Evaluation of physiotherapeutic procedures after ACL reconstruction in males

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Abstract

Background and Study Aim: Evaluation of the four-stage physiotherapy program following ACL reconstruction.

Material/Methods: The sample comprised 108 males divided into two groups. Group I included physically active patients (n=54) after endoscopic ACL reconstruction using semitendinosus and gracilis muscle graft, as well as Regidfix stabilising. Group II included physically active males with no injuries of the knee joint (n=54). The subjects were examined by the physician and referred to four stages of physiotherapy. The range of movement was measured for flexion and extension of the knee joints (°) and the knee joint circumference was measured (cm) during the first and twelfth week following the reconstruction. The values of gait kinematics parameters including gait speed (m/s), step length, step frequency (step/s) and stance/swing ratio (%) were measured during the second and tenth week following the reconstruction. Based on the measurement of torque (Nm) for flexor and extensor muscles of the involved and uninvolved knee joints, performed during the thirteenth and twenty first week following the reconstruction, relative torque (Nm/kg) value was calculated. Fitness test was performed to assess the running speed during the run with maximal speed and envelope run (s). The evaluation was performed only once in the control group. The results obtained for the involved limbs were compared to those obtained for the uninvolved limbs and then, subjected to statistic analysis.

Results: During the second examination a significant improvement was noted in the mean values obtained for the range of movements, knee joint circumference and most of the measured gait kinematics parameters and relative torque of the involved knee muscles compared to the first examination results, the values obtained for the uninvolved knees and the control group results.

The time of run with maximal speed and envelope run, obtained in patients during the twenty fourth week of physiotherapy was similar to the time obtained for the control group.

Conclusions: The first two stages of physiotherapy (three months following ACL reconstruction) restored full range of movements, knee circumferences and most of the gait kinematics parameters, which were then similar to the values obtained for the control group. The restored torque values for extensor and flexor muscles of the operated knees and the time of runs: with maximal speed and envelope run required four stages of physiotherapy (6–8 month following the reconstruction).

Key words: medical rehabilitation • physiotherapy after ACL reconstruction • gait kinematics • muscle torque • special test

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Background

Knee joint injuries occur in 13–71% of athletes involved in different sport disciplines [1]. Anterior cruciate ligament (ACL) injuries constitute up to 60% of sports-related injuries [2,3]. Complete ACL ruptures may lead to knee joint instability, manifested by a positive Lachman test results, anteroposterior tibial translation

towards the thigh and Pivot Shift test, which results in the knee "giving way" during movement performance. The above mentioned symptoms are most frequent when getting off the car, ascending and descending stairs and running with changing direction (envelope run). Given the results of clinical examinations revealing knee instability with certain clinical symptoms, we may conclude that ruptured cruciate ligaments most frequently undergo surgical procedures. Partial injuries undergo conservative treatment, yet this approach is still open to discussion [4–6]. Recent reports describe anatomic and clinical prerequisites to one- and two-channel ACL reconstruction [7]. There are different programmes of rehabilitation and physiotherapy following ACL injuries [8–15]. Some papers present clinical evaluation of the outcome of ACL injury treatment, based on imaging and functional examination results [4,16]. Some authors, apart from clinical evaluation, used the scales of International Knee Documentation Committee (IKDC, 2000), Cincinnati, Knee Outcome Server Activities of Daily Living Scale (KOS-ADLS), Visual Analogue Scale (VAS) and measured the changes in **gait kinematics** and kinetics parameters or muscle strength in patients after ACL reconstruction [17–19]. This paper presents a four-stage physiotherapeutic procedure including natural healing processes after ACL reconstruction and improvement in functional fitness of the lower limbs, based on many years' experience at the Rehabilitation Centre of the College of Physiotherapy in Wrocław.

Gait kinematics – a branch of biomechanics comprising the issues pertaining to the changes in space and time parameters of motion in humans. The most frequently recorded, measured and evaluated parameters include changes in step length, gait velocity, stance phase of gait and stepping frequency, and ranges of movement in each articulation during gait in humans.

The goal of the paper was to evaluate the effectiveness of the four stage physiotherapeutic procedure and its usefulness in the therapeutic programme following ACL reconstruction.

Material and Methods

The sample comprised 108 males aged 17–35 years who were next divided into two groups (Table 1). The first group (I) included 54 patients after reconstruction of completely ruptured ACLs (operated from 2002 to 2006) who underwent an individual regular physiotherapy program within 6 to 8 months following the reconstruction. The semitendinosus and gracilis muscles with Regidfix stabilisation were used for the graft implantation. The patients had previously sustained injuries during participation in different sport activities (skiing, football, combat sports, basketball). The second group (II – control group) included 54 males without knee joint injuries, involved in physical activities 3 times a week on average. The surgeon, depending on the patient's clinical condition, referred him to different stages of the four-stage physiotherapeutic procedure. The patients (after signing their informed consent forms) were informed about the objective and course of physiotherapy and the scope of examinations. The study was approved by the Bioethics Committee at the University School of Physical Education in Wrocław.

Physiotherapeutic procedure

The patients underwent the four-stage physiotherapeutic procedure at the Rehabilitation Centre of the College of Physiotherapy in Wrocław. It was based on the previously developed rehabilitation model, involving functional improvement within a defined period of time [20]. After the reconstruction, the surgeon took history and performed a medical examination followed by specialist (orthopaedic) examination. The orthopaedic examination included: examination of ACL stability; test of anterior tibial translation towards the thigh, Lachman Test, examination of collateral ligament stability and the menisci, evaluation of the patellofemoral joint, Q-angle and articular cartilage as well as additional tests for stability of the remaining knee joint structures and body posture according to the rules accepted in literature [21]. The physician also paid attention to subjective assessment of pain and joint stability. This scheme of clinical procedure was carried out prior to each stage of physiotherapy and after finishing rehabilitation. The patients started their first stage of physiotherapy at the hospital (from the first day to six weeks postoperatively). During the first 4 days following surgery, cold packs were applied on the knee and passive movements were exercised on the continuous passive motion (CPM) splint of the affected knee as well as isometric exercises. The patients were taught to move with two crutches in orthotics and being self-sufficient; they were informed about the course of physiotherapy. From the fifth day following reconstruction at the Rehabilitation Centre of the College of Physiotherapy, they underwent cryotherapy of the knee joint and additionally, the patients were applied cold packs on the knee every six hours. Patellofemoral joint mobilization involved the following exercises: passive exercises with a CPM splint, isometric of the quadriceps muscles and other lower limb muscles, and proprioceptive exercises in closed kinematic chains. Gait was trained with crutches; the quadriceps and posterior thigh muscles were subjected to electrostimulation. During the second week, the values for surface reaction forces (N) of the vertical component were measured on the MTD balance platform. Based on the measurement results, the load values were selected for the affected extremity during proprioceptive exercises in closed kinematic chains on MTD balance platforms. Gradually, the patient was prepared to stand on one, affected leg and next, the load was increased to 1.1–1.3 of body mass and taught how to walk without crutches. The range of exercises stimulating deep sensibility in closed kinematic chains was

Table 1. Anthropometric profile of the study subjects.

Group	n=108	Age (years)		Body 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

extended. Active exercises of the flexor muscles of the affected knee were applied. Active exercises including these with partial resistance of all muscle groups except extensor and rotator muscles in open kinematic chains were introduced. Additionally, the patients were advised to apply cold packs on the knees every six hours and to perform the recommended exercises at home.

During the second stage of the rehabilitation program (from the sixth week following the reconstruction), carried out at our Centre, the patients underwent physiotherapeutic procedures of the first stage with additional exercises aimed at full ROM recovery in the affected knees. Different exercises were introduced including: cycloergometer, balance exercises and additional exercises with gradual resistance for flexor muscles of the affected knees. The training involved walking without crutches and normal gait. During subsequent weeks, exercises on steppers and training devices were introduced. Next, the patients were taught to walk on treadmills, later with the changed inclination angle of the treadmill, and next, to walk on stairs. Deep sensibility and neuromotor coordination were stimulated during exercises on trampolines, mattresses and other devices with unstable surface; they made partial squats with physiotherapist's support. The exercises were interrupted when the patient reported first signs of fatigue or reached pain threshold. The patients were partly instructed how to perform exercises adjusted to the second stage of the physiotherapeutic programme every day at home.

The third stage (exercising 3–4 times a week) was started on the 13th week postoperatively. This involved procedures from the second stage and additionally, torque measurements (Nm) were taken under static conditions with 70° angle for extensor muscles and 30° for flexor muscles of the affected and unaffected knees. Muscle strength deficit between the studied limbs was compared and, during subsequent weeks, appropriate exercises were performed in order to reduce this deficit. Based on the measurement results, strength training was started with alternant cycles – 5 second isometric tone followed by a 5 second interval. Initially, the load was applied with 35% of individual peak torque (PT), obtained in each patient from consecutive measurements. The training was interrupted when the patient was no longer able to sustain the preset load value which was visible on the monitor of the UPR-1 rehabilitation equipment or when the patient reported the first symptoms of fatigue or pain. During subsequent weeks, resistance was increased up to 40–50% of the maximal load and next to 50–60% and more, based on the obtained values (PT). When the torque of the affected limbs reached 70% of the values obtained for the healthy limbs, run on the treadmill and on the soft surface was introduced, initially at low speed (trot). Next, with the development of muscle strength in the lower limbs, trunk and upper limbs, run on the parquet (then, on a hard surface) was introduced as well as jumping exercises and other discipline-specific exercises (at low speed). The duration of exercises was next prolonged and exercise intensity gradually increased, always with the physiotherapist's support. From the 16th week following the reconstruction, isokinetic exercises were introduced for knee extensor and flexor muscles. The exercises for the operated limbs were started at angular velocity of 180°/second with the value of 35–40% of peak torque (PT) based on the control measurement for this angular velocity. After the patient's adaptation to such load, its value was increased to 40–45% PT, and during subsequent training sessions it was increased to 50 and next to 60% and higher values, until it was close to the values obtained for the unaffected knees. During next weeks, the angular velocity during exercise was decreased to 120° or 90°/second. At the turn of the 19th and 20th week, angular velocity of 60°/sec. was introduced. The load was selected according to the above mentioned rule, for which PT deficit was noted in the affected knees as compared to the healthy ones. The training was stopped when the patient experienced subjective or objective symptoms of fatigue or pain (the same as during the training under static conditions). Initially, the exercises were performed at limited ROM during extension and flexion of the affected knees. Centrifugal massage was applied twice week and the patients were instructed to exercise at home on the days when they did not undergo physiotherapy at our Centre.

The fourth stage (3 times a week) was started from the 19th/20th week and it lasted from 6 to even 8 months following the reconstruction; the elements of physiotherapy from the third stage were continued and the strength

Medical rehabilitation – a medical, social and socio-psychological process aimed at patients' health state improvement.

Physiotherapy after endoscopic reconstruction of ruptured ACL – treatment by application of kinesiotherapy (movement therapy) and special exercises stimulating deep sensibility and balance. It can also be performed using physical factors, such as cryotherapy, electrotherapy, magnetic field and hydrotherapy as well as massage and special techniques including mobilisation of soft tissues in the knee joint area.

Gait kinematics – a branch of biomechanics comprising the issues pertaining to the changes in space and time parameters of motion in humans. The most frequently recorded, measured and evaluated parameters include changes in step length, gait velocity, stance phase of gait and stepping frequency, and ranges of movement in each articulation during gait in humans.

Muscle torque (MT) – is the product of force (N) developed by the studied muscle group in humans multiplied by the lever arm (r). The value of MT is measured in Newton metres (Nm) on a special rehabilitation equipment.

The special test – involves run with maximum speed and envelope run using a 5×5 metre square, performed by the subjects twice on a flat surface. The time of the covered distance is measured(s).

training was extended by peak torque (PT) measurements (Nm) and isokinetic training in full ROM with gradually increased load. Also complementary strength training was applied for each muscle group of the whole body. The dynamics of run and envelope run on different surfaces was gradually increased. Complex movements, stimulating deep sensibility in different ways were trained. Additionally, attention was paid to the development and recovery of strength, endurance, fitness and next, the development of speed, agility, jumping and orientation in the environment during different exercise performance. Additionally, once a week the patients used the swimming pool, doing appropriate exercises.

Measurements

The measurements of ROM during active flexion and extension of the affected and unaffected knees was performed twice in patients (group I) – at the end of the first week and during the twelfth week of physiotherapy. In the control group (group II), the measurement was taken for the left and right knees once, using protractor with the accuracy to 1 degree in prone position.

Measurements of circumference at the level of the gap in the affected and unaffected knee joints were performed during the first and twelfth week of physiotherapy and for left and right knees – once in the supine position using a measuring tape, with the accuracy to 0.1 cm.

The record of measurements and gait kinematic values was performed in the group of patients during the second and tenth week postoperatively. In group II, the tests were carried out once. 17 photo-reflective, spherical markers with the diameter of 0.8 cm were placed on the subjects' bodies, marking the main biochemical body segments. Two digital cameras with 50 Hz record frequency recorded each movement towards the Y laboratory axis. The measurement was automatic and synchronised by SIMI movement analysis software (SIMI GMBH Germany). One of the cameras recorded movement in the patient's sagittal plane while the other one was shifted by about 80° towards the optic axis of the first camera. Film recording has a light gray background. Video cameras were connected to the computer to synchronise the signals. For synchronisation of the cameras, an optical signal was used from the signalling diode, monitored by both cameras and switched on at the start of data recording. For calibration, a cube was used, whose dimensions were 1×1×1 m; the cube was used as reference. The subjects covered the 5 meter distance at their own speed without shoes on (gait was not allowed when pain occurred). The motor task was repeated four times and gait started twice with the left limb and twice with the right limb which allowed us to derive 7–10 gait cycles depending on gait velocity. For the analysis, the mean values were used, obtained from full gait cycles. The values of gait velocity were measured in meters per second (m/s) as well as gait frequency – the number of steps per minute (stance/second) and the length of a single step in metres (m) and the percentage of stance phase duration (%). The first and the last step were not included in the measurement. Based on the recorded film, multidimensional time characteristics of were obtained joint markers in: the ankle joints and hip joints of both examined limbs; also a three-dimensional biomechanic model of each subject was obtained, allowing the insight in the technique and dynamics of movement.

Peak torque (PT) measurement in the extensor and flexor muscles of the operated and non-operated patients was carried out at the beginning of the 13th and at the end of the 21st week of physiotherapy on the UPR-1 equipment with SUMER Moment 2 software. Prior to the measurement, a 10 minute warm-up was performed on a cycloergometer. PT measurement (Nm) of knee joint extensor muscles were performed in the supine position (SP) with the shank flexed towards the thigh at 70° and for flexor muscles in the prone position (PP) with the shank flexed towards the thigh at 30°. The pelvis was stabilised at the level of greater trochanters of the femur in their distal 1/3 using stabilising belts. The lever axis passed through the axis of the examined joints. The lever arm was placed at 40 cm distance from the knee joint axis. The measurements were taken twice for each muscle group for both lower extremities and the result with the highest PT values (Nm) was selected for the analysis. Relative PT (RPT), expressed in Nm per 1 kg of body mass was calculated (Nm/ kg) dividing the PT value measured in NM for each extremity and muscle group by body mass value (BM) expressed in kg for each subject:

$$RPT(Nm/kg) = \frac{PT(Nm)}{BM(kg)}$$

The run with maximal speed and the envelope run were performed within a 5×5 m square and the subjects covered the "envelope" distance twice with no break. The group of patients performed the test during the 24th week of physiotherapy and the control group – during regular physical training. Prior to the test, the subjects performed a warm-up on a cycloergometer. With the "start" command, the subject performed the test with the maximal speed from the left to the right starting block at 5 m distance. Next, the subject passed the right starting block at its outer side and ran straight passing the

Table 2. Range of extension and flexion (°) of the affected and unaffected knees between the 1st and 12th week postoperatively in patients as compared to the control group.

n=108	Range of knees motion											
	Patients n=54								Control group n=54			
	Operated knees one week following physiotherapy		Operated knees 12 weeks following physiotherapy		Unaffected knees one week following physiotherapy		Unaffecetd knees 12 weeks following physiotherapy		Left knees		Right knees	
	X	SD	X	SD	X	SD	X	SD	X	SD	X	SD
Range of knee extension	11.24 p<0.001	6.17	–0.15	0.65	–0.22	0.98	–0.17	0.8	–0.12	0.93	–0.05	1.01
Range of knee flexion	57.00 p<0.001	21.2	129.9	5.2	130.7	4.2	131.0	4.2	131.7	5.37	131.5	5.41

Table 3. Comparison of the operated knee joint circumferences to the circumferences of the non-operated knee joints in the group of patients between the first and 12th week postoperatively and the results obtained for the control group.

N=108	Knee joint circumference											
	Patients n = 54								Control group n = 54			
	Operated knees 1st week of physiotherapy		Operated knees 12th week of physiotherapy		Unaffected knees 1st week of physiotherapy		Unaffected knees 12th week of physiotherapy		Left knees		Right knees	
	X	SD	X	SD	X	SD	X	SD	X	SD	X	SD
Knee joint circumference	39.4 p<0.001	2.1	37.2	1.9	37	1.8	37	1.8	36.3	1.6	36.4	1.6

middle block of the envelope outside, on the left side. Next, still running, the subject changed the running direction by 90° to the right and again performed maximal run straight, reaching the right block of the envelope, passing it at the outer side to the left. Then the subject started sideway run to the left, again covering the 5 m distance, passing the next block running sideway at the outer side. Next, after passing the block, the subject ran backwards changing the direction by 90° and running towards the starting block. After that, the subject performed the test again till the end of the run after passing the start block again and hearing "stop" command. The time of covering the distance was measured (s) with the accuracy to 0.1 s. The subjects were asked whether they felt pain, experienced the so called "giving way" of the knee, or fear prior to and during the test performance.

Statistic analysis

The distribution of the results was evaluated using Shapiro-Wilk Test. The results were presented as mean values (x) and standard deviations (SDs) using student-t test for evaluation of statistic significance. Statistic significance was accepted at the level $p<0.005$. All the calculations were made using Statistica 6 software.

Results

The patients (group I) were found to have limited ROM, which was statistically significant ($p=0.001$) for extension and flexion of the affected knees as compared to the unaffected ones (Table 2). The mean values of extension and flexion in the affected knees during the 12th week of physiotherapy were close to the results obtained for the unaffected limbs and to the values obtained for both examined legs in the control group, with no statistically significant differences (Table 2).

During the first week postoperatively, circumferences of the operated knee joints in patients were significantly greater by 2.2 cm ($p<0.001$) as compared to the results obtained for the non-operated knee joints (Table 3). During the 12th week postoperatively, the values of circumferences of the operated knee joints significantly decreased and were close to the values obtained for the unaffected limbs and in the control group.

During the 10th week of physiotherapy, as compared to the 2nd week post surgery, improvement was noted in most of the studied gait kinematic parameters, the difference being statistically significant (Table 4). Increase was noted in the mean gait velocity by over 0.7 m/s and

Table 4. Comparison of gait kinematic parameter values between the 2nd and 10th week of physiotherapy, obtained for the group of patients.

Patients (n=54)	Gait kinematic parameters	Step length in the operated limb (m)	Step length in the non-operated limb (m)	Gait velocity (m/s)	Step frequency (step/s)	Stance – operated limb (%)	Stance – unaffected limb (%)	Swing – operated limb (%)	Swing – unaffected limb (%)
2nd week of physiotherapy	X	0.3 P<0.001	0.4 P<0.001	0.6 p<0.001	1.7 p<0.001	44.6 p<0.001	69.4 p<0.01	55.4 p<0.001	30.6 p<0.05
	SD	0.5	0.1	0.1	0.2	5.6	7.2	5.6	7.2
10th week of physiotherapy	X	0.6	0.6	1.3	2.1	60.7	61.6	39.3	38.4
	SD	0.1	0.1	0.2	0.2	1.4	1.4	1.4	1.4

Table 5. Comparison of the values of selected gait kinematics parameters between the group of patients (I) during the 10th week of physiotherapy and the control group (II).

Gait kinematic parameters	Single step length (m)	Gait velocity (m/s)	Step frequency (step/s)	Stance – operated limb (%)	Swing – operated limb (%)
Control group (II)	x=0.7 p<001	x=1.2	x=1.8 p<0.001	x=59.0	x=41.0
SD	0.04	0.1	0.1	4.0	4.0
=Group I – patients 10th week of physiotherapy	x=0.6	x=1.3	X=2.1	x=60.7	x=39.3
SD	0.1	0.2	0.2	1.4	1.4

gait frequency by 0.4 steps per second. Single steps were also longer, both in the affected and unaffected legs, on average by 0.3 and 0.2 m.. The stance to swing ratio between the operated and the unaffected limbs also improved. Between the last and the first examination, prolongation of the stance phase was noted by about 16% and shortening of the swing phase in the operated leg by 16%. During the tenth week of physiotherapy, the total swing phase for the operated limbs reached the value of 60.7% and was close to the results obtained for the non-operated legs (61.6%) while the total swing phase was restored in both extremities and reached the value of 39.3–38.4%. During the physiotherapeutic procedure, 10 weeks postoperatively, the step length and stance to swing ratios for the operated extremities did not differ from the results obtained for the unaffected ones.

Table 5 presents comparison of the results of kinematic parameters measurement, obtained in the group of patients during the 10th week of physiotherapy and in the control group. The results obtained in the patients for most of the studied gait parameters were close to those obtained for the control group and the former had higher values of gait velocity by 9% and gait frequency – by 16% compared to the control group, and in consequence, significantly lower values for step length in the operated limbs – on average by 0.1 m compared to the control group.

The between group values for stance to swing ratios were similar and the difference did not exceed 2%.

Table 6 indicates that the mean values of relative torque (Nm/kg), obtained during the 13th week postoperatively in the patients were significantly lower, both for the extensor and flexor muscles as compared to the results obtained for the non-operated limbs and in the control group at the level p=0.001. During the 21st week of physiotherapy, a statistically significant increase in relative torque values for extensor and flexor muscles of the operated knees was noted, compared to the measurement results from the 13th week post surgery and the results obtained for these muscle groups of the non-operated knees. Importantly, the final test results for torque in extensor muscles of the operated knees were higher than the values obtained for the control group, yet the difference turned out statistically insignificant. Conversely, the relative torque values for flexor muscle group, were significantly higher during the 21st week as compared to those obtained for the control group.

During the test – run with maximal velocity and envelope run, the patients during the 24th week of physiotherapy obtained similar time to that of the control group; no statistically significant between group differences were noted (Table 7).

Table 6. Comparison of relative torque values (N m /kg) obtained for the extensor and flexor muscles of the operated and non-operated knees between the 13th and 21th week of physiotherapy and in the control group.

Relative PT for extensor and flexor muscles (N m / kg)	Group I – patients Operated knees		Group I – patients Non-operated knees		Group II – control group	
	13th week of physiotherapy	21st week of physiotherapy	13th week of physiotherapy	21st week of physiotherapy	Left knees	Right knees
Extensor muscles	**X=2.0** SD=0.7 P<0.001	**X=3.8** SD=0.7	**X=3.4** SD=0.7	**X=3.9** SD=0.7	**X=3.7** SD=0.5	**X=3.7** SD=0.5
Flexor muscles	**X=1.2** SD=0.3 P<0.001	**X=1.6** SD=0.3 p<0.01	**X=1.5** SD=0.4	**X=1.7** SD=0.4 p<0.01	**X=1.3** SD=0.2	**X=1.4** SD=0.3

Table 7. Comparison of the time of running with maximal velocity and changing directions between the studied groups (s).

Envelope run	Group I – patients		Group II – control group	
	X	SD	X	SD
Time (s)	**21.4**	2.2	**21.9**	2.0

Discussion

During the early period following ACL reconstruction, limited ROM was noted in the patients as well as enlargement of circumference in the operated knee joint, impairment of gait kinematic parameters as compared to the non-operated knees and to the results obtained in the control group. At the end of the second stage of physiotherapy (10–12 weeks following the reconstruction), ROM improvement was noted as well as reduction in knee circumferences in the operated legs and significant improvement in gait kinematics parameters, which resulted in prolonged single and double steps, gait velocity and significant improvement in stance phase duration and step frequency. However, during the 13th week, the PT values for extensor muscles in the operated knees were still low, amounting to 58% only of the values for the non-operated legs and 54% of the control values. This was due to the applied physiotherapeutic procedure involving mainly the exercises in closed, and next, partly open kinematic chains during the first two stages. These exercises stimulate mutual activities of large muscle groups with prevailing compressive forces applied on joints and do not allow shear forces to act on the ligament implant. It is impossible however, to mobilise the lever with resistance in open kinematic chain which provides appropriate conditions for muscle strength recovery. On the other hand, an attempt to introduce resistance exercises in open kinematic chain is not justifiable during the first two stages of the physiotherapeutic procedure due to the time necessary for the process of angiogenesis, healing of the implant into the bone and recovery of local innervation of the implant in the knee joint area, reflexive control of the joint including deep sensibility [22–24].

There are well known papers by the authors who studied gait kinematics in patients with ACL injuries using also electromyography and evaluation of muscle strength and deep sensibility [25–27]. Other studies found that patients during rehabilitation may obtain the values of surface reaction forces of about 1.2 of the body mass with preserved asymmetry index between the operated and the unaffected limb below 5% and obtain the values of gait kinematic parameters similar to the males from the control group [28,29].

During the thidr stage of physiotherapy, the patients additionally performed isolated exercises with load exerted on knee extensor muscles with 35–40% from the PT values obtained during control measurements at 70 degree shank flexion. Next, after subsequent days of training, during the patients' load adaptation, manifested by the improvement in twitch coordination (prolonged time of repeated exercises with preset torque values) the load was increased during consecutive weeks [20]. Proprioceptive exercises were also performed under dynamic conditions of movement patterns as well as trot and, gradually, envelope run. Exercises simulating movement elements for various sport disciplines, initially at low and then higher speed and gradually changed scale of difficulty. During the 16th week postoperatively, concentric exercises were performed, followed by concentric-eccentric exercises. Initially, the exercises involved extensor and flexor muscles with angular velocity of 180°/sec. in limited ROM; after adaptation to the load applied, the applied angular velocity was 120°/sec. During consecutive weeks and during the 6th month it was 60°/sec. Finally, during the 6th month of physiotherapy, the patients reached the PT values in extensor muscles of the operated knees, similar to the relative values obtained for the unaffected limbs and even higher than the values obtained in the control group. Other authors' results of the recovered PT, obtained between the 12th and 18th

month following ligament reconstruction, were similar [30]. Later, other authors noted PT deficit in extensor muscles of the operated knees at the level of 34% when tested under isokinetic conditions [31]. Some studies found that in the 12th month the PT deficit was from 8 to 10% [32].

During the fourth stage of physiotherapy, the patients were able to run with maximal acceleration and changing direction of movement. Sudden changes in direction and movement stopping result in substantial knee flexion and shank rotation against the thigh, associated with high load exerted on the knees and knee ligaments. It is of note that during the 24th week of physiotherapy, the time of running with maximal speed and changing directions in patients (the so-called envelope run) was similar to that obtained for the control group and 91% of the patients did not report pain, fear, or "giving way" of the knee. After the test and on the next day the subjects reported no pain or effusion either. Considering the above mentioned biomechanical and functional potential of the motor organ (lower limbs) the return to the previous forms of sports and recreational activity was recommended. The return to favourite motor activities motivated the patients to participate in the entire four-stage rehabilitation program.

The obtained highly positive results of this study were probably due to the correctly applied surgical technique, no complications, adjustment of the stages of the physiotherapeutic procedure to biomechanical conditions and the healing process, and tissue regeneration in systematically exercising and motivated patients who realised a six and sometimes eight month rehabilitation program.

In future, the tests evaluating envelope run or other forms of dynamic locomotion, performed in patients after ligament reconstruction, should be accompanied by assessment of motion kinematics and kinetics. The aim of such studies may be to obtain objective quantitative and qualitative information including the data on asymmetry ratios between the studied extremities [33–35]. This study may also verify the usefulness of selected exercises for programs of knee joint injury prevention and rehabilitation [34–37].

Conclusions

1. The presented four stages of physiotherapy (6-8 months) are very useful in complex physiotherapeutic procedures following ACL reconstruction and provide the young male patients an opportunity of return to the pre-injury sport and recreational activities.

2. During the first two stages of physiotherapy (about 3 months) after ACL reconstruction, the patients regained their full range of movements (ROM), baseline values of knee circumferences in the operated extremities and most of the kinematic parameters of gait which were then close to the values obtained for the unaffected knees and in the control group.

3. The recovery of relative peak torque (PT) values extensor and flexor muscles of the operated limbs compared to those obtained for the uninvolved limbs, run with maximal speed and envelope run in time close to that obtained for the control group required six months of physiotherapy.

4. The performed measurements and functional (biomechanical) tests allowed to perform objective evaluation of the physiotherapy program outcome during consecutive stages in patients after ACL reconstruction and proved helpful as a complementary evaluation tool.

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