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Moments of muscular strength of knee joint extensors and flexors during physiotherapeutic procedures following anterior cruciate ligament reconstruction in males

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The objective of this paper was to evaluate maximal muscular strength moments of knee joint extensors and flexors in males subjected to physiotherapeutic procedures. 120 males were selected for the study. The first group consisted of 54 patients who underwent a 6 month physiotherapy programme following anterior cruciate ligament (ACL) reconstruction. The control group comprised 54 males without knee joint injuries. The measurement of muscular strength moments was performed in healthy and affected knee joint flexor and extensor muscles postoperatively, during the 13th and 21st week of physiotherapy. The patients' results were next compared with the results obtained in the control group.

During the 13th week of physiotherapy, the values of postoperative maximal strength moments in knee joints were significantly lower compared to the results obtained in non-operated limbs and in the control group. The introduction of individual loads adjusted to the course of ACL graft reconstruction and fixation in the bone tunnel resulted in the improvement of maximal muscle strength values in the patients' knee joints from 13 to 21 weeks postoperatively. During the 21st week of physiotherapy, the values of the muscular strengths in the operated limbs were similar to those obtained in non-operated limbs of the patients and in the control group.

Key words: *physiotherapy, muscular strength, muscular strength moments, rehabilitation following anterior cruciate ligament injuries*

1. Introduction

ACL limits anterior translation of the shank towards the thigh, excessive extension and flexion of the shank. This prevents excessive varus and valgus knee movements [1]. Cruciate ligaments participate in reflex regulation of three-dimensional joint location. The response to the ligament proprioceptive information involves altered tension, size and reciprocal proportion of muscle group contraction [2], [3]. Total ACL shear with clinical symptoms may result in knee joint instability. This can lead to a positive Lachman test result, excessive anterior tibial translation towards the thigh and reduced neuromuscular control of the knee joint due to the damage to deep sensibility receptors [4], [5]. The quadriceps strength is reduced. The proportion of concentric-eccentric loads, adjusted to the course of ACL graft reconstruction and stabilization in the bone tunnel affecting the knee joint, is disturbed. Rapid changes in the direction of movements are often limited in the affected limb. Knee joint instability may lead to chondropathy unless the problem is associated with cruciate ligament damage [6]–[9]. Total ACL shear with full clinical symptoms requires surgical intervention. One of the stages of postoperative physiotherapeutic procedures involves restoration of maximal strengths and proportions of the knee joint maximal muscular group strength moments and proprioception.

The studies of muscular strength moments under static and isokinetic conditions in normal subjects are generally known [10]–[12]. Similar studies are conducted to evaluate therapeutic procedures in patients after motor apparatus injuries [13]–[15]. There are fewer reports on the monitoring of the values of

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muscular strength moments in current physiotherapeutic procedures, which can show whether there is any relationship between muscular strength restoration and underlying biological processes in the ligament graft and whether muscular strength can be safely restored.

The aim of the paper was to evaluate maximal muscular strength moments of knee joint extensors and flexors in patients subjected to the author's own physiotherapeutic procedure after endoscopic reconstruction of the knee joint ACL.

2. Material and methods

120 males participated in the study. 12 of them (including 6 patients) did not complete the planned study programme. The measurement of maximal strength moments (Nm) were taken in two groups of 108 subjects. The first group comprised 54 patients after endoscopic reconstruction of the isolated, total shear of the knee joint ACL. The graft was taken from the semitendinous and gracilis muscles. The graft was stabilized using the Regidfix method. The second control group comprised 54 males without knee joint injuries. Right lateralization was noted in 47 patients and in 45 controls. Anthropometric parameters and the level of physical activity of the control group were similar to those in the first group prior to the injury. The subjects signed their informed consent to participate in the study. The subjects' characteristics is presented in table 1. The study was approved by the Bioethical Committee.

ware. The study was performed according to the principles of statics [16].

a)

b)

Fig. 1. Preparation for the measurement (a); measurement of strength moments (Nm) in knee joint extensors (b)

The measurements were preceded by a 12-minute warm-up on a cycloergometer. The measurement of

Table 1. Characteristics of the subjects

Study groups	***n* = 104**	Age (years)		Height (cm)		Body mass (kg)	
		X	SD	*X*	SD	*X*	SD
Group I (patients)	**54**	**25.5**	8.3	**181.8**	7.7	**78.2**	10.7
Group II (control)	**54**	**24.4**	5.1	**180.2**	6.2	**77.4**	9.5

Full range of movement (ROM) was restored in patients' knee joints after surgery between the 8th and 12th week of physiotherapy compared to the unaffected joints. The measurements of maximal muscular strength values were performed in the group of patients at the beginning of the 13th and at the end of the 21st week of physiotherapy and the measuring-rehabilitation UPR-1 using Moment 2 SUMER soft-

strength moments (Nm) of knee joint extensors was taken in the prone position with 70° shank flexion towards the thigh. The measurement for knee joint flexors was taken in the supine position 30° shank flexion towards the thigh. The pelvis was stabilized at the level of the greater trochanter of the femurs and thighs. The lever arm was at 40 cm distance from the knee joint axis. After preparing the study (figure 1 a) the measurement was

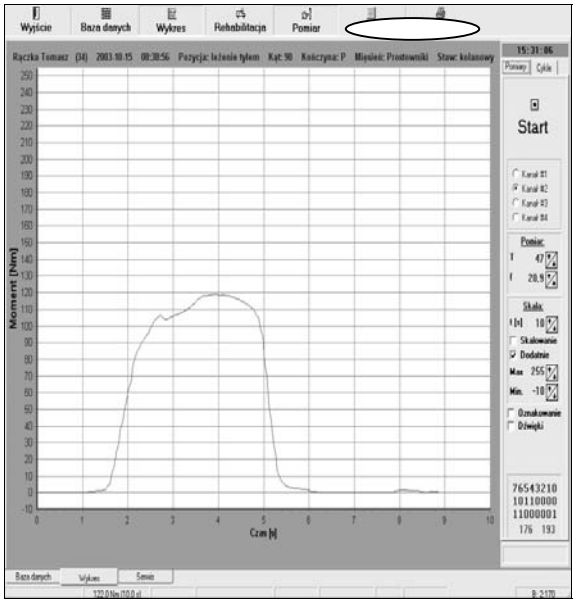

Fig. 2. The values of strength moments (Nm) in extensor muscles following surgery during the 13th week of physiotherapy

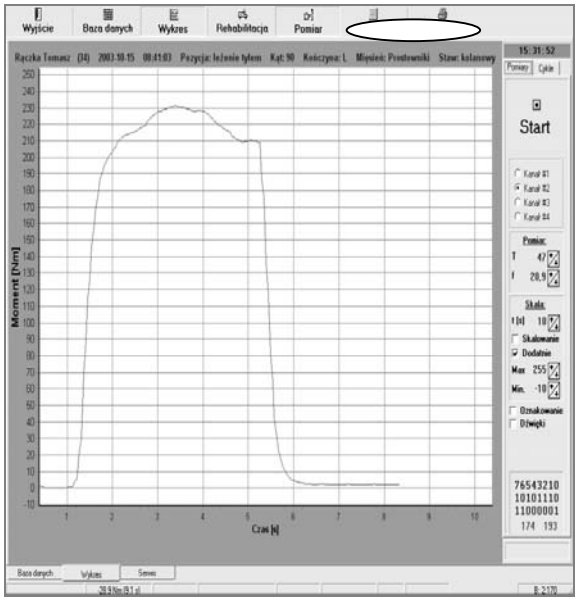

Fig. 3. The value of strength moments (Nm) in extensor muscles of the non-operated knee joint during the 13th week of physiotherapy

a)

b)

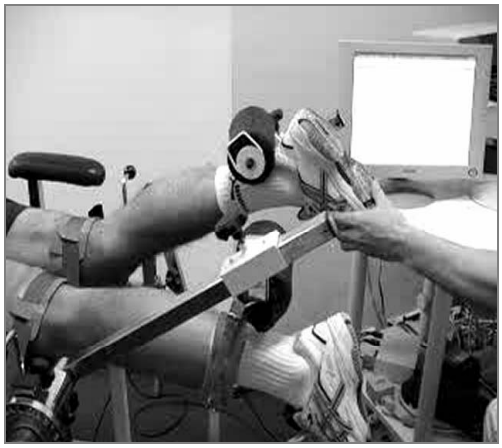

Fig. 4. Preparation for the measurement (a); measurement of maximal strength moments of knee flexors (b)

started with the "Start" signal (figure 1b). The extensor muscles were first measured in the unaffected limb, then in the operated limb. The measured strength moment values were recorded separately for the unaffected limb and the operated limb (figures 2 and 3). On completion of the measurement there was a 2-minute break for subject positioning and calibration (figure 4a). Next the strength moment was measured for flexor muscles of the unaffected limb, and after the break, the strength moment was measured in the flexors of the operated limb (figure 4b).

After a 2-minute break, the measurement was performed again according to the above scheme. For further analysis, the results of the highest strength moment values were selected. In the second (control) group, the study was performed according to the procedure described for the first group of patients, starting with the right limb after having prepared the study.

The relative strength moment was calculated according to the formula presented below. The relative strength moment (RMS) (Nm/kg) was calculated based on the division of maximal strength moments for each limb and muscle group separately by body mass (BM) value in kg for each subject.

$$\mathrm{RMS} = \frac{\mathrm{MSM\ (Nm)}}{\mathrm{BM\ (kg)}}.$$

3. Statistical analysis

The results were subjected to statistical analysis which comprised:

t-Student test for independent samples – for the assessment of the differences between the mean values obtained in two independent groups,

t-Student test for dependent samples for the assessment of the differences between the mean values obtained in two dependent groups, Shapiro–Wilk test for studying normality of feature distribution.

For statistical analysis the Statistica 6 Stat. Soft package was used. The results with minimum significance level $p < 0.05$ were considered significant.

4. Physiotherapeutic procedure

Physiotherapeutic procedure was divided into four stages.

Stage 1 started immediately after the surgery and comprised cooling, passive movement on CPM splints with movement limitation for the operated knee joint, isometric exercises and learning to walk with two crutches. The patients were informed about the course and principles of physiotherapeutic procedures. Cryotherapy was performed as well as patellofemoral joint mobilization and isometric exercises of both lower limbs. Electrostimulation of quadriceps and posterior muscles of the thigh was performed together with proprioception exercises in closed kinematic chains. Following physician's orders, additional physiotherapeutic procedures were performed. The measurement of surface response strength (N) vertical component was performed under static conditions (pressure). Based on the measurement results, the exercises were carried out in closed kinematic chains on mtd-balance platforms. The load was gradually increased in the vertical component. Passive movement range was gradually increased on the CPM splint. When full load was applied on the operated limb (full pressure), the patients were taught to walk without crutches. The range of exercises stimulating deep sensibility was extended.

Stage 2. Starting from the 6th week of physiotherapy, the movement range in the knee joint was increased. The strength of knee joint flexor muscles was gradually increasing. Active exercises, including those with gradual resistance of muscle groups, were performed beyond the anterior area of the knee joint after surgery and for the remaining muscle groups of different body parts. The patients walked without crutches. Exercises on cycloergometers, treadmills and steppers were introduced. March with altered inclination angle of the treadmill and walk on the stairs were performed. Deep sensibility was stimulated by the exercises on trampolines and other equipment developing equilibrium and neuromuscular coordination with physiotherapist's support.

Stage 3. From the 13th to the 19th week of physiotherapy, the second stage elements were continued. During the 13th week, strength moment measurements were performed (the angle of 70^{o} for extensors and 30° for flexors). Based on the results obtained, (figure 2), strength training under static conditions was performed. At the beginning 35–40% loads were applied from measurement results of maximal strength moments (N m). During subsequent weeks, 40–50% loads were applied based on the results obtained. Next, after the adaptation to the above load, 50–60% of the maximal value was applied. When the values of muscle strength moments of the operated limbs reached 70% of the values of muscular strength of the unaffected limbs, march on a treadmill on a soft surface was started at low speed (trot). The speed gradually increased with the development of muscle strength in the lower limbs, the trunk and the upper limbs on the parquet and hard surface. Exercises specific to a given sports discipline were introduced with low speed and gradually increased duration. Next, exercise intensity was increased. After the 16th week of physiotherapy, exercises were performed under isokinetic conditions with the angular velocity of 180°/sec and next of 120°/sec. During subsequent weeks, angular velocity was gradually reduced to 90°/s and next to 60°/s. Initially, these exercises were performed with a limited range of movements when extending and flexing the knee joint in the operated limb. At the end of the third stage, the above exercises were gradually intensified till the full range of movements was obtained. Rotating massage was applied once or twice a week.

Stage 4 lasted from the 20th week to 8 months following reconstruction, depending on the patient. The third stage elements of physiotherapy were continued with additional power training programme in open kinematic chains with a full range of movement and a gradual increase in resistance. Running dynamics was then gradually increased with changes in movement direction and angle of inclination. Speed, agility and orientation were gradually restored under specific conditions for a given sports discipline or occupational activity. Deep sensibility was mastered under conditions of complex movements and neuromuscular coordination. The applied exercises developed strength, endurance and equilibrium. The programme aimed at the development of speed, agility and orienteering. Additionally, the swimming pool was used once a week. A detailed physiotherapeutic procedure with

individual and objective selection of exercises is presented in a separate work – the author's doctor's thesis [17].

5. Results

During the 13th week postoperatively, the mean value of maximal strength moments (Nm) of knee joint extensors was $X = 155.9$ Nm – significantly lower compared to the values obtained in healthy limbs, $X = 265.1$. During the 21st week of physiotherapy, a significant increase in the examined feature was obtained in the group of patients – up to $X = 290.1$ Nm, compared to the value from the 13th week of physiotherapy. At that time, the results obtained for the operated limbs did not statistically differ from the results obtained for unaffected limbs: $X = 301.8$ Nm (T2).

The moments of maximal strength of flexor muscles of the operated knee joints were significantly lower during the 13th week ($p < 0.001$) compared to

Table 2. Comparison of the mean values of maximal strength moments (Nm) of knee joint extensors and flexors during the 13th and 21st week of physiotherapy in the group of patients

Group I (patients)	Maximal strength moments (Nm)							
	Patients $n = 54$							
	Operated limb, 13th week of physiotherapy		Operated limb, 21st week of physiotherapy		Unaffected limb, 13th week of physiotherapy		Unaffected limb, 21st week of physiotherapy	
	X	SD	***X***	SD	***X***	SD	***X***	SD
Knee joint extensors	**155.9** $p < 0.001$	4.5	**290.1**	50.6	**265.1**	51.4	**301.8**	52.3
Knee joint flexors	**88.7** $p < 0.001$	21.7	**122.9**	24.6	**110.8**	28.5	**129.6**	27.1

Table 3. Comparison of the mean values of maximal strength moments (Nm) in knee joint extensor and flexor muscles between the group of patients (I) and the control group (II) during the 21st week of physiotherapy

***n* = 108**	Maximal strength moments (Nm)							
	Group I – patients ($n = 54$)				Group II – control ($n = 54$)			
	Operated limb, 21st week of physiotherapy		Unaffected limb, 21st week of physiotherapy		Left limb		Right limb	
	X	SD	***X***	SD	***X***	SD	***X***	SD
Knee joint extensors	**290.1**	50.6	**301.8**	52.3	**281.3**	43. 2	**282.7**	42.8
Knee joint flexors	**122.9** $p < 0.001$	24.6	**129.6** $p < 0.001$	27.2	**101.0**	17.6	**106.3**	21.0

Table. 4. Comparison of the relative strength moment values (Nm/kg) for extensor and flexor muscles in the first group of patients during the 13th and 21st week of physiotherapy and comparison with the results obtained in the control group (group II)

***n* = 108** Relative strength moment (Nm/kg)	Group I – patients Operated limb		Group I – patients Unaffected limb		Group II – controls	
	13th week of physiotherapy	21th week of physiotherapy	13th week of physiotherapy	21th week of physiotherapy	Left limb	Right limb
Extensor muscles	$X = 2.04$ SD = 0.73 $p < 0{,}001$	***X* = 3.75** SD = 0.69	***X* = 3.44** SD = 0.73	***X* = 3.91** SD = 0.72	***X* = 3.65** SD = 0.53	***X* = 3.67** SD = 0.52
Flexor muscles	***X* = 1.15** SD = 0.31 p < 0.001	***X* = 1.59** SD = 0.34 $p < 0.001$	***X* = 1.46** SD = 0.37	***X* = 1.67** SD = 0.36 $p < 0.05$	***X* = 1.31** SD = 0.21	***X* = 1.37** SD = 0.25

the value of the examined feature obtained for unaffected limbs. During the 21st week, the strength in flexors of the operated knee joints significantly increased, reaching the values similar to those obtained in the unaffected limbs (table 2).

During the 21st week postoperatively, the moments of maximal muscle strength in shank extensors were similar to those obtained in the unaffected limbs and in the control group. Interestingly, the postoperative values of muscle strength moments in the group of patients were significantly higher compared to the control group (table 3).

During the 21st week of physiotherapy, a significant increase in relative values was noted for extensors (from $X = 2.04$ to $X = 3.75$) and flexors (from $X = 1.15$ to $X = 1.59$) of the knee joints after surgery compared to the values measured during the 13th week.

The results obtained postoperatively during the 21st week of physiotherapy were similar to the results obtained in the unaffected limbs and in the control group. The group of muscles flexing the shank towards the thigh obtained even higher results of relative muscular strength moments compared to the control group (group II) (table 4).

6. Discussion

In the first study, the values of muscular strength of the operated limbs were significantly lower compared to the values obtained for the unaffected limbs. The question is whether it was possible to restore muscular strength, which is one of the basic goals of physiotherapy. Attempts to restore muscular strength should not interfere with the biological processes necessary for obtaining graft stability, restoring ligament perfusion and innervation, and connective tissue reconstruction. All these factors affect endurance and resistance of the graft to shear strengths; this process requires some time [18]–[21].

Soft tissue grafts require about 12 weeks to heal in the bony tunnel. Bone-ligament-bone grafts however, require about 6 weeks to heal [22], [23]. Up to 6 weeks postoperatively, graft endurance is four times smaller compared with the baseline endurance. During the 12th week following surgery, ligament reconstruction is still incomplete with about 40% of its future potential restored [24]. Therefore, during the first two stages of the physiotherapeutic procedure, exercises stimulating proprioception were performed with a prevalent number of exercises performed in closed kinematic chains. The exercises which could exert great shear strengths to the ligament were limited. From the 13th week postoperatively, apart from standard physiotherapeutic procedures, isolated loads were applied to extensor muscles under static conditions. These were isometric exercises with 35–40% resistance from the obtained value of maximal strength moments during measurements. When the patients adapted to the planned loads extending training time in the applied compartments of strength moment values and their contraction coordination improved, the author gradually increased the load applied individually to each patient during subsequent weeks. From the 16th week following reconstruction, individual concentric-eccentric exercises were introduced under isokinetic conditions. Initially, exercises involving extensor and flexor muscles were performed under isokinetic conditions with the angular velocity of 180°/sec; after patients adaptation to these conditions, the angular velocities of 120, 90 and 60°/sec were applied.

Allowing patients to perform dynamic movements without proper training of muscular strength and neuromuscular coordination may be a serious problem and interfere with the goals to be achieved by implementing a rehabilitation programme. This opinion is confirmed by other authors [25]–[30].

During the 6th month, the maximal and relative values of muscular strength moments for the limbs after surgery were close to the values obtained in the unaffected limbs and in the control group as well as to the results of other groups of healthy males [31], [32].

The patients achieved better results compared to the results of isokinetic measurements performed in normal subjects [32], [33]. Other researchers showed that between the 10th and 18th month following reconstruction, relative strength moments of knee joint extensors were similar to those obtained in unaffected limbs and in the control group [34].

The results presented may be considered model results for the reconstruction of maximal muscular strength moments. The result is affected by the surgical technique, lack of complications and realization of all four stages of physiotherapy. Initially, however, there were 6 more patients than during the final phase of the study. These were males who did not complete the study due to some complications or withdrawal from the physiotherapeutic program (12% of the patients). The outcome of the study is further confirmed by the author's other study performed in 400 patients after ACL reconstruction, which showed about 10% of complications requiring secondary arthroscopic procedures. The patients underwent a longer rehabilitation programme, which did not always result in complete recovery of movement range, locomotion

and muscular strength. Most of the patients, who returned to full activity required from 6 to 8 months of physiotherapy with elements of sports rehabilitation and gradual return to physical activity [35].

Summing up, the results of muscular strength obtained during a four-stage physiotherapeutic programme mainly concerned men motivated by the need to return to occupational and physical activity. The patients realized a 6-month physiotherapeutic programme and met all the above mentioned criteria. It should be emphasized that this is a model situation. The everyday practice, however, indicates that the results presented in this paper are not frequent.

7. Conclusions

1. The process of ACL graft healing and reconstruction and its adaptation to loads presumes the speed of muscular strength restoration.

2. The introduction of individual loads adjusted to clinical evaluation, the course of reconstruction and postoperative adaptation of ACL in the physiotherapeutic programme improved the values of maximal muscular strength moments from the 13th to the 21st week following surgery.

3. During the 13th week of physiotherapy, the values of maximal muscular strength moments in knee joint were significantly lower compared to those obtained in the unaffected limbs and the control group.

4. During the 21st week of physiotherapy, the values of muscular strength moments following surgery were close to the values obtained in the unaffected limbs of the patients examined and the patients in the control group.

References

[1] CISZEK B., KISIELEWSKI J.M., *Morfologia więzadeł krzyżowych stawu kolanowego*, Acta Clinica, 2001, 1(4), 278–283.

[2] SOLOMONOW M., KROGSGAARD M., *Sensorimotor control of knee stability. A review*, Scand. J. Med. Sci. Sports, 2001, 11, 64–80.

[3] GIANNI E., SCALA A., PUDDU G., *Rehabilitation following the surgical and nonsurgical management of posterior cruciate ligament injuries*, Journal of Sports Traumatology and Related Research, 1998, 20 (1), 23–40.

[4] BARRACK R.L., SKINNER H.B., BUCKLEY S.L., *Proprioception in the anterior cruciate deficient knee*, Am. J. Sports Med., 1989, 16–17.

[5] SCOT L., DANNY P., JORGE G., FREDDIE H.F., *Current concepts. The role of proprioreception in the management and rehabilitation of athletic injuries*, Am. J. Sports Med., 1997, 25 (1), 130–137.

[6] WIDUCHOWSKI J., *Endoprotezoplastyka – całkowita wymiana stawu*, Sport & Med., Katowice, 2001, 55–81.

[7] PATYK C., KWIATKOWSKI K., ORŁOWSKI J., KUŚ W.M., *Uszkodzenia stawu kolanowego*, [in:] Tylman D., Dziak A. (eds.), Traumatologia narządu ruchu, PZWL, Warszawa, 1996, 582–583.

[8] ŻUK T., DZIAK A., GUSTA A., *Podstawy ortopedii*, PZWL, Warszawa, 1983, 313–315.

[9] ADAMCZYK G., ANTOLAK Ł., SKROK T., ŚMIGIELSKI R., *Uszkodzenia chrząstki stawów kolanowych stwierdzane w czasie artroskopii stawów kolanowych u chorych z ostrymi i zastarzałymi uszkodzeniami więzadła krzyżowego przedniego na podstawie 144 operacji*, Acta Clinica, 2001, 2 (1), 138–144.

[10] REICHARD L.B. et al., *Testing knee extension and flexion strength at different ranges of motion: an isokinetic and electromyographic study*, Eur. J. Appl. Physiol., 2005, 95, 371–376.

[11] WYCHOWAŃSKI M., *An approach to a norm of knee muscle isometric torque depending on gender, joint angle and body mass*, Lecture Notes of the ICB Seminars, Polska Akademia Nauk, Warsaw, 2000, 90–95.

[12] TRZASKOMA Z., *Maksymalna siła mięśniowa i moc maksymalna kobiet i mężczyzn uprawiających sport wyczynowo*, Studia Monograficzne, AWF, Warszawa, 2003, 59–60.

[13] SHELBURNE K.B., TORRY M.R., PANDY M.G., *Altered quadriceps control in people with anterior cruciate ligament deficiency*, Med. Sci. Sports Exer., 2004, 36 (7), 1089–97.

[14] VAGENAS G., RISTANIS S., GEORGOULIS A.D., *Thigh muscle weakness in ACL – deficient knees persists without structured rehabilitation*, Clin. Orthop. Relat. Res., 2006, 450, 211–18.

[15] CHARLES A., BUSH J. et al., *Dynamic function after anterior cruciate ligament reconstruction with autologous patellar tendon*, The American Journal of Sports Medicine, 2001, Vol. 29. No. 1, 36–41.

[16] KABSCH A., *Pomiar wybranych parametrów ruchu i testowanie cech fizycznych człowieka*, [in:] Milanowska K., Dega W. (eds.), *Rehabilitacja medyczna*, Wyd. IV, PZWL, Warszawa, 2001, 203–207.

[17] CZAMARA A., *Ocena postępowania fizjoterapeutycznego po rekonstrukcji więzadła krzyżowego przedniego*, Rozprawa doktorska, AWF, Warszawa, 2006, 25–63.

[18] WOO S.L.-Y., WU C., DEDE O., VERCILLO F., NOORANI S., *Biomechanics and anterior cruciate ligament reconstruction*, Journal of Orthopaedic Surgery and Research, 2006, 1:2, 1–9.

[19] ARI Y., HARA K., TAKAHASHI T., URADE H., MINAMI G., TAKAMIYA H., KOBO T., *Evaluation of the vascular status of autogenous hamstring tendon grafts after anterior cruciate ligament reconstruction in humans using magnetic resonance angiography*, Knee Surg. Sports Traumatol. Arthrosc., 2008, 16, 342–347.

[20] HUNT P., SCHEFFLER S.U., UNTERHAUSER F.N., WEILER A., *A model of soft-tissue graft anterior cruciate ligament reconstruction in sheep*, Arch. Orthop. Trauma Surg., 2005, 125(4), 238.

[21] ARNOCZY S.P., TARVIN G.B., MARSHALL J.L., *Anterior cruciate ligament replacement using patellar tendon. An evaluation of graft revalscularization in the dog*, J. Bone Joint Surg. Am., 1982, 64 (2), 217.

[22] PAPAGEORGIOU C.D., MA C.B., ABRAMOWITCH S.D., CLINEFF T.D., WOO S.L., *A multidisciplinary study of the healing of an intraarticular anterior cruciate ligament graft in a goat model*, Am. J. Sports Med., 2001, 29, 620–626.

[23] RODEO S.A., ARNOCZKY S.P., TORTILLI P.A., *Tendon-healing in bone tunel. A biomechanical and histological study in the dog*, J. Bone Joint Surg. Am., 1993, 75, 1795–803.

[24] BOSCH U., KASPERCZYK W.J., *Healing of the patellar tendon autograft after posterior cruciate ligament reconstruction – a process of ligamentization? An experimental study in a sheep model*, Unfallchirurg, Mar. 1996, 99 (3), 183–90.

[25] DEVITA P., HORTOBAGYI T., BARRIER J., *Gait biomechanics are not normal after anterior cruciate ligament reconstruction and accelerated rehabilitation*, Medicine and Science in Sports and Exercise, 1998, 30 (10), 1481–488.

[26] CZAMARA A., *Zmiany wartości momentów sił mięśni w programie fizjoterapii po rekonstrukcji więzadła krzyżowego przedniego stawu kolanowego*, Fizjoterapia Polska, 2002, 2(4), 263–272.

[27] DEVITA P., HORTOBAGYL T., BARRIER J., TORRY M., GLOVER K., SPERONI D., MONEY J., MAHAR M., *Gait adaptations before and after anterior cruciate ligament reconstrution surgery*, Medicine and Science in Sports and Exercise, 1997, 853–859.

[28] PFEIFER K., BANZER W., *Motor performance in different dynamic tests in knee rehabilitation*, Scandinavian Journal of Medicine and Science in Sports, 1999, 9, 19–27.

[29] MUNETA T., SEKIYA I., OGIUCHI T., YAGISHITA K., YAMAMOTO H., SHINOMIYA K., *Objective factors affecting overall subjective evaluation of recovery after anterior cruciate ligament reconstruction*, Scandinavian Journal of Medicine and Science in Sports, 1998, 8, 283–289.

[30] CZAMARA A., BUGAJSKI A., *Fizjoterapia w zanikach prostych mięśni czworogłowych uda po urazach kończyn dolnych*, Medycyna Sportowa, 1998, rok XIV, 78, 13–17.

[31] BOBER T., HAY J.G., *Topografia siły mięśni kończyn człowieka*, Wychowanie Fizyczne i Sport, 1990, 3, 3–25.

[32] BOBER T., PIETRASZEWSKI B., *Strength of muscle groups in swimmers*, Biology of Sport, 1996, 13(2), 155–164.

[33] BOBER T., KULIG K., BURNFIELD J.M., PIETRASZEWSKI B., *Predictive torque equations for joint of the extremities*, Acta of Bioengineering and Biomechanics, 2002, 4, (2), 50–60.

[34] WIT A., MIROWSKI M., *Biomechaniczna ocena własności dynamicznych mięśni stawu kolanowego*, Acta Clinica, 2002, 2(1), 77–85, 30.

[35] ANDRZEJEWSKI T., CZAMARA A., DYREK W., TRYTEK-PYSIEWICZ A., *Wtórne rekonstrukcje po pierwotnych operacjach więzadeł krzyżowych przednich w materiale własnym*, Medicina Sportiva, 2005, 9(2), 77.