Evaluation of gait kinematics and symmetry during the first two stages of physiotherapy after anterior cruciate ligament reconstruction

SŁAWOMIR WINIARSKI[1, 2]*, ANDRZEJ CZAMARA[1]

[1] Centre of Rehabilitation, University College of Physiotherapy, Wrocław, Poland.
[2] Department of Biomechanics, University School of Physical Education, Wrocław, Poland.

One of the primary goals of physiotherapy after anterior cruciate ligament (ACL) reconstruction is to restore of the patient's normal gait patterns. However, to date, only a limited number of studies have examined gait during physiotherapeutic procedures following ACL reconstruction. Thus, the objective of the present study was to evaluate gait kinematics and symmetry in male patients after ACL reconstruction during the first two stages of their physiotherapy programme.

Ninety-seven males, including 53 patients after primary ACL reconstruction in one limb and 44 healthy controls, participated in the study. The patients were examined using a movement analysis system during their physiotherapeutic programme (from the 2nd to the 12th week following reconstruction). Some selected parameters of gait kinematics, a dynamic range of movement in the knee joint and gait asymmetry coefficients were evaluated. During the 12th week of physiotherapy, a mean gait velocity increased by more than 0.97 m/s compared to that obtained during the 2nd week of physiotherapy. A statistically significant increase in the relative length of stance phase was observed in the involved extremity, from 36.1% to 62.7% ($P = 0.01$); the range of movement significantly improved from 25.8 degrees during the 2nd week to 63.7 degrees during the 12th week of physiotherapy. At the same time, the stance time asymmetry coefficient decreased from 68.5% to –0.4%.

We observed a significant improvement in most of the gait parameters from the 2nd to the 12th week of physiotherapy after reconstruction and also in comparison to the results obtained for the control group.

Key words: gait analysis, asymmetry, anterior cruciate ligament (ACL), reconstruction, physiotherapy assessment

1. Introduction

Gait is one of the basic and most effective ways of human locomotion involving motion of the body mass centre along a track, with the lowest possible energy expenditure [1]. It is a motive, cyclic and alternant movement of the lower limbs, accompanied by asynchronous movements of the upper limbs. The movements of the right and left body sides with individual lateralisation should be relatively symmetric in terms of time and space [2]. This form of locomotion is subject to complex control at different levels of the nervous system and is characterised by precise neuromuscular coordination [3], [4]. Numerous monographies have been dedicated to the subject of gait. Indeed, VAUGHAN et al. [5] reported in 2005 that there were over 6,500 publications and textbooks on gait analysis. The standard evaluation of gait consists of an initial subjective visual assessment and the assessment of gait components. Objective methods are in turn applied to measure the kinematic and kinetic parameters of gait [6]–[8], ground reaction force components [9]–[12], muscular activity [12], energy expenditure and other physiological parameters [13]. Gait symmetry evaluation is a separate issue as it is based on asymmetry

indices [14], [15]. Symmetry indices are used for the assessment of the degree of asymmetric behaviour by calculating the relative difference between the left and the right sides for a given parameter. Index values close to zero indicate symmetric behaviour. Symmetry indices have previously been used in several studies to determine whether asymmetries exist in parameters that describe the behaviour of the lower limbs. The parameters used in the indices have comprised vertical ground reaction forces, plantar pressure distribution, speed and stride frequencies [14], [16].

Complete tears of the anterior cruciate ligament (ACL) of the knee joint with associated clinical symptoms may lead to knee joint function disorders. The symptoms include positive results of the Lachman test and tibial translation relative to the femur and are accompanied by proprioception disorders. Patients often report the knee "giving way" while changing movement direction. Complete ACL tears with full clinical symptoms in physically active individuals are normally treated surgically. Following surgery, complex physiotherapeutic procedures are applied. Several different physiotherapeutic programmes for patients with ACL injuries have been reported [17]–[21].

The gait of individuals with ACL-deficient knees has been discussed by many authors. FERBER et al. [22], [23] investigated the mechanics of human gait after chronic ACL deficiency and subsequent repair to determine how normal gait patterns change and how patients respond to unexpected forward perturbations during gait, as compared to healthy controls. ALKJAER et al. [24] studied whether different walking patterns in healthy subjects and in copers and non-copers with deficient ACL could be quantified. LINDSTRÖM et al. [25] examined deviations in gait parameters and muscular activity patterns in the injured and healthy legs of chronic ACL-deficient subjects.

To date, only a few articles have been published detailing studies performed during the physiotherapeutic procedures for patients after ACL reconstruction. Furthermore, a limited sample size was not uncommon in these studies. HART et al. [26] performed a two-year follow-up gait evaluation (flat-ground walking and stair-descent tasks) with 18 patients after multi-ligament knee reconstruction. TIMONEY et al. [27] studied gait patterns based solely on the kinematic parameters in 10 healthy controls and 10 patients after ACL reconstruction using bone–patellar tendon–bone grafts. Comparison of this study's results with the results obtained by SCHIPPLEIN and ANDRIACCHI [28], [29] revealed a gait pattern more similar to that of healthy individuals than to the pre-

surgery pattern. BULGHERONI et al. [30] compared an ACL-deficient group (10 subjects) with 15 ACL-reconstructed subjects (17 ± 5 months after surgical intervention) and 5 normal male subjects. A study of gait kinematics and muscular activity was performed by KNOLL et al. [31] with 25 subjects. The aim of their study was to determine how kinematic parameters and electromyography data of selected muscles change as a result of ACL deficiency and following ACL reconstruction. This was also the aim of a study by DeVITA et al. [32] conducted on 25 ACL-deficient subjects prior to and 6 weeks, 4 months, 8 months and 12 months following ACL reconstructive surgery using the bone-patellar tendon-bone technique. In a subsequent study, DeVITA et al. [33] compared lower extremity joint kinematics, kinetics and energetics between individuals who underwent ACL reconstruction and an accelerated rehabilitation programme (8 subjects) and healthy individuals (22 subjects). STERGIOU et al. [34] assessed tibial rotation in ACL-deficient and ACL-reconstructed knees during walking and proposed a theoretical perspective of abnormal joint loading leading to the development of osteoarthritis.

The aim of the present study was to evaluate selected parameters of gait kinematics and symmetry in male patients after ACL reconstruction on three occasions during the first two stages of their physiotherapeutic programme.

2. Material and methods

2.1. Patients and controls

Ninety-seven males were divided into two groups. The experimental group included 53 patients with completely torn ACLs due to participating in amateur sports who had undergone endoscopic ACL reconstruction using grafts of the semitendinosus and gracilis muscles and Rigidfix stabilisation. All subjects underwent an identical physiotherapy programme. The mean age of the patients was 31.5 years (SD 9.6), the mean body height was 177.5 cm (SD 10.8) and the mean body mass was 80.6 kg (SD 13.5). The control group included 44 subjects with no history of musculoskeletal pathology. The subjects' mean age was 23.1 years (SD 9.6), their mean body height was 177.9 cm (SD 8.2) and their mean body mass was 78.4 kg (SD 6.2). The subjects in this group were physically active and in employment.

All subjects gave written consent to participate in this study. The work was approved by the Ethical Committee of the University School of Physical Education in Wrocław.

2.2. Clinical evaluation

For each patient, the operating surgeon performed a medical and diagnostic examination including the patient's subjective evaluation of stability and pain in the involved extremity. The surgeon evaluated ACL stability by means of anterior tibial translation towards the femur, the Lachman test and Pivot Shift test, and the stability of other knee structures, comparing the results to those obtained from the uninvolved extremity [35]. Following the evaluation, the patient was referred to physiotherapy.

2.3. Physiotherapeutic procedure

Stage I (from the 1st to the 5th week following ACL reconstruction). The surgery was followed by cooling procedures and continuous passive motion (CPM) on a splint within a limited range of movement, isometric exercises and learning how to walk with two crutches. The patients were also instructed on the course of the physiotherapy programme and the exercises they should perform at home. From the 5th day of the ambulatory treatment at the Rehabilitation Centre of the College of Physiotherapy in Wrocław, the following procedures were applied: cryotherapy and mobilisation of the patellofemoral joint and soft tissues of the lateral thigh. Active exercises of the shank muscles (interchangeably for the involved and uninvolved limbs) were performed as well as isometric exercises of the quadriceps and posterior muscles of the thigh. Active and resistance exercises of the gluteal and iliolumbar muscles were also performed. All the remaining muscle groups, except the anterior area of the operated knee joint, were strengthened. The strengthening exercises of the muscle groups of different body regions were performed in positions which were safe for the operated knee. The programme also included electrostimulation of quadriceps muscles and proprioceptive exercises in closed kinematic chains, in the supine position, using devices providing unstable surfaces. According to the physician's recommendation, additional physiotherapeutic procedures were performed. Furthermore, the vertical component of ground reaction forces (contact force) was measured. Based on the measuring results, exer-

cises in closed kinematic chains were performed on the MTD balance platform. The values of pressure forces were gradually increased and the CPM range of movement on a splint was extended. After full loading of the operated limb, the load was increased for the vertical component above the body mass. The patients were instructed on how to perform each gait phase and balance exercises and gradually had their gait restored. Exercises stimulating deep sensibility were performed on springboards, mattresses, specially designed machines and platforms with unstable surfaces.

Stage II (from the 6th to the 12th week following ACL reconstruction). From the 6th week of physiotherapy, the knee joint range of movement was increased. The muscular strength of knee joint flexors was also gradually increased. Active exercises and active exercises with gradual resistance of muscle groups beyond the anterior region of the knee joint and for the remaining muscle groups of different body regions were performed. Gait without crutches was coached and the normal components of different phases of movement were restored. Exercises on cycle ergometers, treadmills and steppers were introduced. Gait patterns were trained on the treadmill with changing inclination angle and while stair walking. The goal of the exercises performed on springboards and other training machines was to develop balance and neuromuscular coordination under the physiotherapist's guidance. A more detailed description of the four-stage physiotherapeutic procedure is presented elsewhere [36], [45].

2.4. Methodology

Measurements of the gait kinematic parameters were performed at the Centre of Rehabilitation and Medical Education in Wrocław. The space-time gait biomechanic parameters were recorded according to the graph presented in figure 1a. The first test (test I) was conducted between the 2nd and the 3rd week post-operatively, the second test (test II) between the 6th and the 8th week post-operatively and the third one (test III) between the 10th and the 12th week post-operatively. The results obtained for the patients were compared to the results of the control group.

Photoreflective markers (0.8-cm diameter) were placed on the subject's anatomical landmarks according to the description in figure 1b. Two digital cameras recorded movements in the direction of the laboratory *y*-axis. The recording and the measurement
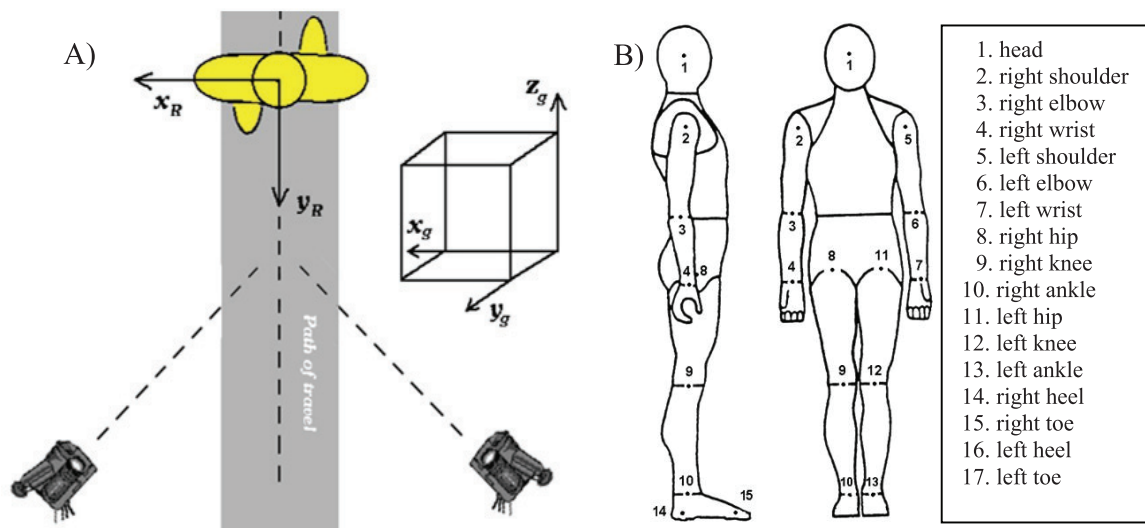
Fig. 1. Schematic representation of the movement analysis measuring system
with two digital cameras and a cube system of reference (A) and attachment sites of markers (B)

were performed with the frequency of 100 frames per second and were synchronised with the SIMI Motion computer program (Simi Reality Motion Systems GmbH, Unterschleissheim, Germany). The films were recorded in the laboratory. A $1 \times 1 \times 1$-m cube model was used for calibration as a reference system. The patients without shoes covered the 5-m distance at their own speed. This movement task involved four repetitions, beginning twice with the left and twice with the right leg, which allowed 8–10 gait cycles to be derived, depending on gait velocity. The extreme cycles (the first and the last) were not considered.

The time and space parameters of gait were derived from the recording of the picture marker trajectory. These included: (1) length of a single and double step (m), (2) mean gait velocity (m/s), (3) gait frequency (steps/s) and (4) swing and stance phase durations relative to gait cycle time for each subject's lower extremity (%GC). Based on the analysis and the recording, time characteristics of the range of movement were determined for the joints: hip, knee and tibiotalar joint for both limbs. The parameters pertaining to the changes in the knee joint were expressed by the following angular values: the angle during the first foot contact (k_{HS}), the angles of maximal flexion (k_1) and extension (k_2) during a single stance, the angle of lifting toes at the end of a stance (k_{TO}), the angle of maximal flexion during swing (k_3), the angle of maximal extension during the preparatory phase (k_4) and the range of movement in the joint (Z). These values are presented in figure 2.

Based on the results obtained, gait symmetry was studied within the range of the selected parameters, according to the asymmetry index proposed by ROBINSON et al. [37]:

$$W1 = \frac{|X_L - X_P|}{\frac{1}{2} \cdot (X_L + X_P)} \cdot 100\% . \qquad (1)$$
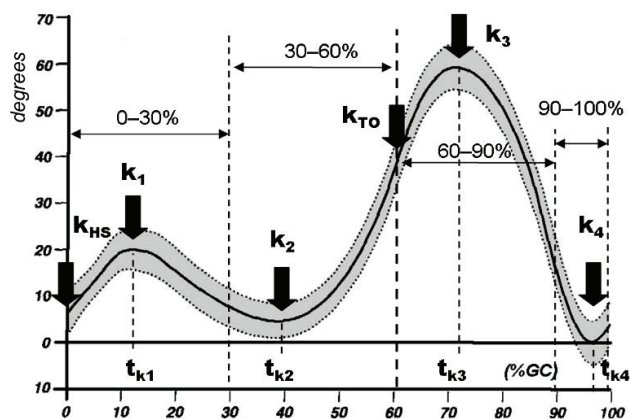

Fig. 2. Definition of the movement characteristics parameters
of the knee joint range of movement.
The graph was divided into four areas
where characteristic values were automatically searched

The asymmetry index (equation (1)) refers to directly measurable values and represents the percentage of differences between all values of X parameter, between the left and right limb (X_L, X_P) [38].

2.5. Statistical analysis

The statistical analysis was performed using the Statsoft Statistica program (Version 9). The measured parameters were analysed using the following tests: the normality of data distributions was studied using

the K–S (Kolmogorov–Smirnov) test and W (Shapiro–Wilk) test. The homogeneity of variance was studied using the L (Levene) test and its modified version F (Brown and Forsythe) test. The significance of differences between selected traits was studied using the Student's *t*-test for independent and dependent variables. ANOVA variance analysis was conducted for selected features in the test groups as well as post hoc comparison using the smallest significant differences method; repeated post hoc comparison of the detailed hypotheses was conducted to determine precisely which groups significantly differed.

3. Results

Based on the measurements of the gait kinematic parameters of patients after ACL reconstruction, it was found that between the 2nd and 3rd week postoperatively (test I), all the parameters studied significantly differed from the results obtained from tests II and III and from those obtained in the control group (table 1). Test II (performed 6–8 weeks postoperatively) revealed an improvement in most of the gait kinematic parameters, including the speed of gait, the length of a single step, gait frequency, the step length asymmetry and stance coefficients. However, the changes in the studied parameter values during test II were not as significant as during test III (performed 10–12 weeks post-operatively), which demonstrated statistically significant improvements most often at the level $P < 0.01$ as compared to the results obtained from test I. Most of the measured gait parameters obtained from test III were similar to the values of the control group (table 1). The average speed of gait increased by over 0.97 m/s as compared to test I. The length of a single step increased in both involved and uninvolved limbs by 0.46 and 0.26 m, respectively; gait frequency increased by 1.05 steps/s and this difference was statistically significant. Furthermore, a statistically significant improvement was noted in the percentage of stance phase between the operated and healthy limbs. Between tests I and III, a statistically significant lengthening of relative stance phase in the involved limbs occurred (from 36.1% to 62.7%), as well as a shortening of the relative stance phase in the uninvolved limbs by almost 11%, which was comparable with the results of the control group. There was a significant gradual decrease in the initial double stance of the operated limbs through tests I to III. It is of note that the average stance time asymme-

try coefficient was 68.5% during test I, 29.4% during test II and reached a negative value of –0.4% during test III, which did not differ significantly from the result of the control group (0.2%). The double stance asymmetry coefficient significantly changed from 89.8% during test I to 34.4 and –0.1% during test II and test III, respectively. The test III result was similar to that of the control group. Importantly, the step length asymmetry coefficient significantly changed from 36.8% during test I to 10.7% and 4.8% during test II and test III, respectively. The test results were significantly higher than the average result of the control group. It should be stressed, however, that the result obtained in patients during test III was within the normal limits of values typical of healthy knee joints.

Table 2 presents the ranges of movement in knee joints – the resultant between the knee joint maximal flexion and extension during gait (Z). During test I, the range of movement in the operated knee joints was significantly limited (25.8 degrees). Test II revealed a significant increase in the range of movement during gait (53.0 degrees), while the result of test III (63.7 degrees) was significantly higher as compared to the results of tests I and II. The result of test III was similar to that of the control group (61.9 degrees). The values of the knee angle at heal strike (k_{HS}) for both the involved and uninvolved limbs did not change significantly over the period studied. The value for the maximal flexion angle of operated limbs at the beginning of a stance phase (k_1) was significantly limited during test I, amounting to only 9.9 degrees. However, tests II and III revealed improvements (to 15.1 and 18.3 degrees, respectively), bringing the value k_1 in line with the one obtained from the control group (19.1 degrees). The average value for the maximal extension angle during a single stance (k_2) of the involved limb gradually improved during subsequent tests (8.0, 6.0 and 5.0 degrees for tests I, II and III, respectively); this improvement was statistically significant, resulting in the value k_2 similar to the one obtained from the control group (4.7 degrees). The angle at the end of a stance phase (k_{TO}) changed between tests I and III by approximately 11 degrees and was similar to the average result of the control group. The maximal flexion angle during a swing phase (k_3) was significantly limited during test I (30.0 degrees). During tests II and III, this value increased to 55.0 and 64.5 degrees, respectively, the latter value being similar to the one obtained from the control group (62.5 degrees). The maximal extension value during the preparatory phase (k_4) significantly de-

Table 1. Gait kinematic parameters for patients after ACL reconstruction,
measured on three occasions during the first two stages of their physiotherapeutic programme, and healthy controls

Parameters	ACL group (n = 53)			Control group (n = 44)
	test I (2–3 wks)	test II (6–8 wks)	test III (10–12 wks)	
Step length, involved limb (m)	0.307 ± 0.111**	0.517 ± 0.103**	0.766 ± 0.194*	0.649 ± 0.036
Step length, uninvolved limb (m)	0.442 ± 0.161**	0.633 ± 0.268**	0.705 ± 0.159	0.649 ± 0.036
Step length asymmetry coefficient (%)	36.8 ± 31.1**	10.7 ± 22.6**	4.8 ± 11.2*	0.2 ± 5.2
Relative stance, involved limb (% GC)	36.1 ± 6.7**	50.5 ± 6.6**	62.7 ± 0.7	62.5 ± 2.4
Relative stance, uninvolved limb (% GC)	72.9 ± 4.3**	67.7 ± 5.0**	62.4 ± 0.5	62.5 ± 2.4
Stance time asymmetry coefficient (%)	68.5 ± 16.9**	29.4 ± 15.6**	−0.4 ± 1.4	0.2 ± 2.5
Initial double stance, involved limb (% GC)	24.4 ± 2.8**	14.3 ± 2.7**	10.2 ± 1.6	9.9 ± 1.7
Initial double stance, uninvolved limb (% GC)	9.4 ± 2.2**	10.2 ± 2.7	10.2 ± 1.6	9.9 ± 1.7
Double stance asymmetry coefficient (%)	89.8 ± 21.5**	34.4 ± 37.6**	−0.1 ± 20.7	1.0 ± 4.5
Mean gait velocity (m/s)	0.28 ± 0.12**	0.88 ± 0.12**	1.25 ± 0.23	1.21 ± 0.15
Gait frequency (steps/s)	0.83 ± 0.47**	1.63 ± 0.26**	1.88 ± 0.46	1.87 ± 0.28

Values represent mean ± SD; * significant in adjacent groups at the level $P < 0.05$; ** significant in adjacent groups at the level $P < 0.01$.

Table 2. Ranges of movement in operated knee joint for patients after ACL reconstruction,
measured on three occasions during the first two stages of their physiotherapeutic programme, and healthy controls

Parameters [°]	ACL group (n = 53)			Control group (n = 44)
	test I (2–3 wks)	test II (6–8 wks)	test III (10–12 wks)	
k_{HS} angle	8.8 ± 2.2	8.0 ± 2.2	7.7 ± 2.1	7.8 ± 3.6
k_1 angle	9.9 ± 4.9**	15.1 ± 1.0**	18.3 ± 1.0	19.1 ± 1.9
k_2 angle	8.0 ± 2.8	6.0 ± 2.5**	5.0 ± 1.8	4.7 ± 3.1
k_{TO} angle	29.3 ± 4.4**	34.7 ± 4.3**	40.1 ± 3.5	39.3 ± 6.0
k_3 angle	30.0 ± 4.7**	55.0 ± 8.3**	64.5 ± 5.6	62.5 ± 10.5
k_4 angle	4.3 ± 1.8**	2.0 ± 1.5**	0.9 ± 1.0	1.0 ± 2.3
Range of movement	25.8 ± 5.3**	53.0 ± 8.1**	63.7 ± 5.7	61.9 ± 11.4

Values represent mean ± SD; ** significant in adjacent groups at the level $P < 0.01$.

creased between tests I and III (from 4.3 to 0.9 degrees), bringing the value k_4 in line with the one obtained from the control group (1.0 degrees).

4. Discussion

The aim of the present study was to evaluate the selected parameters of gait kinematics and the symmetry of these parameters in patients after ACL reconstruction during the first two stages of their physiotherapy. Between the 2nd and the 3rd week post-operatively (test I), gait velocity, the length of steps and the range of movement were limited and the stance phase in the operated knees was shorter. The gait of the patients at this stage was slow and asymmetric, similar to the results presented by DeVITA et al. [32], [33]. MINNING et al. [39] in their study of gait kinematics on a treadmill (with patients during the 4th week following ACL reconstruction) also noted a significant limitation regarding step length and gait velocity. It is often assumed that patients modify their gait pattern in order to keep the knee from excessive anterior translation of the tibia, reducing the amount of extension during stance [40]. In a previous study of gait kinematics [41], we found significant differences in ground reaction forces and their components between the 2nd and the 3rd week following ACL reconstruction. Several factors probably contribute to this finding, including the consequences of ACL injury and temporal effects of reconstruction which, to a small extent, exert additional stress on the operated knee joint and cause transient enlargement of its circumference limiting the range of movement [31], [40], [42], [43]. Disorders of reflex arc reaction due to the impairment of some of the surface sensibility receptors in the knee joint may be another contributing factor. Patients also experience local circulation disorders and decreased physical

activity. Importantly, ACL tear and surgical procedures result in decreased muscular strength which is restored at different times after reconstruction [21], [44], [45]. Some patients experience psychological problems manifested by an increased fear of falling and walking without crutches.

Following ACL reconstruction, the physicians attempted to decrease swelling and pain in the patients using physiotherapy combined with pharmacotherapy. A physiotherapist cooled the operated knee and the area of graft harvesting. The patients performed isometric exercises of large muscle groups of the operated and uninvolved limbs and continuous passive motion (CPM) of the operated knees on splints within a limited range of movement, which was gradually increased. The physiotherapist mobilised the patello-femoral joint and soft tissues of the lateral thigh. During each physiotherapeutic session, drainage of the popliteal bursae was carefully performed. Additionally, the patients were informed about the range and types of exercises to be performed at home. Initially, at the Rehabilitation Centre, the patients exerted load on their operated limb on the dynamometric platform, from 150 to 250 newtons (N); the load was gradually increased, depending on the patient's body mass, from 30 to 50 N every two to three days. The patients learned how to walk with crutches. Electrostimulation of extensor and flexor muscles was performed. During the following weeks, the range of movement in the operated knees was increased as well as the stress for the vertical component until full overload of the involved limbs was obtained. Balance exercises were performed in closed kinematic chains. The ranges of active exercises and active resistance exercises were extended for the muscle groups of the involved and uninvolved limbs, except the extensor muscle of the operated knee, and load was exerted on muscle groups of other regions of the body. Different types of exercises stimulating deep sensibility were applied, such as pressing a medicine ball or other soft objects with the feet, first when lying, then when seated and finally in a standing position. After the wound had healed, hydrotherapy was applied at the temperature of 35–36 °C, twice or thrice a week. Next, the patients learned how to walk without crutches. During the following weeks, the patients were instructed on how to perform each gait phase. Additionally, balance exercises were performed on an unstable surface in closed kinematic chains to improve movement coordination and deep sensibility.

During transition from the first to the second stage of the physiotherapeutic programme, tensometric platforms were used for weight-bearing training on the involved limb for the vertical component with controlled average load between 1.1 and 1.3 of the patient's body weight. Over subsequent weeks, the overload for this component was increased by 15–20% each week. It should be noted that the gait kinematic parameters measured between the 6th and the 8th week post-operatively (test II) revealed significant improvements as compared to test I. The biomechanical method applied allowed the evaluation of gait kinematics in each patient, helping the physiotherapist to adjust the procedure to the patient's individual needs. Following test II, the range of biofeedback stimulating exercises was increased with increasing weight bearing on the balancing board using a visual computer program. This allowed the patient's overload to be increased, and modification of the overload profile by the physiotherapist using the computer program enabled the patient to change body position. The increased weight bearing on one leg allowed unloading of the other one, resulting in the body mass centre's position being changed in different directions, maintaining body equilibrium. The degree of difficulty of the balance exercises was increased under static conditions and while the patients exercised on mattresses, springboards, steppers and treadmills. In order to improve physical fitness, the patients exercised on cycle ergometers and, alternately, walked on the treadmill. Individual phases and components of gait were trained, first on a hard surface and then on a soft surface, and then on both surfaces in an alternating manner. The patients learned to walk backwards, sideways and to change movement direction. They were also instructed to bend their knees during a stance phase when the foot touched the ground and to lower the gravity centre when doing this (amortisation of hitting the ground with the heel). Next, the patient curled the quadriceps muscle, which resulted in backward movement of the operated knee. At the same time, the patient had to stimulate movement of the gluteal muscles for hip joint extension in the involved extremity and also move the trunk and hips upwards and shoulders and head upwards and backwards. These movements allowed the patients to balance the dynamic forward movement of the hips. The cycle of movements was repeated in the gait sequences presented above using the involved and uninvolved limbs alternately. Next, the same algorithm of movement was performed with proprioceptive stimulation of the patient's individual muscle groups by the physiotherapist. When the patient learned the algorithm, the physiotherapist forced partial resistance of different body regions which were to move in a given sequence of gait. During the next stage, these move-

ments were performed in lower baseline positions, such as partial squats, sitting on a chair or kinesiotherapy table at different heights.

The physiotherapeutic procedure applied allowed the patients to regain most of the studied parameters of gait kinematics and symmetry on a flat surface between the 8th and the 12th week post-operatively. Statistically, the patients' gait kinematics and symmetry results between the 10th and the 12th week post-operatively and on completion of the first two stages of the physiotherapeutic programme were similar to those of the control group comprised of males of a similar age and with a similar body mass. This is in agreement with previous studies of gait under various conditions [6], [39], [41], [46]–[48]. The effectiveness of the gait assessment methods applied during the physiotherapeutic procedure has been confirmed in patients who sustained injuries of other structures of the motor organ [6], [49].

We should highlight that the present study of gait kinematics pertains mainly to the sagittal plane. Future studies will focus on the gait kinematics of patients after ACL reconstruction in different planes of movement, in particular tibial rotation towards the femur. RISTANIS et al. [50] studied the kinematics of different forms of movement, including tibial rotation, in patients two years after ACL reconstruction. TSAROUHAS et al. [51] made an initial assessment of knee rotation kinematic and kinetic parameters in patients after a single- and double-bundle ACL reconstruction. BUSH-JOSEPH et al. [52] evaluated a series of dynamic functions of movements, including kinematics and kinetics, in patients after ACL reconstruction using patellar tendon graft.

Study protocols for both genders evaluating injury risk and studies dealing with procedures aimed at ACL injury prevention may have important implications for the future [53]. Clinical findings concerning risk factors for osteoarthritis in the knee after ACL injuries are of equal importance [54].

In conclusion, we would like to emphasise that the second stage of physiotherapy is the part of the four-stage physiotherapeutic programme for patients after ACL reconstruction who want to regain a higher level of physical activity in the future (cf. [43], [45]). This requires improvement of muscular strength through an appropriate exercise protocol, including jumps, changing direction while running and changing the ground inclination angle while running. The patients also require enough time for mood improvement, graft ingrowth in the bone and adaptation of the implant within the time period necessary for safe bearing of the loads presented above.

5. Conclusions

1. During the first two stages of physiotherapy, the patients after ACL reconstruction exhibited an improvement in most of the studied parameters of gait kinematics and symmetry as compared to the results obtained from test I (performed 2–3 weeks post-operatively) and those of the control group.

2. Between the 6th and the 8th week and then between the 10th and the 12th week of physiotherapy, the patients gained significant improvements in gait velocity, step frequency and step length in the involved lower extremities as compared to the results obtained between the 2nd and the 3rd week following ACL reconstruction.

3. Significant improvements were also noted in the range of movement of the operated knees, gait symmetry indices and stance time in the involved limbs as compared to the uninvolved ones.

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