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Are the knee extensor and flexor muscles isokinetic parameters affected by the duration of postoperative physiotherapy supervision in patients eight months after ACL reconstruction with the use of semitendinosus and gracilis tendons autograft?

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Purpose: The observational study evaluated isokinetic parameters in patients at eight months after anterior cruciate ligament reconstruction (ACLR) utilizing semitendinosus and gracilis tendons autograft, with two different modes of physiotherapy, and investigated whether analysed parameters were affected by the postoperative physiotherapy supervision duration. *Methods*: Strict exclusion criteria were employed on a group of 259 ACL-reconstructed patients to identify two groups of males preoperatively well trained and frequently participating in sports, with different durations of postoperative physiotherapy supervision: Group I (n = 18; x = 27.67 weeks) and Group II (n = 20; x = 10.75 weeks). The patients underwent knee extensor and flexor muscles torques measurements with the 180°/s and 60°/s. The torque, position and time parameters were analysed. Limb Symmetry Index (LSI) was calculated. The parametric tests for dependent samples, parametric tests for independent samples, and linear Pearson's correlation coefficient calculations were performed. *Results*: There were significant between-limb differences in the Group II in the knee extensor and flexor muscles torque parameters, with LSI ranging from x = 75.72 to x = 78.75 and from x = 78.69 to x = 87.82, respectively. The knee extensor muscles torque parameters and LSI values were positively correlated with the physiotherapy supervision duration. The inter-limb differences in the Group I and II in knee flexor muscles PT angle amounted to x = 10.94° (180°/s), x = 9.39° (60°/s), and x = 12.00° (180°/s), x = 9.75° (60°/s), respectively. *Conclusions*: The longer postoperative physiotherapy supervision was more effective for improving knee muscles torque parameters. The knee flexor muscles PT angle was shifted towards extension in the ACL-reconstructed limb, regardless of the time of postoperative physiotherapy supervision duration.

Key words: *clinical decision making, home-based rehabilitation, knee joint, ligament rupture treatment, unsupervised physiotherapy*

1. Introduction

Isokinetic dynamometry-based knee muscles strength and strength balance evaluations have been used as an objective marker after anterior cruciate ligament reconstruction ACLR. From the 1990s, there was a general assumption that a, so called, unsupervised, partially supervised, out-of-clinic, gym-based or home-based rehabilitation procedure after the reconstruction produces results equal to those obtained with a clinic-based procedure in terms of muscle strength [1], [10], [13], [19]. The assumption has been changing [8], but since most studies of muscle strength, related to ACLR, use the peak torque as main analysed parameter, to date, the effect of not fully supervised physiotherapeutic procedures on the particular isokinetic parameters has not been demonstrated.

The study aimed to assess the isokinetic parameters in patients eight months after the ACLR using semitendinosus and gracilis tendons autograft, with two different modes of postoperative physiotherapy, and to investigate whether analysed parameters were affected by the duration of postoperative physiotherapy supervision.

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2. Materials and methods

2.1. Experimental approach to the problem

The conducted experiment was an observational cohort study. To assess the impact of the postoperative physiotherapy supervision duration after ACLR with the use of ipsilateral semitendinosus and gracilis muscles tendons autograft on the particular knee muscles isokinetic parameters, the peak torque measurements of knee extensor and flexors muscles were carried out at 180°/s and 60°/s. Patients after ACLR utilizing ipsilateral semitendinosus and gracilis muscles tendons autograft with different postoperative physiotherapy supervision duration were recruited to the study. The test was performed once, on average at eight months postoperatively.

2.2. Participants

The experiment gained approval of the local ethics committee, and was conducted according to the ethics guidelines and principles of the Declaration of Helsinki. All the patients participating in the study were informed about the purpose and approach to be used, and signed their informed consent form to participate in the study. The cohort study was carried out in an academic centre in years 2012–2017.

The initial sample consisted of 259 patients who started the postoperative physiotherapeutic procedure after ACLR in the physiotherapy centre, where the study was conducted.

As the younger age, lower BMI, and minimal articular cartilage degeneration are significantly associated with excellent functional and isokinetic test result at 6 months following the ACLR [14], the patients in the present study were matched in those terms. The studied patients were also matched in terms of gender, as the knee muscles torques are significantly different in males than in females [24]. The leg dominancy was not taken into account, as there are no differences between dominant and nondominant limbs in terms of knee muscles torques measured under isokinetic conditions [24].

The patients were excluded if they had at least one of the following diagnosed medical problems: heart disease, high blood pressure, asthma or pulmonary disease, diabetes (n = 1), ulcer or stomach disease, kidney disease, liver disease, anaemia or other blood disease, osteoarthritis, degenerative osteoarthritis, rheumatoid arthritis, back pain, Lyme disease, or alcoholism. Consecutively, excluded were: (1) females (n = 113), (2) participants who underwent ACLR with the use of a method other than autologous ipsilateral hamstring tendon graft (n = 32), (3) patients who underwent double-bundle ACLR (n = 3); (4) participants with any abnormalities in the contrateral knee (n = 10); (5) participants who underwent at least one of the following procedures: medial and/or lateral meniscectomy, medial and/or lateral meniscal transplant, posterior cruciate ligament repair, or medial or/and lateral collateral ligament repair/reconstruction (n = 26); (6) extensor mechanism surgery (n = 7); (7) patellofemoral surgery (n = 10); (8) osteoarthritis surgery other than shaving (n = 7); (9) participants exhibiting one of the following: preoperative activity level, participant in highly competitive sports, occasional sporting participant preoperatively, and non-sporting participant preoperatively; (10) participants under the age 18 or over the age 35 (n = 10); (11) participants with a body mass index (BMI) value less than 18.50 or greater than 29.99 (n = 2). Then, based on the Ebert et al. [8], the patients were divided into those who completed supervised physiotherapy (>6 months) including structured agility and landing exercises with supervised return to sport (Group I; n = 18), and patients who completed supervised physiotherapy (3 months), followed by independent return to structured gym exercises and return to activity (Group II; n = 20) [8].

The patients from Group I and Group II were 27.67 ± 5.84 and 31.35 ± 8.44 weeks after the reconstruction (p = 0.13), respectively. The two groups differed significantly (p < 0.01) regarding the amount of time each was subject to postoperative supervised physiotherapy. The duration of postoperative physiotherapy amounted to 27.67 ± 5.84 weeks in Group I and to 10.75 ± 6.62 weeks in Group II. The patients were matched in terms of gender (males), age (p = 0.23), body mass (p = 0.77), body height (p = 0.06), body mass index (p = 0.08), and activity level as all of them were well trained and frequently participated in sports preoperatively. The characteristics of the studied patients are presented in Table 1.

There have been nine right limbs operated in the Group I, and nine right limbs in the Group II (Table 1). In the nine cases in the Group I, the operated limb was the dominant one. Also, in the Group II there have been operated nine dominant limbs. In all studied participants, the ACL injuries were sustained with no contact at the time of injury (Table 1). In none of the patients studied, the time between injury and reconstruction was more than three months. In addition,

Table 1. Characteristic of studied material

Test compound	Group I (n = 18)	Group II (n = 20)	p
Age [years]	25.11 ± 5.58	27.25 ± 5.23	0.23
Body mass [kg]	80.44 ± 11.76	81.45 ± 9.63	0.77
Body height [cm]	183.83 ± 7.82	179.65 ± 5.48	0.06
Body mass index [kg*m^{-2}]	23.73 ± 2.47	25.22 ± 2.67	0.08
Time since ACLR [weeks]	27.67 ± 5.84	31.35 ± 8.44	0.13
Physiotherapy [weeks]	27.67 ± 5.84	10.75 ± 6.62	**<0.01**
Involved leg: right/left [n]	9/9	9/11	n/a
ACL injury mechanism n/c [n]	18/0	20/0	n/a

Values expressed as the mean and standard deviation (±). ACLR – anterior cruciate ligament reconstruction; c – contact; Group I – fully supervised physiotherapy participants; Group II – participants with a shorter duration of physiotherapy supervision; n – number of individuals in the studied group; n – non-contact; n/a – not applicable; p – level of significance; physiotherapy – postoperative supervised physiotherapy duration. $p \leq 0.05$ is indicated in bold.

none of the patients participated in pre-operative physiotherapy.

2.3. Surgical technique

All of the studied patients underwent post-traumatic primary unilateral single-bundle ACLR with the use of autologous ipsilateral semitendinosus and gracilis tendon graft. All patients had similar one-incision, arthroscopically assisted reconstructions. The transtibial technique was used in all cases. Tourniquet use was the same in all patients. Femoral nerve blocks were not utilized.

2.4. Postoperative physiotherapy

In Group I, postoperative physiotherapy followed the procedure described by Czamara [4] divided into four stages. The first stage (1st–5th week postoperatively), starting on the day of surgery, aimed to reduce pain and effusion, and to restore ACL-reconstructed knee range of motion and gait. Additionally, the patients were taught how to exercise correctly at home and which activities should be avoided. The second stage (6th–12th week postoperatively) aimed to improve the gait pattern and to stimulate proprioception. The third stage (13th–20th week postoperatively) was focused on the reduction of limbs strength asymmetries and teaching proper landing technique, and running for general endurance training. The fourth stage (21st week up to eight months postoperatively) was mainly based on complex movement patterns exercises, strength, power and specific endurance training [6]. Each session with a physiotherapist lasted two hours. According to the recommendations, frequency of physiotherapy attendance was 4–5 times a week for the first stage, four times a week for the second stage, four times a week for the third stage, and three times a week for the fourth stage [6]. In Group I, the average total number of meetings with a physiotherapist was 106, with an average frequency of 3.79 visits per week, for the average of 28 weeks. The patients from Group II underwent only the two first stages of the supervised postoperative procedure on average as they refused to continue the supervised physiotherapy, based on reasons independent of their orthopaedic surgeons and physiotherapists. The patients were informed about the main goals and characteristic of the third and fourth stages of the physiotherapeutic procedures and continued home-based and gym-based physiotherapy without physiotherapist supervision. In the Group II, the average total number of meetings with a physiotherapist was 49, with the average frequency of 4.45 visits per week, for an average of 11 weeks postoperatively.

The patients from Group II were contacted by phone six months after the reconstruction and were asked to participate in the examination, while the patients from the Group I underwent the measurements in the end of their fully supervised physiotherapeutic procedure.

2.5. Procedures

All patients underwent the measurements of knee extensor and flexor muscles torques under isokinetic conditions. The patients were asked to abstain from

unaccustomed strenuous exercise for at least 24 hours before the testing. They were asked to avoid eating a heavy breakfast in the morning before the test, and to avoid eating within two hours of the test. The patients were dressed in a comfortable sport outfit, and sports shoes. The torque measurements under isokinetic conditions were performed bilaterally, starting with the uninvolved limb. Verbal "start" and "stop" commands were used. All measurements were performed by the same examiner. The measurements were preceded by a 12-minute long warm-up on a cycloergometer. All participants were tested by the same researcher.

The measurements were carried out using the Humac Norm™ Testing & Rehabilitation System (CSMI Computer Sports Medicine, Inc., Stoughton, MA, USA). The measurements were performed in the sitting position, with 90 degrees of hip flexion. The length of the lever arm was 42 cm for all the patients. The patient's trunk and examined limb were stabilized with the belts. The second limb was stabilized using a support. The patient's arm were crossed on his chest, and his head was leaned on the chair. The foot of the examined limb was in a dorsiflexion.

Two series of alternate concentric repetitions for extension and flexion of the knee joint were performed; first at constant angular velocity of 180°/s (10 repetitions), and secondly at the velocity of 60°/s (5 repetitions). There was a 120-s long interval between the two series of repetitions. Each set of repetitions was proceeded by one trial repetition. Between the trial repetition and the set of repetition there was a 10-second break [5].

The following parameters were analyzed: peak torque in the best repetition, PT [Nm]; total work achieved in the repetition with the highest PT [J], max rep. TW; average power per repetition, AP [W]; angle of PT [°]; range of motion, ROM [°]; time to PT [s]; time PT held [s]; force decay time, [s]; reciprocal delay [s]; delay time [s]. The torque parameters were normalized to body mass, and expressed as relative PT, RPT [$N*m*kg^{-1}$]; relative TW, RTW [$J*kg^{-1}$]; and relative AP, RAP [$W*kg^{-1}$].

2.6. Statistical analysis

Microsoft Office Excel 2007 (Microsoft, Redmond, WA, USA) and IBM SPSS Statistics 20 (IBM, Armonk, NY, USA) were used for statistical analysis. The arithmetic mean (x) and the standard deviation (SD, ±) for the three examined groups were calculated for particular studied features. The number of individuals was indicated as n. To verify the clinical relevance of the results, torque parameters were additionally expressed as "limb symmetry index" (LSI). The LSI for each patient was calculated by dividing the result obtained in the involved limb by the result obtained in the uninvolved limb, with the result multiplied by 100. The LSI was used to define limb symmetry deficits, with values closer to 100 indicating smaller deficits. In the intra-group and inter-group comparisons, the Shapiro–Wilk test was first performed. The parametric test for dependent samples or parametric test for independent was consecutively carried out. In addition, the linear Pearson's correlation coefficient r-values were calculated for the strength and direction of a linear relationship between the selected isokinetic parameters and the time since ACLR, and the postoperative physiotherapy supervision duration. The r-value indicated whether the dependence was directly proportional (positive r-value) or inversely proportional (negative r-value). The p-values ≤ 0.05 were considered significant. The p-values less than 0.01 were indicated as $p < 0.01$.

3. Results

3.1. Torque parameters

Knee extensor muscles

The intra-group comparison revealed results statistically significantly worse in the involved limb, compared to the uninvolved one in Group I, in terms of the RPT (180°/s), and RTW, and RAP (180°/s and 60°/s). In Group II, the between-limb comparison revealed statistically significant differences in favour to the uninvolved limb, in terms of all studied torque parameters (Table 2). However, the clinical relevance of the statistically significant differences in Group I remain questionable, as the mean lowest value of LSI of RPT, RTW and RAP didn't exceed 92, while in Group II the mean LSI ranged from 76 to 79. What's more, the values of all analysed parameters obtained in the knee extensor muscles were statistically significantly better for Group I than for Group II (Table 2). The inter-group comparison revealed statistically significantly better results obtained in Group I in terms of studied parameters (Table 2). A positive correlation between the RPT, RTW, and RAP values (180°/s and 60°/s), and the postoperative supervised physiotherapy duration was noted (Tables 3 and 4). The values were not correlated with time since ACLR.

Table 2. Intra-group and inter-group comparison of torque parameters of the knee extensor and flexor muscles

Torque Parameters							
		Knee Extensor Muscles			Knee Flexor Muscles		
	Studied limb	Group I	Group II	*p*	Group I	Group II	*p*
RPT 180°/s [N*m*kg^{-1}]	Involved	2.08 ± 0.30	1.41 ± 0.36	**<0.01**	1.21 ± 0.31	0.92 ± 0.28	**0.01**
	Uninvolved	2.17 ± 0.32	1.81 ± 0.30	**<0.01**	1.26 ± 0.26	1.05 ± 0.25	**0.02**
	p	**<0.01**	**<0.01**		0.13	**<0.01**	
	LSI	95.77 ± 4.61	78.51 ± 16.84	**<0.01**	95.48 ± 10.47	87.82 ± 16.38	0.10
RPT 60°/s [N*m*kg^{-1}]	Involved	2.82 ± 0.41	1.91 ± 0.54	**<0.01**	1.63 ± 0.32	1.35 ± 0.39	**0.02**
	Uninvolved	2.94 ± 0.35	2.53 ± 0.43	**<0.01**	1.68 ± 0.28	1.54 ± 0.30	0.14
	p	0.06	**<0.01**		0.48	**0.01**	
	LSI	96.13 ± 8.38	75.72 ± 18.57	**<0.01**	98.09 ± 14.26	87.49 ± 17.53	**0.05**
RTW 180°/s [J*kg^{-1}]	Involved	23.84 ± 4.60	16.22 ± 4.82	**<0.01**	13.97 ± 4.45	10.28 ± 3.75	**0.01**
	Uninvolved	25.86 ± 3.54	21.43 ± 4.75	**<0.01**	14.91 ± 3.19	12.61 ± 4.27	0.07
	p	**<0.01**	**<0.01**		0.13	**<0.01**	
	LSI	91.82 ± 9.52	76.24 ± 15.78	**<0.01**	92.83 ± 16.22	83.22 ± 21.42	0.13
RTW 60°/s [J*kg^{-1}]	Involved	16.92 ± 3.15	11.63 ± 3.05	**<0.01**	9.54 ± 2.53	7.44 ± 2.88	**0.02**
	Uninvolved	18.03 ± 2.43	15.22 ± 2.67	**<0.01**	10.58 ± 1.92	9.54 ± 3.03	0.25
	p	**0.03**	**<0.01**		0.12	**<0.01**	
	LSI	93.66 ± 11.16	76.71 ± 16.25	**<0.01**	92.08 ± 23.75	78.69 ± 17.42	**0.05**
RAP 180°/s [W*kg^{-1}]	Involved	3.73 ± 0.62	2.45 ± 0.70	**<0.01**	2.27 ± 0.63	1.64 ± 0.49	**<0.01**
	Uninvolved	3.98 ± 0.62	3.15 ± 0.68	**<0.01**	2.41 ± 0.54	1.95 ± 0.58	**0.02**
	p	**0.02**	**<0.01**		0.08	**<0.01**	
	LSI	93.86 ± 7.82	78.75 ± 18.09	**<0.01**	94.04 ± 12.38	85.87 ± 16.33	0.10
RAP 60°/s [W*kg^{-1}]	Involved	1.93 ± 0.30	1.33 ± 0.33	**<0.01**	1.15 ± 0.24	0.94 ± 0.25	**0.01**
	Uninvolved	2.05 ± 0.31	1.71 ± 0.29	**<0.01**	1.23 ± 0.21	1.17 ± 0.24	0.40
	p	**0.01**	**<0.01**		0.16	**<0.01**	
	LSI	94.56 ± 8.29	76.53 ± 22.73	**<0.01**	94.30 ± 18.93	81.55 ± 16.11	**0.03**

Values expressed as the mean and standard deviation (±). Group I – fully supervised physiotherapy participants; Group II – participants with a shorter duration of physiotherapy supervision; LSI – limb symmetry index; *p* – level of significance; RAP – relative average power; RPT – relative peak torque; RTW – relative total work. $p \leq 0.05$ is indicated in bold.

Table 3. Correlations between the torque parameters values and the time since ACL reconstruction, and the time of postoperative physiotherapy duration

Torque Parameters					
		Knee Extensor Muscles		Knee Flexor Muscles	
		Time since ACLR	Physiotherapy	Time since ACLR	Physiotherapy
RPT 180°/s	Involved	*r* = –0.17; *p* = 0.32	*r* = 0.60; ***p* < 0.01**	*r* = –0.02; *p* = 0.89	*r* = 0.32 ***p* = *0.05***
	Uninvolved	*r* = –0.26; *p* = 0.12	*r* = 0.43; ***p* = 0.01**	*r* = –0.01; *p* = 0.97	*r* = 0.27; *p* = 0.10
RPT 60°/s	Involved	*r* = 0.15; *p* = 0.36	*r* = 0.52; ***p* < 0.01**	*r* = –0.02; *p* = 0.92	*r* = 0.24; *p* = 0.14
	Uninvolved	*r* = –0.15; *p* = 0.37	*r* = 0.34; ***p* = 0.04**	*r* = –0.08; *p* = 0.64	*r* = 0.12; *p* = 0.49
RTW 180°/s	Involved	*r* = –0.10; *p* = 0.54	*r* = 0.52; ***p* < 0.01**	*r* = 0.06; *p* = 0.72	*r* = 0.31; *p* = 0.06
	Uninvolved	*r* = –0.07; *p* = 0.70	*r* = 0.43; ***p* = 0.01**	*r* = 0.16; *p* = 0.34	*r* = 0.21; *p* = 0.21
RTW 60°/s	Involved	*r* = –0.11; *p* = 0.50	*r* = 0.48; ***p* < 0.01**	*r* = –0.03; *p* = 0.86	*r* = 0.23; *p* = 0.16
	Uninvolved	*r* = –0.08; *p* = 0.65	*r* = 0.35; ***p* = 0.03**	*r* = 0.10; *p* = 0.56	*r* = 0.11; *p* = 0.50
RAP 180°/s	Involved	*r* = –0.10; *p* = 0.56	*r* = 0.56; ***p* < 0.01**	*r* = –0.01; *p* = 0.98	*r* = 0.39; ***p* = 0.01**
	Uninvolved	*r* = –0.14; *p* = 0.41	*r* = 0.44; ***p* = 0.01**	*r* = 0.03; *p* = 0.86	*r* = 0.31; *p* = 0.06
RAP 60°/s	Involved	*r* = –0.18; *p* = 0.29	*r* = 0.53; ***p* < 0.01**	*r* = –0.08; *p* = 0.62	*r* = 0.21; *p* = 0.21
	Uninvolved	*r* = –0.17; *p* = 0.32	*r* = 0.40; ***p* = 0.01**	*r* = 0.09; *p* = 0.60	*r* = 0.02; *p* = 0.90

Values expressed as the correlation coefficient (*r*) and level of significance (*p*) values. ACLR – anterior cruciate ligament reconstruction; Group I – fully supervised physiotherapy participants; Group II – participants with a shorter duration of physiotherapy supervision; physiotherapy, postoperative supervised physiotherapy duration; RAP – relative average power; RPT – relative peak torque; RTW – relative total work. $p \leq 0.05$ is indicated in bold.

Table 4. Correlations between the limb symmetry index of torque parameters values and the time since ACL reconstruction, and the time of postoperative physiotherapy duration

Torque parameters; Limb Symmetry Index				
	Knee extensor muscles		Knee flexor muscles	
	Time since ACLR	Physiotherapy	Time since ACLR	Physiotherapy
RPT 180°/s	$r = 0.06$; $p = 0.73$	$r = 0.52$; **$p < 0.01$**	$r = –0.01$; $p = 0.97$	$r = 0.19$; $p = 0.24$
RPT 60°/s	$r = –0.08$; $p = 0.63$	$r = 0.45$; **$p < 0.01$**	$r = 0.06$; $p = 0.74$	$r = 0.24$; $p = 0.14$
RTW 180°/s	$r = –0.06$; $p = 0.72$	$r = 0.39$; ***p = 0.02***	$r = –0.03$; $p = 0.80$	$r = 0.22$; $p = 0.18$
RTW 60°/s	$r = –0.07$; $p = 0.67$	$r = 0.40$; **$p < 0.01$**	$r = –0.17$; $p = 0.32$	$r = 0.21$; $p = 0.21$
RAP 180°/s	$r = –0.04$; $p = 0.81$	$r = 0.39$; ***p = 0.02***	$r = 0.02$; $p = 0.93$	$r = 0.21$; $p = 0.21$
RAP 60°/s	$r = –0.04$; $p = 0.80$	$r = 0.70$ ***p = 0.02***	$r = –0.17$; $p = 0.31$	$r = 0.20$; $p = 0.23$

Values expressed as the correlation coefficient (r) and level of significance (p) values. ACLR – anterior cruciate ligament reconstruction; Group I – fully supervised physiotherapy participants; Group II – participants with a shorter duration of physiotherapy supervision; physiotherapy, postoperative supervised physiotherapy duration; RAP – relative average power; RPT – relative peak torque; RTW – relative total work. $p \leq 0.05$ is indicated in bold.

Knee flexor muscles

In Group I no statistically significant differences between the involved and uninvolved limb were noted in terms of the knee flexor muscles RPT, RTW, and RAP (180°/s and 60°/s). The mean LSI values in this group ranged from 92 to 98 (Table 2). In Group II the comparison of the values of RPT, RTW, and RAP obtained in the involved limb were significantly worse than in the uninvolved one (180°/s and 60°/s). The LSI values ranged from 79 to 88 (Table 2). The LSI values in Group I were significantly better, compared to Group II in terms of all knee extensor muscles torque parameters (Table 2).

The inter-group comparison revealed significantly better results in the involved limb in Group I, in comparison with the involved limb in Group II (Table 2). The results obtained in the uninvolved limb in Group I were statistically significantly better, compared to Group II in terms of the RPT (180°/s) and RAP (180°/s). The LSI values were significantly better in Group I, compared to Group II in terms of RPT (60°/s), RTW (60°/s), and RAP (60°/s).

A positive correlation between the knee joint flexor muscles RPT and RAP at 180°/s, and the time of postoperative physiotherapy duration was found (Table 3). No other correlations between studied torque parameters and the time of postoperative physiotherapy duration, and between the studied parameters and the time since ACLR were found (Table 3).

A positive correlation between the LSI of knee extensor muscles torque parameters and the postoperative physiotherapy supervision duration was also found (Table 4). The analysis of the correlation between the time since ACLR and the time of postoperative physiotherapy supervision duration and the LSI values didn't reveal any relationship between those features in terms of knee flexor muscles torque parameters (Table 4).

3.2. Position parameters

Knee extensor muscles

No statistically significant differences between involved and uninvolved limbs in Group I as well as in Group II in terms of knee extensor muscles position parameters were found (Table 5).

The inter-group comparison of knee extensor muscles position parameters revealed no statistically significant differences in terms of studied knee extensor muscles position parameters (Table 5).

No correlations between the studied knee extensor muscles position parameters and the time since ACLR, and the postoperative physiotherapy supervision duration were found (Table 6).

Knee flexor muscles

The intra-group comparison revealed statistically significant lower value of the knee flexor muscles PT angle at 180°/s and 60°/s in Group I. There were also noted statistically significantly lower values of the

Table 5. Intra-group and inter-group comparison of position parameters of the knee extensor and flexor muscles

Position Parameters							
		Knee Extensor Muscles			Knee Flexor Muscles		
	Studied limb	Group I	Group II	*p*	Group I	Group II	*p*
PT angle 180°/s [°]	Involved	60.32 ± 6.36	61.90 ± 9.18	0.55	44.16 ± 8.01	45.10 ± 9.88	0.75
	Uninvolved	59.86 ± 7.39	60.35 ± 8.88	0.86	52.44 ± 8.67	55.60 ± 13.84	0.40
	p	0.80	0.34		**<0.01**	**<0.01**	
	Difference [°]	6.44 ± 3.84	5.15 ± 4.91	0.38	10.94 ± 7.17	12.00 ± 12.48	0.76
PT angle 60°/s [°]	Involved	64.18 ± 9.37	65.75 ± 9.78	0.62	34.07 ± 7.29	37.80 ± 14.07	0.32
	Uninvolved	67.43 ± 7.96	67.60 ± 7.50	0.95	39.81 ± 8.43	46.75 ± 18.13	0.15
	p	0.06	0.38		**0.02**	**<0.01**	
	Difference [°]	5.72 ± 4.55	5.45 ± 7.65	0.90	9.39 ± 5.54	9.75 ± 7.94	0.87
ROM 180°/s [°]	Involved	2.18 ± 1.34	2.20 ± 1.74	0.98	112.05 ± 7.20	111.45 ± 10.55	0.84
	Uninvolved	2.12 ± 1.49	1.90 ± 1.12	0.61	114.46 ± 6.05	116.60 ± 7.17	0.33
	p	0.77	0.40		0.20	**0.01**	
	Difference [°]	0.72 ± 0.57	1.00 ± 1.21	0.38	6.28 ± 4.96	7.55 ± 6.28	0.50
ROM 60°/s [°]	Involved	3.90 ± 4.84	3.50 ± 3.95	0.78	110.99 ± 7.01	106.20 ± 19.55	0.33
	Uninvolved	3.89 ± 5.96	3.45 ± 5.88	0.82	114.63 ± 6.33	113.10 ± 17.00	0.72
	p	0.99	0.97		0.06	**<0.01**	
	Difference [°]	1.56 ± 2.57	2.95 ± 4.71	0.27	6.11 ± 5.57	7.50 ± 6.49	0.49

Values expressed as the mean and standard deviation (±). Difference – absolute difference between the values obtained in both studied limbs; Group I – fully supervised physiotherapy participants; Group II – participants with a shorter duration of physiotherapy supervision; *p* – level of significance; PT – peak torque; ROM – range of motion. $p \leq 0.05$ is indicated in bold.

Table 6. Correlations between the position parameters values and the time since ACL reconstruction, and the time of postoperative physiotherapy duration

Position Parameters					
		Knee Extensor Muscles		Knee Flexor Muscles	
	Studied limb	Time since ACLR	Physiotherapy	Time since ACLR	Physiotherapy
PT angle 180°/s	Involved	*r* = 0.13; *p* = 0.44	*r* = –0.14; *p* = 0.41	*r* = 0.11; *p* = 0.53	*r* = –0.01; *p* = 0.97
	Uninvolved	*r* = 0.27; *p* = 0.10	*r* = 0.07; *p* = 0.88	*r* = 0.11; *p* = 0.52	*r* = –0.15; *p* = 0.37
	Difference	*r* = –0.33; *p* = 0.06	*r* = –0.06; *p* = 0.71	*r* = 0.01; *p* = 0.95	*r* = –0.07; *p* = 0.69
PT angle 60°/s	Involved	*r* = 0.26; *p* = 0.11	*r* = –0.04; *p* = 0.80	*r* = –0.04; *p* = 0.82	*r* = –0.18; *p* = 0.28
	Uninvolved	*r* = 0.16; *p* = 0.34	*r* = –0.15; *p* = 0.38	*r* = 0.13; *p* = 0.43	*r* = –0.16; *p* = 0.34
	Difference	*r* = –0.20; *p* = 0.24	*r* = –0.03; *p* = 0.86	*r* = 0.12; *p* = 0.48	*r* = 0.02; *p* = 0.92
ROM 180°/s	Involved	*r* = –0.02; *p* = 0.91	*r* = 0.05; *p* = 0.75	*r* = 0.26; *p* = 0.11	*r* = 0.043; *p* = 0.80
	Uninvolved	*r* = –0.04; *p* = 0.81	*r* = 0.18; *p* = 0.28	*r* = 0.36; *p* = 0.30	*r* = –0.11; *p* = 0.50
	Difference	*r* = 0.03; *p* = 0.84	*r* = –0.26; *p* = 0.11	*r* = –0.17; *p* = 0.32	*r* = –0.25; *p* = 0.14
ROM 60°/s	Involved	*r* = 0.07; *p* = 0.69	*r* = 0.12; *p* = 0.46	*r* = 0.146; *p* = 0.38	*r* = 0.23; *p* = 0.17
	Uninvolved	*r* = 0.06; *p* = 0.71	*r* = 0.22; *p* = 0.18	*r* = 0.10; *p* = 0.55	*r* = 0.17; *p* = 0.32
	Difference	*r* = 0.14; *p* = 0.42	*r* <–0.01; *p* = 0.98	*r* = –0.20; *p* = 0.23	*r* = –0.16; *r* = 0.35

Values expressed as the correlation coefficient (*r*) and level of significance (*p*) values. ACLR – anterior cruciate ligament reconstruction; Difference – absolute difference between the values obtained in both studied limbs; Group I – fully supervised physiotherapy participants; Group II – participants with a shorter duration of physiotherapy supervision; physiotherapy, post-operative supervised physiotherapy duration; PT – peak torque; ROM – range of motion. $p \leq 0.05$ is indicated in bold.

angle PT and ROM in the involved limb, compared to the uninvolved one at both 180°/s and 60°/s (Table 5). The between-group comparison revealed no differences in terms of angle PT and ROM at 180°/s and 60°/s (Table 5). In both groups studied no correlations between the time since ACLR and the postoperative physiotherapy supervision duration, and the studied knee flexor muscles position parameters were found (Table 6).

3.3. Time parameters

Knee extensor muscles

In Group II statistically significantly lower values of the time to PT at 180°/s and 60°/s in the involved limb, compared to the uninvolved one, were found (Table 7).

Table 7. Intra-group and inter-group comparison of time parameters of the knee extensor and flexor muscles

Time Parameters							
		Knee Extensor Muscles			Knee Flexor Muscles		
	Studied limb	Group I	Group II	*p*	Group I	Group II	*p*
Time to PT 180°/s [s]	Involved	0.34 ± 0.04	0.34 ± 0.04	0.65	0.28 ± 0.04	0.34 ± 0.34	0.30
	Uninvolved	0.35 ± 0.03	0.37 ± 0.05	0.31	0.33 ± 0.06	0.37 ± 0.12	0.16
	p	0.14	**0.01**		**<0.01**	**0.05**	
Time to PT 60°/s [s]	Involved	0.82 ± 0.16	0.74 ± 0.17	0.99	0.54 ± 0.08	0.59 ± 0.14	0.19
	Uninvolved	0.84 ± 0.14	0.84 ± 0.17	0.59	0.63 ± 0.15	0.70 ± 0.22	0.24
	p	0.49	**0.01**		**0.01**	**<0.01**	
Time PT held 180°/s [s]	Involved	0.02 ± 0.01	0.02 ± 0.01	0.06	0.02 ± 0.01	0.02 ± 0.01	0.28
	Uninvolved	0.02 ± 0.01	0.02 ±0.01	0.52	0.02 ± 0.01	0.02 ± 0.01	0.94
	p	0.28	0.16		0.79	0.37	
Time PT held 60°/s [s]	Involved	0.04 ± 0.01	0.04 ± 0.02	0.67	0.04 ± 0.02	0.04 ± 0.02	0.48
	Uninvolved	0.04 ± 0.02	0.05 ± 0.03	0.66	0.06 ± 0.03	0.06 ± 0.03	0.83
	p	0.79	0.76		0.07	0.07	
Force decay time 180°/s [s]	Involved	0.34 ± 0.04	0.35 ± 0.04	0.28	0.39 ± 0.05	0.39 ± 0.07	0.75
	Uninvolved	0.30 ± 0.17	0.34 ± 0.05	0.30	0.36 ± 0.04	0.39 ± 0.18	0.57
	p	0.32	0.16		0.06	0.97	
Force decay time 60°/s [s]	Involved	0.98 ± 0.14	0.98 ± 0.45	0.98	1.25 ± 0.15	1.20 ± 0.20	0.36
	Uninvolved	0.92 ± 0.50	1.07 ± 0.18	0.22	1.21 ± 0.16	1.10 ± 0.31	0.16
	p	0.59	0.36		0.31	0.11	
Reciprocal delay 180°/s [s]	Involved	0.04 ± 0.01	0.05 ± 0.01	0.09	0.04 ± 0.01	0.05 ± 0.02	0.28
	Uninvolved	0.04 ± 0.01	0.05 ± 0.02	0.24	0.06 ± 0.09	0.05 ± 0.02	0.49
	p	0.77	1.00		0.29	0.55	
Reciprocal delay 60°/s [s]	Involved	0.07 ± 0.03	0.09 ± 0.04	0.10	0.07 ± 0.02	0.08 ± 0.03	0.40
	Uninvolved	0.10 ± 0.04	0.12 ± 0.09	0.36	0.09 ± 0.04	0.08 ± 0.03	0.36
	p	0.06	0.16		0.09	0.72	
Delay time 180°/s [s]	Involved	–0.02 ± 0.00	–0.02 ± 0.01	0.13	–0.01 ± 0.01	0.01 ± 0.02	0.06
	Uninvolved	–0.02 ± 0.01	–0.02 ± 0.01	0.11	–0.01 ± 0.01	0.01 ± 0.02	0.24
	p	0.30	0.06		0.85	0.75	
Delay time 60°/s [s]	Involved	–0.03 ± 0.01	–0.03 ± 0.02	0.38	–0.02 ± 0.01	–0.01 ± 0.03	0.30
	Uninvolved	–0.03 ± 0.01	–0.02 ± 0.02	0.12	–0.02 ± 0.02	0.01 ± 0.06	0.07
	p	0.97	0.26		1.00	0.18	

Values expressed as the mean and standard deviation (±). Group I – fully supervised physiotherapy participants; Group II – participants with a shorter duration of physiotherapy supervision; *p* – level of significance; PT – peak torque. $p \leq 0.05$ is indicated in bold.

Table 8. Correlations between the time parameters values and the time since ACL reconstruction, and the time of postoperative physiotherapy duration

Time parameters					
		Knee Extensor Muscles		Knee Flexor Muscles	
	Studied limb	Time since ACLR	Physiotherapy	Time since ACLR	Physiotherapy
Time to PT 180°/s	Involved	$r = 0.05$; $p = 0.78$	$r = 0.06$; $p = 0.73$	$r = –0.03$; $p = 0.84$	$r = –0.25$; $p = 0.13$
	Uninvolved	$r = 0.01$; $p = 0.94$	$r = –0.21$; $p = 0.21$	$r = 0.08$; $p = 0.64$	$r = –0.31$; $p = 0.06$
Time to PT 60°/s	Involved	$r = 0.08$; $p = 0.63$	$r = 0.20$; $p = 0.22$	$r = 0.01$; $p = 0.94$	$r = –0.24$; $p = 0.15$
	Uninvolved	$r = 0.08$; $p = 0.63$	$r = 0.17$; $p = 0.30$	$r = 0.07$; $p = 0.70$	$r = –0.13$; $p = 0.44$
Time PT held 180°/s	Involved	$r = –0.18$; $p = 0.27$	$r = 0.22$; $p = 0.18$	$r = –0.30$; $p = 0.07$	$r = –0.02$; $p = 0.91$
	Uninvolved	$r = 0.05$; $p = 0.77$	$r = –0.10$; $p = 0.55$	$r = 0.07$; $p = 0.68$	$r = –0.05$; $p = 0.77$
Time PT held 60°/s	Involved	$r = 0.02$; $p = 0.91$	$r = –0.12$; $p = 0.47$	$r = 0.13$; $p = 0.43$	$r = –0.05$; $p = 0.76$
	Uninvolved	$r = –0.14$; $p = 0.40$	$r = –0.25$; $p = 0.13$	$r = 0.01$; $p = 0.93$	$r = 0.01$; $p = 0.97$
Force decay time 180°/s	Involved	$r = 0.27$; $p = 0.11$	$r = –0.15$; $p = 0.37$	$r = –0.01$; $p = 0.93$	$r = –0.01$; $p = 0.96$
	Uninvolved	$r = 0.09$; $p = 0.59$	$r = –0.16$; $p = 0.34$	$r = –0.09$; $p = 0.58$	$r = –0.14$; $p = 0.40$
Force decay time 60°/s (s)	Involved	$r = –0.13$; $p = 0.43$	$r = 0.05$; $p = 0.76$	$r = 0.22$; $p = 0.19$	$r = 0.10$; $p = 0.56$
	Uninvolved	$r = 0.17$; $p = 0.31$	$r = –0.19$; $p = 0.24$	$r = 0.12$; $p = 0.47$	$r = 0.06$; $p = 0.72$
Reciprocal delay 180°/s	Involved	$r = 0.05$; $p = 0.77$	$r = –0.38$; $p = 0.06$	$r = –0.01$; $p = 0.97$	$r = –0.23$; $p = 0.17$
	Uninvolved	$r = 0.06$; $p = 0.74$	$r = –0.27$; $p = 0.11$	$r = 0.14$; $p = 0.42$	$r = 0.20$; $p = 0.23$
Reciprocal delay 60°/s	Involved	$r = 0.25$; $p = 0.13$	$r = –0.22$; $p = 0.18$	$r = –0.03$; $p = 0.84$	$r = –0.24$; $p = 0.15$
	Uninvolved	$r = –0.23$; $p = 0.16$	$r = –0.11$; $p = 0.53$	$r = –0.31$; $p = 0.06$	$r < –0.01$; $p = 0.98$
Delay time 180°/s	Involved	$r = 0.06$; $p = 0.74$	$r = 0.31$; $p = 0.06$	$r = 0.09$; $p = 0.61$	$r = –0.26$; $p = 0.12$
	Uninvolved	$r = 0.04$; $p = 0.80$	$r = –0.22$; $p = 0.19$	$r = 0.29$; $p = 0.08$	$r = –0.11$; $p = 0.52$
Delay time 60°/s	Involved	$r = 0.12$; $p = 0.49$	$r = –0.17$; $p = 0.32$	$r = –0.02$; $p = 0.89$	$r = –0.06$; $p = 0.71$
	Uninvolved	$r = 0.22$; $p = 0.19$	$r = –0.26$; $p = 0.12$	$r = –0.11$; $p = 0.51$	$r = 0.00$; $p = 1.00$

Values expressed as the correlation coefficient (r) and level of significance (p) values. ACLR – anterior cruciate ligament reconstruction; Group I – fully supervised physiotherapy participants; Group II – participants with a shorter duration of physiotherapy supervision; physiotherapy – postoperative supervised physiotherapy duration; PT – peak torque. $p \leq 0.05$ is indicated in bold.

No differences between the two studied groups in terms of the knee extensor muscles time parameters were found (Table 7).

The knee extensor muscles time parameters in Group I and Group II were not correlated with the time since ACLR, and the time of postoperative physiotherapy supervision duration (Table 8).

Knee flexor muscles

Statistically significantly lower values of the knee flexor muscles time to PT at 60°/s and 180°/s in the involved limb, compared to the uninvolved limb, were noted in both studied groups (Tables 7). The knee flexor muscles time parameters in Group I and Group

II were not correlated with the time since ACLR, and the time of postoperative physiotherapy supervision duration (Table 8).

5. Discussion

There were two the most important findings of the study. Firstly, that the knee extensor muscles torque parameters including RPT, RTW, and RAP as well as LSI of those parameters were directly correlated with the postoperative supervision duration. In the group of patients with shorter duration of postoperative physiotherapy supervision, inter-limb knee flexor muscles torque parameters differences were also noted, however, they were not as significant as in terms of knee extensor muscles. It was also noted that the knee extensor muscles time to PT was longer in the ACL-reconstructed limb, compared to the contrateral one in the group of patients with shorter duration of postoperative physiotherapy supervision. Secondly, it was noticed that the knee flexor muscles PT angle was shifted towards extension in the ACL-reconstructed limb regardless of the time of postoperative physiotherapy supervision duration. The shift was not affected by the PT value, as it was observed in both studied groups, regardless of the obtained RPT values and RPT LSI. Also, it could have not been affected by the ROM, as the shift was noted regardless of any ROM limitations. The derivative of reducing the knee flexors muscles PT angle in the ACL-reconstructed limb was to shorten the time to PT.

The LSI is a measure of strength our function of the operated limb, in relation to the non-operated limb. The LSI values are commonly used for strength tests and hop test in patients after ACLR to calculate the inter-limb difference, with the values lower than 90 being commonly considered as cut-off values for return to sport. In the present study, majority of patients in Group I passed the so-called quadriceps strength criterion (LSI > 90) at both 180° (94% of patients) and 60°/s (89% of patients) at eight months after the ACLR. The results were opposite to Welling et al. [23], who noted that almost half of the patients in their study at nine months after ACLR did not pass the quadriceps strength criterion. The patients with shorter time of postoperative physiotherapy supervision duration obtained quadriceps strength LSI values mostly lower than 90, and the quadriceps strength criterion (LSI > 90) was passed in the case of 25% of patients at 180°, and in the case of 25% of patients at 60°/s (Fig. 1).

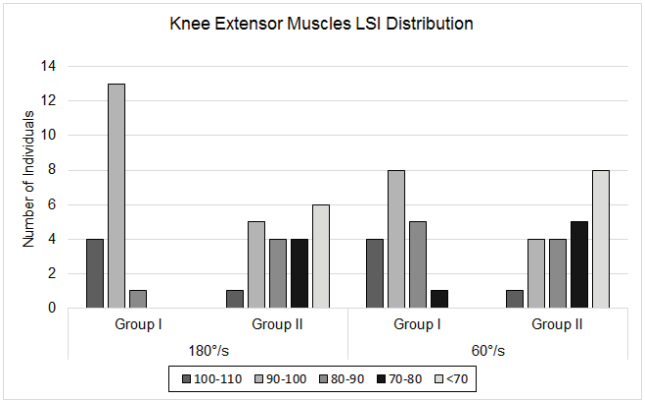

Fig. 1. Knee extensors muscles limb symmetry index distribution in particular groups at 180°/s and 60°/s

On the other hand, caution is advised for the use of LSI since it can mask bilateral deficits, as the uninvolved limb can be also affected, and it may also be experiencing quadriceps weakness after the reconstruction [12]. As the greater quadriceps muscle strength is associated with successful return to sport after ACLR [7], in the literature the commonly recommended threshold of the absolute values normalized to body weight for the quadriceps muscle torque test for the operated limb is being set at > 3.0 $N*m*kg^{-1}$ [15]. According to that, 83% from Group I and only 10% from Group II passed the quadriceps strength criterion based on normalized ACL-reconstructed knee PT value measured at 180°/s. Similarly for measurements at 60°/s, the criterion was passed by 89% of patients from Group I and only 20% from Group II. It's also noteworthy that comparing the ACL-reconstructed patients quadriceps strength to the set threshold was more critical than LSI analysis alone, which is in line with other authors, that the LSI should be always used with caution [11], [23].

The terminology concerning supervised, clinic-based and non-supervised, home-based postoperative physiotherapy after ACLR remains debatable, as the amount of physiotherapy input attained with so-called non-supervised physiotherapy is unclear. All the more noteworthy is the very precise division of physiotherapy modes after ACLR employed by Ebert et al. [8] to evaluate whether patients undertook particular components of physiotherapy including the level of supervision (both during therapy but also upon return to sport), duration of postoperative physiotherapy, and whether structured jumping, landing and agility exercises were undertaken. The present study is not the first one highlighting the relationship between specialist postoperative physiotherapy and functional limb symmetry [8], but it is the first to demonstrate no association between postoperative physiotherapy and

shifting the ACL-reconstructed knee flexor muscles PT angle.

According to many authors, the post-operated morbidity associated with harvesting autograft for the ACLR results in the weakness in knee flexion [9], [16], [21]. Additionally, some authors suggest that tendon harvest causes significant weakness of hamstring muscle strength at high knee flexion angles, but such weakness can be minimized if the gracilis tendon is preserved [22]. On the other hand, other authors undermine the clinical significance of the existing differences in knee flexors muscle strength between the addition of gracilis harvest to an isolated semitendinosus harvest, however, they admit that hamstring strength deficits may be larger at higher flexion angles [20].

The PT angle is defined as the flexion or extension angle at which PT occurs. No abnormalities in the knee extensor muscles PT angle were found. There has been also a general assumption since the nineties of the last century that a home-based rehabilitation programme produces results equal to those obtained with a clinic-based procedure in terms of muscle strength [1], [10], [19]. However, the angle of PT has never been investigated in that matter. The present study confirmed finding of Yosmaoglu et al. [25] investigating differences in the angle of PT and that the PT angle was influenced by the graft choices in patients one year after the ACLR. They noted that the ACL-reconstructed knee flexor muscles PT angle at 180°/s was shifted toward extension when the graft was harvested from hamstring tendons [25].

According to Makihara et al. [17], the decrease of deep ACL-reconstructed knee flexion torque could be caused by the atrophy and shortening of the semitendinosus after its tendon has been harvested, as well as the lack of compensation from the semimembranosus and biceps femoris, because of the architectural differences between the semitendinosus and the semimembranosus and biceps femoris [17]. The biceps femoris and semimembranosus are unipennate muscles having short fiber lengths and pennation angles. The biceps femoris and semimembranosus fiber length is three-to-four times shorter than on the semitendinosus and gracilis muscle [17]. After harvesting the semitendinosus for the reconstruction, the biceps femoris and semimembranosus are left as the primary knee flexors, however, they are insufficient to produce torque, especially at deeper flexion angles. The importance of preserving the morphology of the semitendinosus muscle-tendon complex was also confirmed by Nomura et al. [18] because of correlation between the tendon regeneration, semitendinosus muscle shortening, and semitendinosus muscle atrophy with decreased knee flexion torque [18]. Another factor that may be responsible for shifting the PT angle in the ACL-reconstructed knee is an impairment in the neuromuscular modulation system [25]. It is well known that the knee joint mechanoreceptor system is disturbed after the ACL injury, and that the impairment remains even after the reconstruction [3].

There is a need for an additional research to clarify clinical and functional importance of shifting the knee flexor muscles PT angle in patients after the ACLR with autologous ipsilateral hamstring graft. Furthermore, the present study confirms the indication that a single peak torque evaluation, may be insufficient information about the quality of torque production status in patients after ACLR [25]. However, in the future studies should resolve the conflict regarding the repeatability of the PT angle measurement [2], while generally the reproducibility of isokinetic measurement is considered to be very high.

The small number of patients may be considered as a limitation of the study. However, the participants' limited number results from the meticulous selection of the test sample, taking into account factors that could affect the muscle strength. Another limitation was the lack of the output data of the examined patients from the period before reconstruction, so very strict initial sample exclusion criteria were employed. The uneven number of patients between the two studied groups may be also considered as a limitation. The same number of patients in both studied groups would have allowed for a more precise statistical analysis in some parameters, however, it did not affect the side-to-side comparison results which were the main findings of the study.

5. Conclusion

A specialist supervision by during the final stages of physiotherapy after ACLR with the use of semitendinosus and gracilis tendons autograft, practising strength, power, complex movement patterns, running, and endurance training was more effective for improving knee muscles torque parameters at eight months postoperatively. Especially the obtained knee extensor muscles torque parameters and LSI values were directly correlated with the physiotherapy supervision duration. On the other hand, the knee flexor muscles PT angle was shifted towards extension in the ACL-reconstructed limb regardless of the time of postoperative physiotherapy supervision duration. The present study confirms the indication that

a single peak torque evaluation may be insufficient information about the quality of torque production status in patients after ACLR.

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