil., 2011, 22 (1), 44–49.