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Original research papers

THE INFLUENCE OF THERAPEUTIC TRAINING ON CHANGES IN SELECTED BIOMECHANICAL VARIABLES AFTER AN ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION

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Abstract

Introduction. The number of arthroscopic reconstructions of the anterior cruciate ligament (ACL) has been increasing not only among competitive athletes, but also among recreational athletes. The monitoring of the rehabilitation process in order to determine a safe time to return to the pre-injury activity is thus of great practical importance. The aim of this paper is to analyse the changes in selected biomechanical variables which occur after the therapeutic training following an anterior cruciate ligament reconstruction. ***Materials and methods.*** Twenty nine males (age 27.3 ± 5.7 years) after the anterior cruciate ligament reconstruction participated in the study. A quadruple-stranded semitendinosus/gracilis graft was used for the reconstruction. The biomechanical evaluation of the rehabilitation process was provided by an isokinetic dynamometer Biodex System Pro-3 working at speeds of 60 deg/s and 180 deg/s during testing the knee extensor and flexor muscles. In the case of an injured limb, the absolute peak torque, relative peak torque, average power and hamstring/quadriceps (H/Q) ratio were determined. In addition, the values of flexor and extensor torques for healthy and injured limbs were compared. The study was carried out in four stages: before the surgery, three, six and twelve months after the surgery. ***Results and analyses***. The results showed significant differences in each value between various stages of the biomechanical rehabilitation process of the knee. The applied therapeutic training influenced significantly the changes in the values of the tested variables. The results have confirmed that the biomechanical measurements can be treated as a supplementation to the clinical evaluation of the patient after ACL reconstruction. They may also be used for the optimisation of the therapeutic training.

Key words: anterior cruciate ligament, arthroscopy, therapeutic training, monitoring of rehabilitation process

Introduction

The knee joint is the largest joint in the human skeletal system. The anatomy and the considerable number of linking structures make this system prone to injuries. Depending on the studied population, they constitute 15-30% of all injuries, while among athletes this ratio increases to 33-70%. In many cases, the injuries are serious, and about 25% of them require a surgical treatment [1].

An untreated instability of the knee joint due to the anterior cruciate ligament (ACL) injury leads to a permanent dysfunction of the entire knee stabilising apparatus. Therefore, the main goal of the treatment of an unstable knee joint is to restore the coherence of the joint. This can be achieved through a surgery followed by a properly applied rehabilitation programme.

The rehabilitation scheme after ACL reconstruction is based primarily on a movement-based treatment technique. The patient performs exercises devised in various series and cycles, of varying duration and intensity. Also, the number of iterations in the series and time intervals between individual sets, as well as external loads transmitted by the muscles undergo changes in the whole process. Systematic monitoring of the rehabilitation programme and the effects of applied biomechanical measurements may result in the modification of the exercise programme [2]. The entire process of the rehabilitation after ACL reconstruction can be thus described as a therapeutic training [3, 4].

The issue of evaluation of the rehabilitation process in the context of the ability to return to the pre-injury physical activity is a priority. Therefore, it is necessary to determine when it is possible for patients with ACL injuries to restore their physical activity. For this purpose, a modified Lysholm-Gillquist test [5, 6], a joint stability test manually carried out by a doctor [7, 8] and a radiological assessment of the position of the graft and the healing process [9] are applied. Clinical tests, however, do not represent the actual functional state of limb, and thus do not provide a sufficient basis for a medical judgment as to when the patient is expected to come back to full physical activity. Supplementing clinical evaluation with biomechanical measurements allows for a more reliable determination of the time of returning to a pre-injury activity [2].

A wide range of biomechanical measurements is offered by devices enabling isokinetic testing of limb muscles. The first protocol of such measurements was defined as early as in 1967 by Hislop and Perrine [10]. The use of isokinetic measurements to quantify changes in the strength of the knee flexors and extensors during the rehabilitation following an arthroscopic ACL reconstruction is under consideration in both foreign [11, 12, 13] and domestic literature [14]. Due to the specific nature of healthcare in each country, native publications are a natural reference point for the research analysed in this paper. The already mentioned dissertation of Ciemniewska-Gorzela [14] states average values of the peak torque and relative peak torque of the knee flexors and extensors, the average power of the muscle groups and H/Q ratio measured a year or more after the surgery. The study group was not homogeneous due to the age and gender of the patients as well as the duration of the study. Another paper of Czamara on the same subject [15] presents values of the both torques in static conditions obtained 13 and 21 weeks after ACL reconstruction. The rehabilitation programme described in detail in this work is characterised by high intensity exercises, but can be carried out only in a specialised, properly equipped medical centre.

The vast majority of patients after the arthroscopic ACL reconstruction do therapeutic training, regularly monitored by a physiotherapist, on their own. The primary objective of this paper is thus to identify and analyse the changes occurring in selected biomechanical variables under the impact of such training. Another goal is to examine the effects of therapeutic training in the context of analyses of more biomechanical variables and when the measurements taken before the surgery in a homogeneous, in terms of age and gender, research group are taken into account.

Material and methods

Twenty nine men after arthroscopic ACL reconstruction surgery participated in the study. The basic anthropometric parameters of the subjects are presented in Table 1. The ACL damage occurred in the course of daily activities and recreation. At the beginning of the rehabilitation all the subjects did exercises to restore full extension in the knee joint. When the symptoms of inflammatory condition and pain vanished they were allowed by an orthopaedist to take part in the isometric strength measurements of the knee extensor and flexors. The subjects were then operated on by the same orthopaedist and in the same hospital. The arthroscopic anterior cruciate ligament reconstruction was performed using the single bundle anatomical technique. The graft was taken from the semitendinosus/gracilis tendons. Following the surgery, all patients underwent an identical protocol drawn up by the Centre for Orthopaedics and Traumatology *Arthros* in Naleczow and the co-author of this study. This programme is focused on the patient's individual work at home. The consultation with the physiotherapist consists mainly of instruction, correction of errors in the performance of motor tasks, and planning exercises to be performed by the patient.

Table 1. Basic anthropometric parameters of the study group

Age	Height	Weight (stage 1)	Weight (stage 2)	Weight (stage 3)	Weight (stage 4)
27.33±5.74	176.41±6.54	81.16±10.58	81.82±10.76	81.02±10.26	81.10±11.21

The patients were informed about the purpose of the research, and the research programme was approved by the Senate Ethics Committee of the University of Physical Education in Warsaw. Biomechanical measurements were taken on an isokinetic Biodex System 3-PRO dynamometer (Fig. 1), and divided into four stages: before the surgery, and then three, six and twelve months after the surgery. Prior to the measurements, the subjects performed a 5-minute warm-up on a cycle ergometer. Then they assumed a standard position on the chair and were stabilised with straps in a manner recommended by the manufacturer of the device [16]. The range of movement in the joint was limited to 90 degrees from the initial position of the lower leg shown in Figure 1. To assess muscle strength of the knee flexor and extensor muscles, isokinetic tests were performed at two commonly used fixed angular velocities of 60 deg/s and 180 deg/s, respectively [12, 13, 17]. The tests consisted of a series of five extending and flexing movements in the first case and 10 movements in the other one. All the measurements were carried out by the same person.

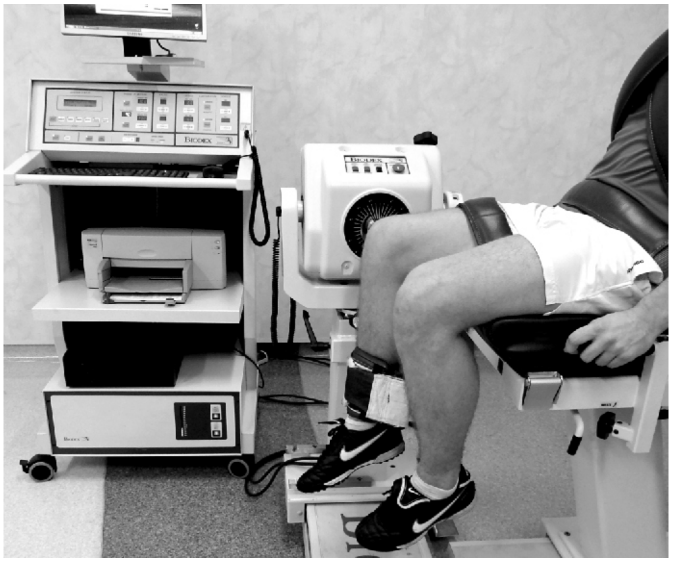

Figure 1. Measuring device and initial position of a patient

We analysed the absolute peak torque of the knee extensors M_{ke} and flexors M_{kf} (Fig. 2) and the relative peak torque of the muscles calculated as the ratio of the peak torque to the body mass m (M_{ke}/m, M_{kf}/m). We examined the average power of the extensors P_e and flexors P_f computed as the ratio of the work (represented graphically by the area under the torque curve) to the time of extending t_e and flexing t_f,. The H/Q ratio for the injured limb, and ratios of corresponding torques for the injured and uninjured extremity were also analysed. It needs to be emphasized that t_p can differ from t_z, if an extending or flexing movement of the shank does not cover the predefined range of motion. This difference is essential when analysing the results of average power calculations of both muscle groups. In the computations, the absolute values of the knee flexors torque were used.

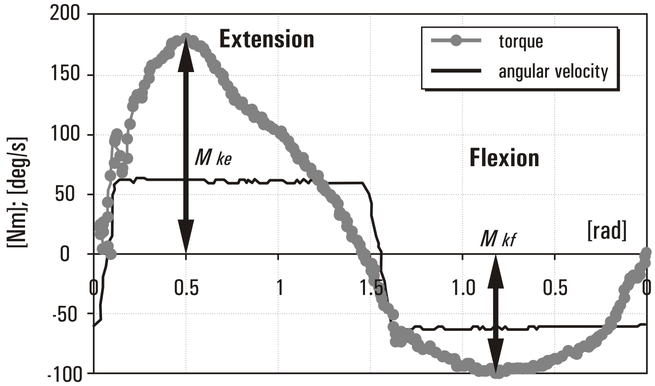

Figure 2. Exemplary course of the knee joint extensors and flexors torque at velocity of 60 deg/s

The biomechanical variables were analysed statistically to determine whether significant differences occur between them at various stages of the rehabilitation process. Firstly, the normality of the distribution and homogeneity of variance of the measured data were checked using the Shapiro-Wilk and Bartlett tests. The distributions of the data turned out to be normal and had homogeneous variances at the level of significance of $\alpha = 0{,}05$. Secondly, a one-way analysis of variance (ANOVA) with repeated measures was applied. The sphericity assumption in this approach was checked by means of Mauchly's test. If sphericity was violated, multivariate ANOVA was used, since this test does not assume sphericity. The correctness of the calculations was then verified by values of Wilks' lambda coefficient. Finally, the Tukey's test was used for a detailed interpretation of significant differences between the mean values of the tested variables.

Results

Figure 3 shows the mean peak torque of extensors and flexors at various stages of rehabilitation. Symbols E_60, E_180 and F_60 and F_180 were assigned to extensors and flexors at movement velocities of 60 deg/s and 180 deg/s. Bearing in mind the transparency of the presented graphs, on some of them we placed the exact values of the variables for the lower velocity, which is more often referenced to in the literature. Statistically significant differences were noted for E_60, F_60 and E_180 between the second and the third stage of the rehabilitation, which for the average peak extensor torque at 60 deg/s reached the level of 49,8 Nm (relative percentage difference – 49,2%). In order to avoid a too detailed interpretation of the results, we focused on differences between adjacent stages of the rehabilitation process. It can be easily seen that the difference between the second and the fourth stage is also statistically significant and larger (65,5 %) than the difference described above. For F_180 the only statistically significant difference observed was the one between the first and the fourth stage. Figure 3 shows a similar nature of torque changes in groups of flexors and extensors.

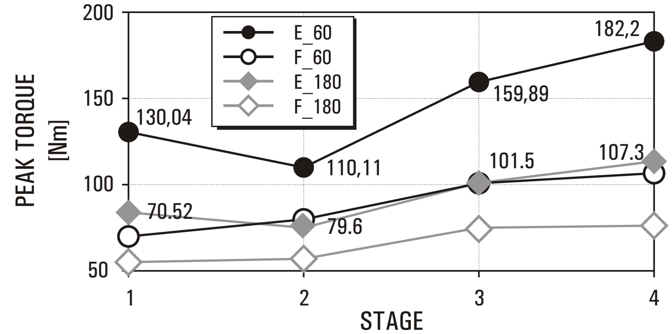

Figure 3. Average values of peak torques of the knee joint extensors and flexors in subsequent stages of rehabilitation

Average values of relative peak torques of extensors and flexors at various stages of the rehabilitation process are presented in Figure 4. The increases of these variables are subject to similar changes and have the same significant differences as those presented above, although the first one of them is slightly smaller reaching the level of 45,1%. During the calculations it turned out that the sphericity assumption was violated in the case of flexors at both angular velocities, but the multivariate test results were in line with the results of ANOVA.

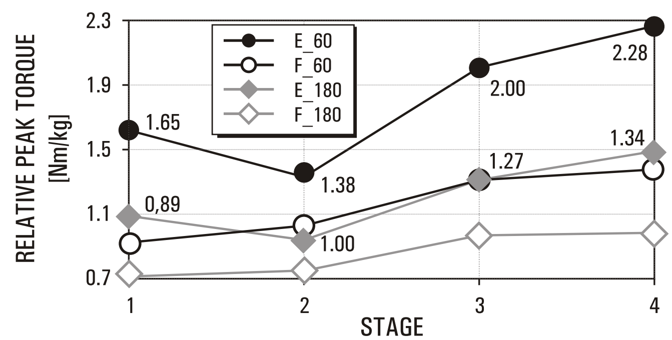

Figure 4. Average values of relative peak torques of the knee joint extensors and flexors at subsequent stages of rehabilitation

Figure 5 shows mean average power values of extensors P_e and flexors P_f at various stages of rehabilitation. The most significant differences occur between the second and the third stage. Maximum increase reached 42,2 W for extensors at angular velocity of 180 deg/s, while the largest relative percentage difference of average power (48,4%) occurred in extensors at the lower velocity. It is also noticeable that the difference between the values of average power of both muscle groups at 60 deg/s is smaller.

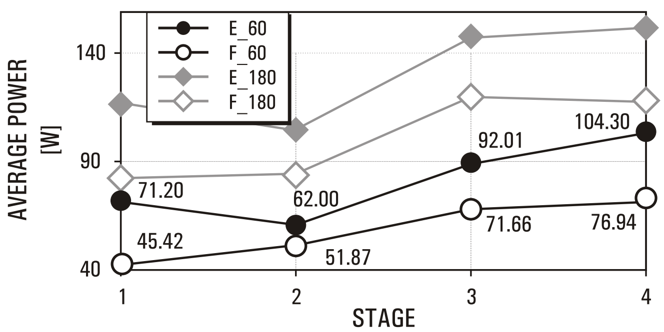

Figure 5. Mean values of average power of the knee joint extensors and flexors at subsequent stages of rehabilitation

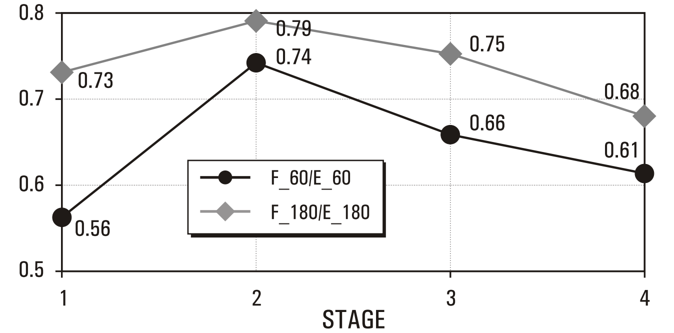

Figure 7. H/Q ratio in the injured leg at subsequent stages of rehabilitation

Figures 3 to 5 show how the variables change their values. However, a direct comparison of these changes is difficult because of different scales adopted in individual graphs. In order to determine whether each of the analysed variables equally described the dynamics of the rehabilitation process, all plots were scaled by taking the values of variables at the fourth stage as the reference points (Fig. 6). The results of the comparison revealed that the peak torque and relative peak torque described the rehabilitation progress in the same manner, but the rate of change of average power was different, particularly in the first half of the rehabilitation. This observation also applies when the angular velocity is 180 deg/s.

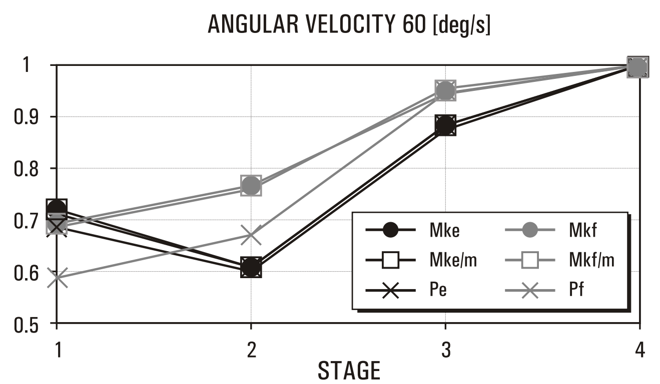

Figure 6. Rate of increase in the analysed biomechanical variables

Figure 7 presents the changes of the H/Q ratio during rehabilitation. This variable, besides peak torque and relative peak torque, is the third indicator most commonly used for the interpretation of isokinetic measurement results. Regardless of the movement velocity, one can observe a significant increase of H/Q ratio in the second stage of rehabilitation, then a linear decrease to values measured before the surgery.

The peak torques of the injured limb with respect to the corresponding torques of the uninjured extremity ratios are also subject to evolution during the rehabilitation process (Figure 8). They are minimal after the operation, and then they increase. In each of the analysed cases the injured limb did not reach the strength of the uninjured extremity within one year after the surgery. The largest strength deficit was observed for extensors at the velocity of 60 deg/s (E_60/E_60u = 0,60), and the smallest one and independent of the velocity was recorded for flexors (F_60/F_60u ≈F180/F_180u ≈0,95).

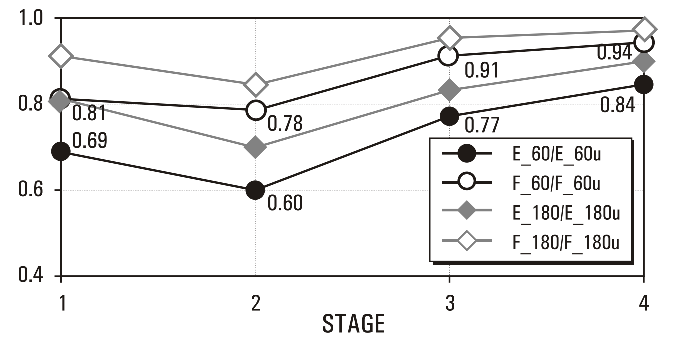

Figure 8. The ratio of the injured limb peak torques to the torques of the uninjured limb

Discussion

It is hard to avoid a fragmentary interpretation of the obtained results, as to the best of our knowledge, there are no documented results of isokinetic testing of the knee after an arthroscopic ACL reconstruction carried out in accordance with the programme described in this work. Also, only occasionally one can find studies on homogeneous groups of patients.

Some of the results obtained in our study differ from those of other researchers. For example, the values of peak torque of the knee extensors and flexors one year after surgery were 182,3 Nm and 107,3 Nm at the velocity of 60 deg/s (Fig. 3), while in the doctoral thesis of Ciemniewska-Gorzela [14] the values are 167,0 and 99,8 Nm. The heterogeneous nature of her group (7 women among 40 subjects, age range 14-57 years) and the way the peak torque was calculated in the cited dissertation have influenced the differences in the results of both studies. Analysing the content of Figure 3, one can also notice that taking graft from the flexors tissue did not decrease the strength of these muscles in the second stage of rehabilitation.

The average values of relative peak torque of the knee extensors and flexors one year after surgery were 2,28 Nm/kg and 1,34 Nm/kg (Fig. 4), whereas their counterparts described in the study [14] were 2,16 Nm/g and 1,28 Nm/kg. For the above mentioned reasons these differences are obvious. For the angular velocity of 60 deg/s, Urabe et al. [17] present the torques before the surgery as well as 3, 6, 9 and 12 months after the surgery, which corresponds to the schedule adopted in this study. The relative percentage differences between the two sets of results fall within up to 10% (flexors one year after the surgery: 1,34 Nm/kg to about 1,2 Nm/kg) to 29% (extensors after surgery: 2,28 Nm/kg to about 1,8 Nm/kg). While the presence of the differences is not surprising (24 men and 20 women, age range 16-47 years and a specific rehabilitation program for Japan), the qualitative nature of the changes in the relative peak torque values of the two tested muscle groups in both studies is similar. Assessing our values of relative peak torque one year after the surgery, they can be described as weak in the context of norms for healthy patients [16, 18]. However, the strength ability of the uninjured extremity tested during this period was qualified as average (E_60, F_60), and weak (E_180, F_180).

The mean values of the average power one year after the surgery reached the level of 104,3 W and 76,9 W for extensors and flexors at the angular velocity of 60 deg/s. These values are similar to those presented in the study [14], which are 112,7 W and 67,7 W, respectively.

In many works the values of the absolute peak torque as well as the values of relative peak torque of the knee joint flexors and extensors are presented [e.g. 14, 15]. This is probably due to the belief that the close relationship between the two variables in the case of a particular person is not retained in the statistical procedures dealing with the whole investigated population. The results obtained in this study (Figure. 6) do not confirm such an assumption but show that the analysis of one of the above mentioned variables is sufficient, both in terms of their values and the rate of their changes. In order to obtain more reliable results, additional measurements of subjects' weight before each session are necessary (Tab. 1).

The H/Q ratio depends on many factors, among which the most important is the angular velocity during the test, the patients' position during testing as well as their gender and age. The value of this ratio for a healthy limb has therefore a fairly wide range from 0,43 to 0,9 [19]. The H/Q ratio of 0,6 at 60 deg/s [19, 20], and 0,72 for the velocity of 180 deg/s [16] are usually accepted as the conventional norm. In our study, the largest value of this ratio occurred 3 months after the surgery (Fig. 7) reaching the level of 0,74 at the velocity of 60 deg/s and 0,79 at the velocity of 180 deg/s. The H/Q ratio before the surgery and one year later also exceeded the norms at the velocities of 60 deg/s and 180 deg/s, respectively. A similar value (0,61) of this ratio one year after the surgery was noted in [14]. The value of H/Q ratio three months after the surgery presented in the study of Urabe et al. [17] is largely in line with the one presented here for velocity of 180 deg/s, and different in the other cases. The largest relative percentage difference of about 22 % appears 3 months after the surgery for velocity of 60 deg/s. The high value of H/Q occurring in such circumstances is mainly due to the weakness of extensors, which was also observed by Kannus [21] in the case of the studies of the lower limb with knee joint dysfunction caused by the damage of the ACL.

The final variable analysed was the ratio of the corresponding muscle torques of the injured limb to the uninjured one. This factor is regarded to be a measure of the symmetry of muscle forces, and its value expressed in the form of relative percentage difference should not exceed ± 10% for the healthy extremities, as indicated by Michnik et al. [18]. In the case of the injured limb, the value of this indicator can be considered as a measure of the strength deficit between the uninjured and injured limb. The achieved results show that one year after surgery, the smallest coefficients of 0,84 and 0,89 belong to extensors (Fig. 8), which expressed as relative percentage differences gives 16% and 11%. Such an outcome is obvious, because on the basis of the data presented by Konishi et al. [22] the strength deficit at the velocity 60 deg/s can be estimated at about 11% for patients examined at least 18 months after surgery.

The analysis of the courses of all the variables, with the exception of those presented in Figure 7, shows the increase in their values between the third and fourth stage of the study. What happens here, is a reduction in the increase of the tested variables. This is probably due to the fact that up to the third stage of the rehabilitation the patients underwent an intensive therapeutic training. The time assigned for exercises was significantly reduced when the treatment was completed after 6 months and the patients returned to work.

The isokinetic measurements described above were an integral part of the patient's clinical evaluation consisting of ultrasonography, radiological, and manual examination as well as the Lysholm-Gillquist test. Discovering the muscle strength abilities during the rehabilitation process proved to be significant from the perspective of controlling the treatment process. The measurement results obtained at the second and third stage became a guideline for modifying the therapeutic training and allowed a quantitative assessment of the progress of the rehabilitation process. The quantitative method of assessment is becoming increasingly important, as clearly emphasized by Wychowański in his study [23].

Conclusions

The study of the impact of the therapeutic training on changes in selected biomechanical variables after anterior cruciate ligament reconstruction has led to the following conclusions:

1. The therapeutic training significantly affected changes in the analysed variables after ACL reconstruction.
2. Biomechanical measurements are a necessary supplementation to the clinical evaluation of patients.
3. The results of biomechanical measurements should be used for the optimisation of therapeutic training by means of changing loads for the knee extensors and flexors during the rehabilitation, and by a proper choice of biological renovation methods.
4. The obtained results can serve as reference data for examining patients coming from similar populations.

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Literature

1. Widuchowski J., Widuchowski W. (2004). Knee injuries and their sequelae: epidemiology, patomechanism and classification schemes. *Polish Journal of Physiotherapy* 4(4), 307-315.
2. Jarocka M., Czaplicki A. (2009). Analysis of changes in biomechanical parameters in the process of rehabilitation after arthroscopic reconstruction of the anterior cruciate ligament of the knee. In C. Urbanik, A. Mastalerz (Eds.), *Biomechanics of sport and rehabilitation - selected issues* (pp. 99-110). Warszawa: AWF. [in Polish]
3. Bator A., Kasperczyk T. (2000). *Health training with elements of physiotherapy*. Kraków: AWF. [in Polish]
4. Groffik D. (2009). *Methods of physical activity in the prevention and treatment*. Katowice: AWF. [in Polish]
5. Lysholm J., Gillquist J. (1982). Evaluation of knee ligament surgery results with special emphasis on use of scoring scale. *The American Journal of Sports Medicine* 10(3), 150-154.
6. Dzierżanowski M., Molski P., Bieńkowska A., Kaźmierczak U., Hagner W. (2006). Multi-faceted look at the development of muscle proprioceptive in the process of rehabilitation of patients after anterior cruciate ligament reconstruction (ACL). *Kwartalnik Ortopedyczny* 53(1), 18-25. [in Polish]
7. Marshall J.L., Fetto J.F., Bolero P.M. (1977). Knee ligament injuries: a standard evaluation method. *Clinical Orthopaedics and Related Research* 123(2), 115-129.
8. Walaszek R., Kasperczyk T., Magiera L. (2007). *Diagnostics in physiotherapy and massage*. Kraków: Biosport. [in Polish]
9. Kannus P., Järvinen M., Paakkala T. (1988). A radiological scoring scale for an exact evaluation of posttraumatic osteoarthritis after knee ligament injuries. *International Orthopaedics* 12(4), 291-297.
10. Hislop H.J., Perrine J.J. (1967). The isokinetic concept of exercise. *Physical Therapy*. 47(2), 114-117.
11. Hiemstra L., Weber S., MacDonald P., Kriellaars D. (2004). Hamstring and quadriceps strength balance in normal and hamstring anterior cruciate ligament-reconstructed subjects. *Clinical Journal of Sport Medicine* 14(5), 274-280.
12. Konishi Y., Ikeda K., Nishino A., Sunaga M., Aihara Y., Fukubayashi T. (2006). Relationship between quadriceps femoris muscle volume and muscle torque after anterior cruciate ligament repair. *Scandinavian Journal of Medicine & Science in Sports* 17(6), 656-661.
13. Natri A., Jarvinen M., Latvala K., Kannus P. (1996). Isokinetic muscle performance after anterior cruciate ligament surgery. *International Journal of Sports Medicine* 17(3), 223-228.
14. Ciemniewska-Gorzela K. (2010). Knee function after anterior cruciate ligament reconstruction. Doctoral thesis, Uniwersytet Medyczny, Poznań. [in Polish]
15. Czamara A.(2008). Moments of muscular strength of knee joint extensors and flexors during physiotherapeutic procedures following anterior cruciate ligament reconstruction in males. *Acta of Bioengineering and Biomechanics*10(3), 37-44.
16. *Biodex multi-joint system – 3 pro. Setup/operational manual*. Shirley, USA: Biodex Medical Systems.
17. Urabe Y., Ochi M., Orani K. (2002). Changes in isokinetic muscle strength of the lower extremity in recreational athletes with anterior cruciate ligament reconstruction. *Journal of Sport Rehabilitation* 11(4), 252-267.
18. Michnik R., Jurkojć J., Czapla K. (2012). Biomechanical evaluation of strength abilities of female volleyball players. *Modelowanie Inżynierskie* 44(2), 217-222. [in Polish]
19. Coombs R., Narbutt G. (2002). Development in the use of hamstring/quadriceps ratio for the assessment of muscle balance. *Journal of Science and Medicine in Sport* 1(3), 56-62.
20. Grygorowicz M., Kubacki J., Pilis W., Gieremek K., Rzepka R. (2010). Selected isokinetic tests in knee injury prevention. *Biology of Sport* 27(1), 47-51.
21. Kannus P. (1988). Ratio of hamstring to quadriceps femoris muscles' strength in the anterior cruciate ligament insufficient knee. Relationship to long-term recovery. *Physical Therapy in Sport* 68(6), 961-965.
22. Konishi Y., Oda T., Tsukazaki S., Kinugasa R. & Fukubayashi T. (2012). Relationship between quadriceps femoris muscle volume and muscle torque at least 18 months after anterior cruciate ligament reconstruction. *Scandinavian Journal of Medicine & Science in Sports* 22(6), 791-796.
23. Wychowański M. (2008). Some methods for assessing the dynamics of human movement. Warszawa: AWF. [in Polish]

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