

# Stabilometric indicators as an element of verifying rehabilitation of patients before and after reconstruction of anterior cruciate ligament

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*Purpose:* The aim of the study was to evaluate effectiveness of rehabilitation in patients before and after rACL, based on stabilographic indicators. *Methods:* The research group was comprised of 31 men aged 20–57 with anterior cruciate ligament injury, qualified for reconstruction surgery. A measurement of static stabilometric indicators and muscle strength was taken twice for each patient – before surgery and after 6 months. To assess stabilographic indicators the stabilographic platform was used and to assess muscle strength a dynamometer was used. In order to assess knee function the Lysholm scale and VAS scale were used. *Results:* The rehabilitation programme improved static stability of the knee in the frontal plane, which is manifested by a significant shortening of the SPML path length. Rehabilitation proceedings should focus on improving static stability of the knee joint in the sagittal plane, because the results obtained indicate only a slight shortening of the SPAP length. The results of the Lysholm and VAS scales point to a positive influence of the applied rehabilitation. *Conclusion:* Inclusion into rehabilitation diagnostic tools to assess stabilometric indicators enables for effective verification of rehabilitation proceedings focused on restoring body posture control before and after the rACL.

*Key words:* ACL, body posture control, stabilometric indicators, muscle strength, rehabilitation

## 1. Introduction

Longer life expectancy, a significantly growing interest in physical activity and improving quality of life cause that the incidence of damage to the anterior cruciate ligament (ACL) is increasing at a rapid pace. It is estimated that only in the United States more than 120 000 cases are diagnosed annually. [12] ACL injuries cause imbalance between mobility and stability of the knee [27]. In the initial post-

traumatic period, instability of the knee is masked by knee-jerk antagonistic muscle tension and slow movements [24].

However, the increasing instability leads to recurrent episodes of subluxations, damage to the meniscus, articular cartilage and early degenerative changes [2]. For this reason, reconstruction of the ACL (rACL) has become one of the most common orthopaedic treatments. Epidemiological studies carried out by Mall et al. [15] indicate a significant increase in the number of reconstructive surgeries in recent years.

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One of the essential elements of restoring active and passive knee stability is intense and complex postoperative rehabilitation. Its task is to protect the transplant as well as to prevent repeated injury [24].

Rehabilitation also includes broadly defined re-education of gait which aims to rebuild correct movement patterns in the whole kinematic chain. Presented in literature studies concerning the results of the impact of the rehabilitation on the reconstruction of the correct pattern of locomotion in most cases are limited to the description of angular changes in the knee [10]. However, damage to the ACL also results in disruption of the anteromedial stability, which, in turn, leads to a significant deterioration of the patient's ability to maintain standing position and control the centre of gravity as well as to dysfunction of the receptors necessary for the proper functioning of joint proprioception [7]. It is also assumed that disturbed proprioception may significantly affect the occurrence of abnormalities in postural control [19]. Therefore, one of the elements of diagnosis and verification of the effectiveness of rehabilitation of patients before and after rACL should be the analysis of static stabilometric indicators which would enable the development of effective rehabilitation patterns in restoring body posture control.

The aim of the study was to evaluate effectiveness of rehabilitation in patients before and after rACL, on the basis of stabilographic indicators.

## 2. Materials and methods

### 2.1. Design

Studies were carried out in accordance with the recommendation Consolidated Standards of Reporting Trials (CONSORT) [23].

The study included 40 patients from a list of people waiting for reconstruction of anterior cruciate ligament at the Clinical Department of Orthopaedics and Rehabilitation of the University Hospital in Cracow. Qualification for the research was random (using coin: obverse – the patient took part in the study, reverse – the patient did not participate), done by the first author.

Inclusion criteria for the research were:

- the form of treatment prescribed by an attending physician – cruciate ligament reconstruction by an autogenic method – ST tendon graft,
- ability to move independently before and after the treatment (without the use of orthopaedic supports),

- lack of other injuries or illnesses which could affect the outcome of the tests (e.g., damage to the menisci, degenerative changes in the joints of the leg),
- a voluntary consent of the patient to participate in the study,
- being without medications affecting motor coordination.

Criteria excluding from the surgery and rehabilitation programme:

- too frequent absence from the arranged training sessions,
- interruption of continuity of the graft/transplant,
- failure to complete the locomotion test.

Tests were conducted at the turn of 2014 and 2015 in the Laboratory of the Diagnostics of the Motor System at the Department of Physiotherapy, University of Physical Education in Kraków.

The research project obtained approval of the Bioethics Commission at the Regional Medical Chamber in Kraków – No. 19/KBL/OIL/2014.

### 2.2. Trail registration

This study was registered in the Australian New Zealand Clinical Trials Registry (ANZCTR). Registration number: ACTRN12616001416482.

The trial was registered retrospectively because it did not include any drug or surgical intervention. Clinical trial was registered after first patient was enrolled, but it is an ongoing trial and patients are still recruited. The kind of intervention allows us to register the trial as an ongoing study after the first participant enrollment. The presented results are part of a larger research project conducted by the authors of the research. The authors confirm that all ongoing and related trials for this intervention are registered.

### 2.3. Intervention

A measurement of static stabilometric indicators and muscle strength was taken twice for each patient. The first test session took place a week before the surgery, the second one was repeated after 6 months.

After the treatment the knee was secured in a stabiliser in full extension and swelling prevention was applied. After the 10th day following the surgery patients were subjected to rehabilitation according to a uniform protocol. For the first 3 months, physiotherapy sessions were held 3 times a week, and in the period between 4th and 6th month – twice a week. Each physiotherapy session lasted for 1 hour.

Table 1. The objectives of the individual stages of physiotherapy

1–10 days after the surgery	11–21 days after the surgery	3–5 weeks after the surgery
<ul style="list-style-type: none"> <li>• pain and swelling control</li> <li>• early range of motion exercises</li> <li>• achieving and maintaining full extension of the joint</li> <li>• gait training</li> </ul>	<ul style="list-style-type: none"> <li>• full extension and flexion in the range of 100–120°</li> <li>• gradual weaning of the orthosis</li> <li>• pain and swelling control</li> <li>• proprioception training</li> </ul>	<ul style="list-style-type: none"> <li>• achieving full range of motion and at least 135° flexion until the 6th week</li> <li>• strength training</li> <li>• continuation of proprioception training</li> </ul>
6–12 weeks after the surgery	12–20 weeks after the surgery	from 6th month after the surgery
<ul style="list-style-type: none"> <li>• the range of flexion minimum 135°</li> <li>• continuation of proprioception and strength training</li> </ul>	<ul style="list-style-type: none"> <li>• Continuation of proprioception and strength training. Start of running and agility training</li> </ul>	<ul style="list-style-type: none"> <li>• a gradual return to sport activity</li> </ul>

The aim of rehabilitation was to improve the function of the knee: the range of motion, strengthening muscles in the operated limb, proprioception and coordination (Table 1).

## 2.4. Outcome measures

### Primary outcomes

#### *The stabilographic indicators*

To assess stabilographic indicators, the CQStab2P stabilographic platform was used, working in a measuring line with a PC. CQStab software was used to archive and process the results [17].

Tensometric sensors placed on the surface of the platform enabled data registration. These sensors reacted to changes in load pressure of patient's feet on the ground (patient was standing in a free position on the platform), by registering the displacement of the centre of pressure of the foot on the ground (CoP). The results of the study were archived in the form of charts of the changes in the position of the CoP (stato-kinesigrams and stabilograms).

In the analysis of the results the following indices were used:

*SP* – CoP sway path in both axes of rectangular coordinate  $yox$  [mm],

*SPAP* – CoP antero-posterior sway path length in the  $y$  axis [mm],

*SPML* – CoP medio-lateral sway path length in the  $x$  axis [mm].

Before data registration, each patient rested for 5 minutes in a sitting position. Then they stood freely, barefoot, with upper limbs placed along the body and with straight legs. During the measurement the subject had to focus attention on a graphic point in the shape of a printed black circle suspended at their eye level, within 2 metres from the platform. Next, the patient was asked to stand on one leg and bend the other limb in the knee to such extent that

touching the ground was impossible without changing the settings of the hip. During the examination the patient could not connect lower limbs, support the elevated leg on the currently examined leg. The study was carried out in silence, with natural daylight. Each measurement was taken at the same time of the day [4], [25].

During the examination four 30-second measurements were taken (2 for each limb):

- standing on the right leg with eyes open (the left leg bent in the knee),
- standing on the left leg with eyes open (the right leg bent in the knee).

#### *Measurement of the maximum muscle torque*

In order to take the measurement, a dynamometer was used, with the use of which the value of maximum muscle force ( $F_{\max}$ ) of knee extensors and flexors was measured. On the basis of the value of  $F_{\max}$  the values of maximum muscle torque ( $\tau_{\max}$ ) and relative muscle torque ( $\tau_r$ ) were calculated for selected muscles according to:

$$\tau_{\max} = F_{\max} * d \text{ [Nm]},$$

$$\tau_r = \tau_{\max}/m \text{ [Nm/kg]},$$

where:  $d$  is the value of the external force arm – the distance from the axis of joint rotation to the line of action of the dynamometer,  $m$  – weight of the subject.

Muscles were examined in isometric contraction and the study was performed in standard positions (angles between the trunk, hip and knee were at 90°). Isometric muscle force measurement and analysis program 2001 Metitur, Ltd. were used for data processing.

### Secondary outcomes

In order to assess knee function before and after the rACL, the Lysholm scale and a subjective pain assessment scale – VAS were used [3], [20].

## 2.5. Statistical analysis

Statistical analysis was developed using Statistica 10 software. Methods of descriptive statistics were used to present the results in the form of tables containing arithmetic means, standard deviation, minimum and maximum values. Methods of mathematical statistics included the *t*-Test for dependent measurements. The study adopted the level of significance  $p < 0.05$

## 3. Results

40 patients were selected for the study, 34 of whom met the inclusion criteria. 34 patients were submitted to the first test, however, 1 patient did not complete the examination on the stabilometric platform (87% follow-up). Eventually, the research group comprised a group of 31 men aged 20–57 (average age  $28.4 \pm 9.5$ ). Figure 1 shows the process of qualification for research. Characteristics of the study group is presented in Table 2.

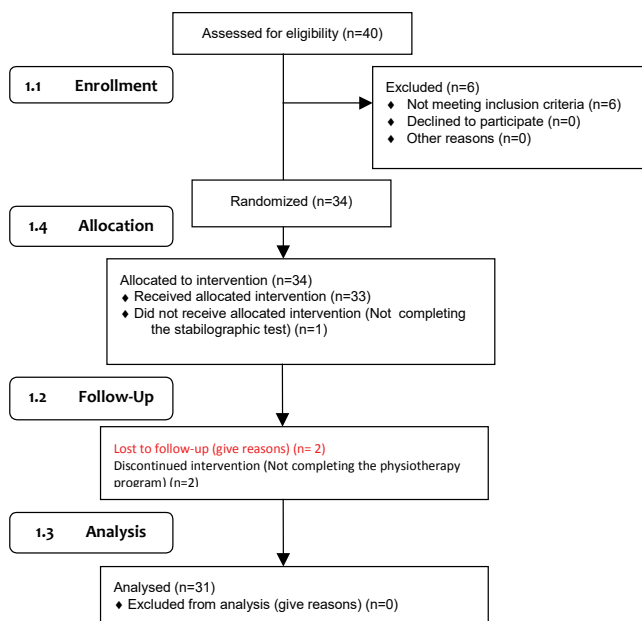


Fig. 1. CONSORT Flow Chart

Table 2. Anthropometric data of the study group

Variable	$x \pm SD$ [yrs]	Min–Max
Age	$28.4 \pm 9.5$	20–57
Height [cm]	$175.1 \pm 8.3$	169.5–193
BMI	$24.8 \pm 3.2$	19.2–31.5

### Descriptive statistics of the measurement of the statokinesiogram path length

Statistical analysis showed a significant shortening of SP and SPML path of the statokinesiogram CoP while standing one-legged on the injured limb before and after rehabilitation. Other results indicate improvement in the static stability of knee joints, but they are not statistically significant (Table 3).

Table 3. Analysis of the stabilometric variables measurement before and after rehabilitation

Variable	$x \pm SD$ [mm]	<i>p</i>
SP In 1	$1186.61 \pm 322.68$	0.000118
SP In 2	$1024.38 \pm 319.47$	
SP nIn 1	$1149.03 \pm 334.34$	0.308
SP nIn 2	$1093.80 \pm 347.95$	
SPAP In 1	$804.54 \pm 313.14$	0.104
SPAP In 2	$731.54 \pm 351.10$	
SPAP nIn 1	$778.96 \pm 337.17$	0.478
SPAP nIn 2	$744.80 \pm 394.93$	
SPML In 1	$791.77 \pm 267.34$	0.006
SPML In 2	$708.77 \pm 259.47$	
SPML nIn 1	$773.83 \pm 230.29$	0.222
SPML nIn 2	$720.45 \pm 276.31$	

SP In/nIn/II – measurement of the total path length of the statokinesiogram CoP while standing one-legged on the injured and non-injured limb before/after rehabilitation.

SPAP In/nIn/II – measurement of the path length of the statokinesiogram CoP in the direction of the *y* axis while standing one-legged on the injured and non-injured leg before/after rehabilitation.

SP In/nIn/II – measurement of the total path length of the statokinesiogram CoP in the direction of the *x* axis while standing one-legged on the injured and non-injured limb before/after rehabilitation.

nIn – non-injured limb.

In – injured limb.

After rehabilitation was reported a significant increase in muscle strength of knee extensors and flexors (Table 4).

Table 4. Analysis of the measurement of the relative muscle torques of knee extensors and flexors before and after rehabilitation

Variable	$x \pm SD$ [Nm/kg]	<i>p</i>
Ext In 1	$2.62 \pm 0.59$	0.000000
Ext In 2	$3.04 \pm 0.53$	
Flex In 1	$1.30 \pm 0.22$	0.000000
Flex In 2	$1.68 \pm 0.21$	
Ext nIn 1	$2.94 \pm 0.64$	0.000000
Ext nIn 2	$3.34 \pm 0.58$	
Flex nIn 1	$1.40 \pm 0.22$	0.000000
Flex nIn 2	$1.80 \pm 0.18$	

The Table 5 shows the results of a correlation between the results of the measurement of CoP total path length indicator with respect to both axes of rectangular coordinate system  $Y0X$  (SP) and moments of relative muscle forces of knee muscles. Correlation analysis showed no statistically significant associations between variables (Table 5).

Table 5. Analyses of correlation between the results of the measurement of the stabtokinesiogram total path length while standing one-legged on the injured and non-injured leg before and after rehabilitation and the results of relative muscle torques of knee extensors and flexors

SP I In	Ext In I	Flex In I
	<i>p</i>	<i>p</i>
	-0.255	0.093
SP II In	Ext In II	Flex In II
	<i>p</i>	<i>p</i>
	-0.280	0.309
SP I nIn	Ext In I	Flex In I
	<i>p</i>	<i>p</i>
	-0.179	0.121
SP II nIn	Ext In II	Flex In II
	<i>p</i>	<i>p</i>
	-0.163	0.198

The results indicate a significant improvement in knee function, according to the Lysholm scale and decrease in ailments, according to the VAS scale (Table 6).

Table 6. The results of the Lysholm scale and VAS before and after rehabilitation

Examination	Lysholm		VAS	
	$x \pm SD$ [pts]	<i>p</i>	$x \pm SD$ [pts]	<i>p</i>
I	$65.96 \pm 15.02$	0.001	$5.64 \pm 1.95$	0.008
II	$96.29 \pm 7.91$		$4.35 \pm 1.76$	

I/II – results of Lysholm scale and VAS scale before and after rehabilitation.

### 4. Discussion

ACL injury is one of the most common damage to motor organs which results in, i.e., decrease in physical activity of patients. The consequence of injury to the ACL is mechanical and functional knee instability which leads to imbalance of body posture during the double and single stance phase, both on the injured and non-injured limb [8]. It has been proved that a torn ACL significantly reduces knee proprioception, and thus fosters the development of degenerative changes

and imbalances. Therefore, this means loss of neuromuscular control in the biokinematic chain [1].

Most of the so far conducted studies evaluating the efficacy of rehabilitation of patients after rACL are based on functional assessment of a patient [14], [21]. Today, when a patient expects a rapid return to physical activity, the most important seems to be the analysis of effectiveness of the therapy made with advanced testing equipment which will in detail assess the objective indicators of knee stability. One of the ways of assessing the stability of the knee joint after ACL reconstruction is the analysis of stabilometric indicators by which one can determine the displacement of the centre of ground pressure of the foot (CoP), and thus estimate, i.e., static stability of body posture.

The purpose of our own study was to evaluate the effectiveness of rehabilitation in patients before and after rACL, based on stabilometric indicators.

The results of the present research indicate a significant shortening of the SP and SPML total length when standing one-legged on the injured leg, after rehabilitation. It may mean an improvement in the static stability in the frontal plane.

Also the values of muscle strength measurement improved, which could mean an increase in muscle control. An increase in static stability and muscle strength translates into a patient's better ability to maintain a standing position and keep control of the center of gravity.

Also, significantly better results of the Lysholm and VAS scales point to a positive impact of the rehabilitation.

Kocak et al. [13] conducted a study on a group of 27 patients after rACL. They analysed, among other things, static postural control indices and made functional assessment of the knee using the Lysholm scale. The study was conducted 3, 6 and 12 months after surgery, and patients were subjected to a unified rehabilitation programme. The results showed a significant improvement of the analysed indicators, which coincides with the results of our research, suggesting that including the proprioception training in combination with strength training in rehabilitation improves body posture and, thus, improves knee stability.

Parus et al. [18] conducted a study on a group of 15 people who underwent rACL along with the medial meniscus sewing. Test results showed that after 2 months after the surgery *static postural control* improved. Similar conclusions were reached by Mattacola et al. [16], and Hopper et al. [11], who found no significant differences between the results of patients after rACL and healthy subjects. These results are consistent with the results of our research.

Slightly different results were obtained by Zouita Ben Moussa et al. [28] who conducted the research with the use of stabilometric platform on a group of 26 patients after rACL. They carried postural control tests 2 years after reconstruction and compared them with the results of healthy people. According to the authors, the lack of significant improvement in the results of static postural control, compared to healthy individuals, may be due to the persistent weakness of proprioception. However, the patients qualified for the study had no unified rehabilitation programme. As the authors point out, the patients were subjected to physiotherapy treatments for a period of 8–10 weeks, but the rehabilitation programme was different for each patient. It is hard to say whether the lack of improvement in static postural control indicators results from the weakening of proprioception or rather from the differences in rehabilitation programmes.

Similar conclusions, pointing to a significant weakening of proprioception in the knee after ACL reconstruction in relation to healthy limbs, were provided by Bonfim et al. [5], [6].

Fibiger et al. [9], who assessed the effectiveness of rehabilitation after conservative treatment of the damaged ACL, believe that rehabilitation does not have such clear effect on passive joint stability, apart from slowing the appearance of degenerative changes. These conclusions were submitted on the basis of studies using an arthrometer which examines the stability of the knee while load-free and subjective feelings of the patient, therefore, it cannot be clearly determined whether the use of such research tools enables the evaluation of the static stability of the knee.

Stability of the knee joint results from several factors influencing one other, such as anatomy of a joint, body weight and loads acting on the joint. On the one hand, bone structure does not provide joint stability. However, ligaments, articular capsule and other soft tissues surrounding the joint are important in maintaining proper joint control. During physical activity, pressure forces acting on a joint (resulting from body weight and activity of muscles) protect it additionally [26].

However, in addition to these mechanical factors, joint stability is largely conditioned by the proper operation of the mechanoreceptors which, located in the articular structures (including ACL), inform the central nervous system about the changes in the position of a joint or about soft tissues tone [22].

In the case of ACL injury or after its reconstruction, the proprioceptive function can be taken over by other articular structures, but this requires appropriate training. Therefore, introducing exercises from the scope of proprioception training into rehabilitation after

damage to the ACL will enable reconstruction of the kinaesthetic function of the ligament, and, thus, help to improve the static control of body posture.

#### *Study limitation*

Extending the observation period and inclusion of a control group to the research would largely contribute to a more thorough analysis of the problem. However, gathering a uniform group of patients and conducting systematic, unified rehabilitation during which patients conscientiously perform their tasks for a period of 6 months is already a significant basis to draw reliable diagnostic conclusions.

Our research, backed up by other authors' studies, indicate the need for the continuation of the undertaken issue. A growing number of patients after rACL and their increasing expectations regarding the effectiveness of physiotherapy incline to broadly analyse rehabilitation programmes. The diagnosis should include all indicators that may contribute to increase of patient's satisfaction, but also to minimise post-operative complications. This means, among other things, increasing the emphasis on proprioception exercises. Therefore, in assessing the effectiveness using stabilometric platforms should become the standard in the diagnosis of patients before and after rACL.

## 5. Conclusions

The rehabilitation programme used in our studies improved static stability of the knee in the frontal plane, which is manifested by a significant shortening of the SPML path length.

Rehabilitation proceedings should focus on improving static stability of the knee joint in the sagittal plane, because the results obtained indicate only a slight shortening of the SPAP length.

The results of the Lysholm and VAS scales point out to a positive influence of the applied rehabilitation.

Inclusion diagnostics tools into rehabilitation to assess stabilometric indicators enables effective verification of rehabilitation proceedings focused on restoring body posture control before and after the rACL.

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