

CLINICAL OUTCOMES OF TORQUE DEFICIT REDUCTION IN KNEE EXTENSORS AND FLEXORS AFTER ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION

RESULTADOS CLÍNICOS DA REDUÇÃO DO DÉFICIT DE TORQUE EM EXTENSORES E FLEXORES DO JOELHO APÓS A RECONSTRUÇÃO DO LIGAMENTO CRUZADO ANTERIOR

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Abstract: In this prospective study, we presented the effect of isokinetic training on the clinical outcome of rehabilitation in relation to the reduction of the torque deficit in thigh muscles (DEF) after anterior cruciate ligament (LCA) reconstruction. The prospective study followed 144 subjects, 72 women and 72 men, with a mean age of 28.20 ± 4.52 , four months after anterior cruciate ligament reconstruction with a hamstring graft. Subjects were divided into two groups according to the type of rehabilitation treatment they underwent. Subjects of the isokinetic group (72 subjects, 36 males and 36 females), underwent kinesitherapy according to the isokinetic exercise protocol which consisted of a one-day isokinetic training lasting for thirty minutes, five times a week for six weeks. Subjects of the classical group (72 subjects, 36 males and 36 females) underwent kinesitherapy based on standard isotonic exercises to increase muscle strength, i.e. exercises with weights and in the gym. The difference in the outcome of rehabilitation was objectified by a concentric-concentric isokinetic test at an angular velocity of 60 °/s before the start, after three weeks and after six weeks of rehabilitation. The monitoring parameters were: torque deficit of the injured leg knee extensor in relation to the uninjured leg (EXDEF) -% and torque deficit of the knee flexor of the injured leg in relation to the uninjured leg (FLDEF) -%.

Keywords: Kinesitherapy program. Isokinetic training. ACL reconstruction. Torque deficit.

Resumo: Neste estudo prospectivo, apresentamos o efeito do treinamento isocinético no resultado clínico da reabilitação em relação à redução do déficit de torque nos músculos da coxa (DEF) após a reconstrução do ligamento cruzado anterior (LCA). O estudo prospectivo acompanhou 144 indivíduos, 72 mulheres e 72 homens, com média de idade de $28,20 \pm 4,52$, quatro meses após a reconstrução do ligamento cruzado anterior com enxerto de isquiotibiais. Os indivíduos foram divididos em dois grupos de acordo com o tipo de tratamento de reabilitação que realizaram. Os sujeitos do grupo isocinético (72 sujeitos, 36 homens e 36 mulheres), foram submetidos à cinesioterapia de acordo com o protocolo de exercícios isocinéticos que consistia em um dia de treinamento isocinético com duração de trinta minutos, cinco vezes por semana, durante seis semanas. Os sujeitos do grupo clássico (72 sujeitos, 36

homens e 36 mulheres) foram submetidos à cinesioterapia baseada em exercícios isotônicos padrão para aumentar a força muscular, ou seja, exercícios com pesos e na academia. A diferença no resultado da reabilitação foi objetivada por um teste isocinético concêntrico-concêntrico com velocidade angular de $60^\circ / s$ antes do início, após três semanas e após seis semanas de reabilitação. Os parâmetros de monitoramento foram: déficit de torque do extensor do joelho da perna lesada em relação à perna não lesada (EXDEF) -% e déficit de torque do flexor do joelho da perna lesada em relação à perna não lesada (FLDEF) -%.

Palavras-chave: Programa de cinesioterapia. Treinamento isocinético. Reconstrução do LCA. Déficit de torque.

I. INTRODUCTION

Injury to the anterior cruciate ligament of the knee is one of the most common injuries in sports and recreation. (Watt at a., 2019; Deckers at al., 2019; Hewett at al., 2016). Rehabilitation is based on monitoring graft healing and restoration of thigh muscle activity. (Deckers at al., 2019; Hewett at al., 2016; Johnson at al., 2015; Snoeker at al., 2020). In any case, one of the basic goals in rehabilitation after anterior cruciate ligament reconstruction is to reduce the deficit of muscle strength of the thigh muscles of the operated leg. This research indicates the benefits of isokinetic exercise in relation to classical, i.e. isotonic, both in terms of increasing muscle performance (strength, power and total work) and in terms of faster return to physical activities and sports recreation. From the aspect of physiology of muscle contraction, the main difference in the effects of different types of therapeutic exercises is in muscle tension and shortening of muscle fibres. Isokinetic exercise allows the shortening of muscle fibres at a constant speed throughout the complete range of motion with variable resistance. The fact is that after the operation there can be either a significant weakening of muscle function even in a healthy leg, or its strengthening due to a pronounced reliance on a healthy leg to spare the operated one, which can significantly affect the fact that postoperative measurements do not give real insight into the magnitude of the strength deficit in the operated leg. (Knapik at al., 1991; Bieler at al., 2014). Since LCA reconstruction is inevitably accompanied by marked deficits in the muscle strength of the operated leg, it is clear why isokinetic tests to assess muscle function are an integral part of the procedures used in monitoring rehabilitation.

The aim of this study was to examine the clinical outcome of isokinetic exercise of the thigh muscles on the deficit of peak torque of the thigh muscles of the operated leg in relation

to the non-operated one, compared to classical (isotonic) exercise in patients after ligamentoplasty of the anterior cruciate ligament (LCA).

II. MATERIALS AND METHODS

2.1. Sample of respondents

The research was conducted at Department VII of the Institute for Physical Medicine and Rehabilitation “Dr Miroslav Zotovic”, in Banja Luka in 2020 and 2021. Prospective research followed 144 subjects, of both sexes (72 men and 72 women), with a mean age of 28.20 ± 4.53 , four months after anterior cruciate ligament reconstruction using a hamstring graft. Subjects were divided into two groups according to the type of rehabilitation treatment they underwent.

The isokinetic group consisted of 72 subjects, 36 males – aged 29.22 ± 4.61 and 36 females –aged 27.53 ± 4.26 . In addition to standard physical therapy, they performed additional strengthening of the thigh muscles according to the isokinetic exercise protocol, which consisted of a one-day isokinetic training lasting 45 minutes, five times a week for six weeks.

The classic group consisted of 72 subjects, 36 males – aged 27.78 ± 4.59 and 36 females – aged 28.28 ± 4.65 . In addition to physical therapy, they performed strengthening of the thigh muscles based on standard isotonic exercises to increase muscle strength with weights and in the gym, also 45 minutes long. Isokinetic tests and exercise in the isokinetic group were performed on a computerized dynamometer Biodex™ Multi Joint System 4 Pro (Biodex Medical System, United States of America). In the classic group, we used classic weights and exercise equipment with added controlled load to strengthen the thigh muscles – the EN Dynamic device.

2.2. Experimental protocol

The isokinetic protocol consisted of warm-up on a bicycle (5 min.), dynamic stretching (5 min.), isokinetic training on a Biodex apparatus at speed of $60 - 240^\circ / s$ in such a way that in the beginning one series and 20 repetitions were performed at higher speed, the angular velocity gradually decreased, increasing the number of series and decreasing the number of repetitions. In the end, another series of 20 – 25 repetitions were performed at the maximum

angular velocity (240 °/s), after which the subject did static stretching and thus the isokinetic training ended. The difference in the outcome of rehabilitation was objectified by a concentric-concentric isokinetic test at an angular velocity of 60 °/s before and after the completion of rehabilitation for three and six weeks.

The classic program consisted of identical warm-up and stretching, followed by the main part of the training with weights and exercise equipment with progressive and dosed load according to the standard established protocol. Both groups of subjects did not exceed 60 minutes of total training of strengthening thigh muscles. Patients were operated on at the Institute for Physical Medicine and Rehabilitation “Dr Miroslav Zotović” in Banja Luka, the anterior cruciate ligament was reconstructed using the hamstring graft method, and the same surgical team participated. At least four months have passed since the operation, five at most. They were referred by the competent doctors for rehabilitation to the Institute for Physical Medicine and Rehabilitation “Dr Miroslav Zotović” to Department VII, where they were undergoing rehabilitation. Patients with any form of cardiac and pulmonary complications (including COVID-19), people with peripheral arterial diseases, cognitive deficits, people with implants, artificial joints, people with inflammatory processes in the skin and mucous membranes, and rheumatologic patients, could not participate in the study. Special attention was paid to patients with bilateral and repeated operations of the anterior cruciate ligament, as well as any surgical procedures on knees, and such patients were necessarily excluded from the research. Here, we would especially like to point out that those patients who had any form of electro-stimulation of muscles within the standard physical therapy could not participate in the research.

The monitoring parameters were: torque deficit of the injured leg extensor in relation to the uninjured leg (EXDEF) -% and torque deficit of the flexor of the injured leg in relation to the uninjured leg (FLDEF) -%. The monitoring period lasted for six weeks. Both groups of subjects were tested by isokinetic test at the beginning of the study, i.e. before the start of the rehabilitation protocol, after three weeks, and then after six weeks of rehabilitation treatment.

Based on the results of the isokinetic test, the subjects were further divided into three subgroups according to the size of the torque deficit of thigh muscles of the operated leg in relation to non-operated one:

- / **no difference** / - those without a significant deficit (DEF ≤ 10%),

- / **rehabilitation needed** / - those who need to continue rehabilitation in the same way as before (DEF = 10 -25%) and

- / **marked functional impairment** / - those who need an additional or different rehabilitation program, i.e. have significant functional impairment (DEF \geq 25%). All tests were performed in the same way, at the same angular velocity (60 °/s) and following the same, specified parameters. The results of the research were analysed by the analytical-statistical software package SPSS, version 24, and presented in tables, using descriptive statistics and the application of adequate statistical tests.

The objective of this study is to prove the advantages of isokinetic exercise in compensating for the torque deficit of extensors and flexors of the knee operated in relation to the non-operated leg in patients four months after surgical reconstruction of the anterior cruciate ligament. In this paper, we also pointed out that the outcome of rehabilitation using isokinetic measurement should not be evaluated only by the deficit of a particular muscle of the injured leg in relation to the uninjured, but it is necessary to compare changes in total isokinetic parameters of muscle performance at all time points of measurement.

III. RESULTS

The results of the research were analysed by the analytical-statistical software package SPSS, version 24, and presented using adequate statistical tests. Friedman's test, Wilcoxon's rank test, Mann-Whitney's U test, t - test of independent samples, Kolmogorov-Smirnov test, Shapiro-Wilk's test were applied. For the level of statistical significance we used $p < 0.05$. The characteristics of the subjects in both examined groups on all three measurements according to gender are presented in Table 1.

Table 1. Characteristics of the subjects of isokinetic and classical groups according to gender.

| Variable / measurement | EXDEF | FLDEF |
|----------------------------------------------|---------------------|---------------------|
| <i>Isokinetic group</i> | | |
| male - i, median (range) | 35.6 (25.3-76.8) | 35.6 (13.4-65.1) |
| male - i, (mean \pm standard deviation) | 41.192 \pm 16.683 | 36.933 \pm 14.187 |
| female - i, median (range) | 29.15 (25.6-87.9) | 29.00 (6.4-70.1) |
| female - i, (mean \pm standard deviation) | 36.408 \pm 14.405 | 32.603 \pm 18.079 |
| male - 3w, median (range) | 10.2 (-9.4-47.1) | 12.65 (-12.1-25.7) |
| male - 3w, (mean \pm standard deviation) | 12.467 \pm 11.876 | 11.122 \pm 8.502 |
| female - 3w, median (range) | 13.4 (-8.6-74.3) | 9.6 (-18.5-42.6) |
| female - 3w, (mean \pm standard deviation) | 16.164 \pm 15.400 | 9.172 \pm 10.859 |
| male - 6w, median (range) | 1.55 (-9.4-5.6) | 6.8 (1.3-10.6) |

| | | |
|-------------------------------------------|------------------|-------------------|
| male - 6w, (mean ± standard deviation) | 1.506 ± 2.609 | 6.797 ± 2.702 |
| female - 6w , median (range) | 2.65 (-8.6-6.8) | 10.7 (3.1-31.8) |
| female - 6w, (mean ± standard deviation) | 2.411 ± 2.714 | 14.592 ± 8.873 |
| <i>Classic group</i> | | |
| male - i, median (range) | 31.4 (25.8-80.2) | 30.75 (6.24-68.9) |
| male - i, (mean ± standard deviation) | 37.447 ± 15.414 | 34.303 ± 14.476 |
| female - i, median (range) | 36.9 (25.8-87.3) | 36.35 (12.5-70.2) |
| female - i, (mean ± standard deviation) | 43.117 ± 19.171 | 35.65 ± 14.623 |
| male - 3w, median (range) | 26.7 (4.0-72.6) | 15.3 (-5.5-40.4) |
| male - 3w, (mean ± standard deviation) | 28.992 ± 18.680 | 14.578 ± 8.723 |
| female - 3w, median (range) | 19.85 (3.7-72.1) | 13.85 (1.5-50.0) |
| females - 3w, (mean ± standard deviation) | 24.603 ± 17.998 | 14.95 ± 9.819 |
| male- 6w, median (range) | 20.4 (1.0-71.2) | 10.45 (4.1-38.5) |
| male - 6w, (mean ± standard deviation) | 24.789 ± 17.588 | 14.219 ± 7.903 |
| female - 6w, median (range) | 17.35 (1.2-65.6) | 32.45 (13.1-68.4) |
| female - 6w, (mean ± standard deviation) | 20.869 ± 16.552 | 32.772 ± 13.984 |

Legend: i - initial measurement; 3w-measurement after three weeks; 6w-measurement after six weeks

3.1 Analysis of the results of change in deficit torque of knee extensors (EXDEF) by subgroups

On the measurement performed after three weeks, in all 45 patients it was recorded that there was no change in the deficit of torque of knee extensors of injured leg in relation to uninjured leg / subgroups / related to the expected - normal condition (subgroup “no difference”) did not change after six weeks (Table 2). Of the 55 patients who were diagnosed with rehabilitation after three weeks, 30 patients had an improved condition after six weeks - no difference from expectations - normal condition (subgroup “no difference”), and in 25 patients, on the measurement after six weeks, it was recorded that further rehabilitation was needed (Table 2).

Table 2. Torque deficit of knee extensors of the injured leg in relation to the uninjured leg / subgroups / on measurements after three and six weeks in both examined groups, by gender.

| Gender EXDEF-6 /difference/ | | EXDEF-3 /difference/ | | | Total |
|--------------------------------|------------------------------|----------------------|--------------------------|------------------------------------|-------|
| | | No difference | Rehabilitation needed | Marked functional impairment | |
| Male | No difference | 24 | 14 | 4 | 42 |
| | Rehabilitation needed | 0 | 11 | 5 | 16 |
| | Marked functional impairment | 0 | 0 | 14 | 14 |
| | Total | 24 | 25 | 23 | 72 |
| Female | No difference | 21 | 16 | 8 | 45 |
| | Rehabilitation needed | 0 | 14 | 3 | 17 |
| | Marked functional impairment | 0 | 0 | 10 | 10 |
| | Total | 21 | 30 | 21 | 72 |
| Total | No difference | 45 | 30 | 12 | 87 |
| | Rehabilitation needed | 0 | 25 | 8 | 33 |
| | Marked functional impairment | 0 | 0 | 24 | 24 |
| | Total | 45 | 55 | 44 | 144 |

Significant functional impairment on the measurement after three weeks was recorded in 44 patients, and on the measurement after six weeks, in 24 patients, marked functional impairment was recorded, while in 20 patients there was an improvement: in eight patients the necessary rehabilitation was recorded, and in 12 patients it was recorded that there was no difference in relation to the expected - normal condition (subgroup “no difference”) (Table 2). Table 1 shows the torque deficit of extensors of the injured leg in relation to the uninjured leg / subgroups / on measurements after three and six weeks, with the presentation by genders in the isokinetic group. Tables 2 and 3 show the results of the torque deficit of the injured leg in relation to the uninjured leg, classified into subgroups on all three measurements, shown by the examined groups (isokinetic and classical). It is evident that in all patients of the isokinetic group, the condition measured after six weeks does not differ from the desired condition (subgroup “no difference”).

In the isokinetic group in EXDEF-6 (subgroup), the subgroup “no difference” was present in all patients, so it was not examined by gender. Tables 3 and 4 show the torque deficit of the extensors of the injured leg in relation to the uninjured leg / subgroup / on measurements after three and six weeks, with the presentation by gender in the classical group.

Table 3. Torque deficit of the knee extensor of injured leg in relation to the uninjured leg / subgroups / on measurements after three and six weeks in both genders, by groups.

| Examined group EXDEF-6 /difference/ | | EXDEF-3 /difference/ | | | Total |
|----------------------------------------|------------------------------|----------------------|-----------------------|------------------------------|-------|
| | | No difference | Rehabilitation needed | Marked functional impairment | |
| Isokinetic | No difference | 32 | 28 | 12 | 72 |
| | Total | 32 | 28 | 12 | 72 |
| Classic | No difference | 13 | 2 | 0 | 15 |
| | Rehabilitation eeded | 0 | 25 | 8 | 33 |
| | Marked functional impairment | 0 | 0 | 24 | 24 |
| | Total | 13 | 27 | 32 | 72 |
| Total | No difference | 45 | 30 | 12 | 87 |
| | Rehabilitation needed | 0 | 25 | 8 | 33 |
| | Marked functional impairment | 0 | 0 | 24 | 24 |
| | Total | 45 | 55 | 44 | 144 |

Table 4. Knee extensors /subgroups/, measurements after 3 and 6 weeks, by gender: classic group.

| Gender EXDEF-6 /difference/ | | EXDEF-3 /difference/ | | | Total |
|--------------------------------|------------------------------|----------------------|-----------------------|------------------------------|-------|
| | | No difference | Rehabilitation needed | Marked functional impairment | |
| Male | No difference | 6 | 0 | 0 | 6 |
| | Rehabilitation needed | 0 | 11 | 5 | 16 |
| | Marked functional impairment | 0 | 0 | 14 | 14 |
| | Total | 6 | 11 | 19 | 36 |
| Female | No difference | 7 | 2 | 0 | 9 |
| | Rehabilitation needed | 0 | 14 | 3 | 17 |
| | Marked functional impairment | 0 | 0 | 10 | 10 |
| | Total | 7 | 16 | 13 | 36 |
| Total | No difference | 13 | 2 | 0 | 15 |
| | Rehabilitation needed | 0 | 25 | 8 | 33 |
| | Marked functional impairment | 0 | 0 | 24 | 24 |
| | Total | 13 | 27 | 32 | 72 |

3.2 Analysis of the results of the change in the knee flexor torque deficit (FLDEF) by subgroups

In 65 patients, the condition remained within the same subgroup after three and six weeks. In 36 patients the condition improved (moved to a higher subgroup), and in 43 patients,

relatively speaking, the condition worsened (moved to a lower subgroup). (Table 4.) The following are the results of the torque deficit of flexors of the injured leg on the measurements after three and after six weeks according to gender and according to the examined groups. Table 5 shows the results of the torque deficit of flexors of the injured knee by gender, and by the examined groups. Then the results are presented separately by gender.

Table 5. Torque deficit of knee flexors of the injured leg in relation to the uninjured leg; / subgroups / on the measurements after three and six weeks in both examined groups, by gender.

| Gender FLDEF-6 /difference/ | FLDEF-3 /difference/ | | | Total | |
|--------------------------------|------------------------------|-----------------------|------------------------------|-------|-----|
| | No difference | Rehabilitation needed | Marked functional impairment | | |
| Male | No difference | 21 | 25 | 1 | 47 |
| | Rehabilitation needed | 2 | 16 | 4 | 22 |
| | Marked functional impairment | 1 | 2 | 0 | 3 |
| | Total | 24 | 43 | 5 | 72 |
| Female | No difference | 9 | 4 | 0 | 13 |
| | Rehabilitation needed | 11 | 16 | 2 | 29 |
| | Marked functional impairment | 8 | 19 | 3 | 30 |
| | Total | 28 | 39 | 5 | 72 |
| Total | No difference | 30 | 29 | 1 | 60 |
| | Rehabilitation needed | 13 | 32 | 6 | 51 |
| | Marked functional impairment | 9 | 21 | 3 | 33 |
| | Total | 52 | 82 | 10 | 144 |

Tables 6 and 7 show the results of the torque deficit of flexors of the injured leg in the classical group, presented by gender and by subgroups. From these results, it can be seen that female subjects after six weeks had more transitions from a lower to a higher group than male subjects.

Table 6. Knee flexors; / subgroups /, measurements after 3 weeks and after 6 weeks, by gender: isokinetic group.

| Gender FLDEF-6 /difference/ | | FLDEF-3 /difference/ | | | Total |
|--------------------------------|------------------------------|----------------------|--------------------------|------------------------------------|-------|
| | | No difference | Rehabilitation needed | Marked functional impairment | |
| Male | No difference | 14 | 19 | 1 | 34 |
| | Rehabilitation needed | 0 | 2 | 0 | 2 |
| | Total | 14 | 21 | 1 | 36 |
| Female | No difference | 9 | 4 | 0 | 13 |
| | Rehabilitation needed | 7 | 8 | 1 | 16 |
| | Marked functional impairment | 3 | 4 | 0 | 7 |
| | Total | 19 | 16 | 1 | 36 |
| Total | No difference | 23 | 23 | 1 | 47 |
| | Rehabilitation needed | 7 | 10 | 1 | 18 |
| | Marked functional impairment | 3 | 4 | 0 | 7 |
| | Total | 33 | 37 | 2 | 72 |

Table 7. Knee flexors; /subgroups/, measurements after 3 weeks and after 6 weeks, by gender: classic group.

| Gender FLDEF-6 /difference/ | | FLDEF-3 /difference/ | | | Total |
|--------------------------------|------------------------------|----------------------|--------------------------|------------------------------------|-------|
| | | No difference | Rehabilitation needed | Marked functional impairment | |
| Male | No difference | 7 | 6 | 0 | 13 |
| | Rehabilitation needed | 2 | 14 | 4 | 20 |
| | Marked functional impairment | 1 | 2 | 0 | 3 |
| | Total | 10 | 22 | 4 | 36 |
| Female | Rehabilitation needed | 4 | 8 | 1 | 13 |
| | Marked functional impairment | 5 | 15 | 3 | 23 |
| | Total | 9 | 23 | 4 | 36 |
| Total | No difference | 7 | 6 | 0 | 13 |
| | Rehabilitation needed | 6 | 22 | 5 | 33 |
| | Marked functional impairment | 6 | 17 | 3 | 26 |
| | Total | 19 | 45 | 8 | 72 |

A statistically significant reduction in the torque deficit of extensors of the injured knee was found in relation to the uninjured one after three and six weeks of the rehabilitation process in patients of the isokinetic group. The torque deficit of flexors of the injured knee in relation to the uninjured was reduced in both examined groups, but was more significant in the

isokinetic group. In 65 patients, the condition remained within the same subgroup after three and six weeks. In 36 patients, the condition improved in terms of transition to a higher subgroup (subgroup of smaller deficit), and in 43 patients the condition, relatively speaking, worsened in terms of transition to a lower subgroup (subgroup of larger deficit). When it comes to analysis by groups, in the isokinetic group there was a significantly higher number of subjects who either remained within the same subgroup or entered the subgroup of better rehabilitation outcome (higher subgroup – subgroup of smaller deficit). There was also a difference in genders when it comes to the transition from higher to lower subgroup in female subjects of the classical group, especially in the deficit of torque of the knee flexors after six weeks of rehabilitation.

Isokinetic testing and exercise are exceptional ways of evaluating and rehabilitating patients after anterior cruciate ligament reconstruction, and when analysing isokinetic parameters, as many parameters as possible should be taken into account and not rely only on the deficit of the operated limb compared to the non-operated one.

3.3 Analysis of statistical significance of changes in parameters by subgroups on measurements after three and six weeks by examined groups

When using the χ^2 test, with probabilities 0.313, 0.382 and 0.305, respectively, a highly statistically significant difference ($\chi^2 = 56.843$, $p = 0.000$) of the knee extensor torque deficit of the injured leg was obtained in relation to the uninjured leg / subgroup / on measurements after three and six weeks. Examining the significance of the difference in the torque deficit of extensors of the injured leg in relation to the uninjured leg (%) within the isokinetic and classical group, no statistically significant difference was found between genders in the initial or measurements after three and six weeks (Table 8).

Table 8. Significance of differences in individual measurements of EXDEF and FLDEF variables in relation to gender and group of subjects.

| | Measurements | | |
|---------------------------------------|-------------------------|---------------------------------|---------------------------------|
| EXDEF | Initial | After 3 weeks | After 6 weeks |
| Isokinetic: males and females | p = 0.201 ¹⁾ | p = 0.258 ²⁾ | p = 0.066 ¹⁾ |
| Classic: males and females | p = 0.121 ¹⁾ | p = 0.230 ¹⁾ | p = 0.230 ¹⁾ |
| Males: isokinetic and classic group | p = 0.356 ¹⁾ | p = 0.000²⁾** | p = 0.000¹⁾** |
| Females: isokinetic and classic group | p = 0.082 ¹⁾ | p = 0.024¹⁾* | p = 0.000¹⁾** |
| | Measurements | | |
| FLDEF | Initial | After 3 weeks | After 6 weeks |
| Isokinetic: males and females | p = 0.197 ²⁾ | p = 0.215 ¹⁾ | p = 0.000¹⁾** |
| Classic: males and females | p = 0.778 ¹⁾ | p = 0.757 ¹⁾ | p = 0.000¹⁾** |
| Males: isokinetic and classic group | p = 0.450 ¹⁾ | p = 0.093 ²⁾ | p = 0.000¹⁾** |
| Females: isokinetic and classic group | p = 0.434 ²⁾ | p = 0.019¹⁾* | p = 0.000¹⁾** |

1) Mann-Whitney's test

2) Independent t test

A statistically significant difference ($p = 0.024$) was obtained on the measurement after three weeks of female subjects between the isokinetic and classical group of subjects. A highly statistically significant difference ($p = 0.000$) was obtained (Table 8):

- on measurement after three weeks of male subjects between isokinetic and classical group of subjects,
- on measurement after six weeks of male subjects between isokinetic and classical group of subjects,
- on measurement after six weeks of female subjects between the isokinetic and classical group.

Testing the torque deficit of the extensors of the injured leg in relation to the uninjured leg (%) of subjects in both isokinetic and classical group, using Friedman's test a highly statistically significant difference ($p = 0.000$) was obtained on initial measurement and measurements after three and six weeks for both male and female subjects. Highly statistically significant differences were obtained ($p = 0.000$) by using the Wilcoxon's test, in both male and female subjects of both isokinetic and classical group when testing the torque deficit of extensors of the injured leg in relation to the uninjured leg (%) at: initial measurement and measurement after three weeks; initial measurement and measurement after six weeks and measurement after three and after six weeks.

Examining the significance of the difference in the torque deficit of flexor of the injured leg in relation to the uninjured leg (%) within the isokinetic and classical group, no statistically significant difference was found between genders of the subjects on the initial measurement (Table 8). A statistically significant difference ($p = 0.019$) was obtained on the measurement after three weeks in female subjects between the isokinetic and classical group, while in other tests when measured after three weeks, no statistically significant difference was obtained in (Table 8). A highly statistically significant difference ($p = 0.000$) was obtained when measured after six weeks (Table 8):

- in subjects of the isokinetic group between males and females,
- in subjects of the classical group between males and females,
- in male subjects between the isokinetic and classical group of subjects,
- in female subjects between the isokinetic and classical group of subjects.

Testing the torque deficit of flexors of the injured leg in relation to the uninjured leg (%) of subjects in both isokinetic and classical group, by using Friedman's test a highly statistically significant difference ($p = 0.000$) was obtained on initial measurement and measurements after three and six weeks for both male and female subjects.

In female patients of the isokinetic group, no statistically significant difference was found in the measurements after three and six weeks, using the Wicoxon's test ($p = 0.015$), and in male patients in the classical group, no statistically significant difference was found in the measurements after three and six weeks ($p = 0.428$). In all other cases, highly statistically significant differences were obtained ($p = 0.000$ or $p = 0.002$).

IV. DISCUSSION

Dynamic asymmetry represents differences in muscle strength between opposite sides of the human body. One of the segments of dynamic asymmetry is the asymmetry in the strength of an individual limb and it is called unilateral asymmetry in which the relationships in strength between the agonist and antagonist muscles are assessed. Muscle balance of agonist and antagonist muscles is very important for stabilization of joint structure during dynamic contractions. [6] Also, a very important segment of dynamic asymmetry is bilateral imbalance, i.e. muscle imbalance in the strength of opposite sides of the body. Bilateral imbalance, i.e. imbalance between opposite sides of the body, can be caused by knee injury, leg dominance or

specific motor requirements in sports. (Newton at al., 2006; Gioftsidou at al., 2008). Isokinetic exercise is a method of muscle training in which a constant speed of movement is selected and used during active movement, whereas the resistance is automatically adjusted. Unlike isotonic exercises in which the speed is variable and the resistance is constant, in isokinetic exercise the speed of movement is constant with adaptive resistance. This way of exercising provides us with the development of maximum force during the entire range of motion with adjustment, accommodation of resistance to pain or fatigue, due to which there can be no overload of muscles and joint structures. Isokinetic exercise enables the achievement of adequate muscle strength and balance of strength between agonistic and antagonistic muscle groups, which is very important in the prevention of injuries to the muscles and ligament apparatus. (Dauty at al., 2014). In the last twenty years, there has been a significant amount of scientific work on the topic of reducing the deficit of thigh muscles of the operated leg after the reconstruction of the anterior cruciate ligament. One of the criteria for assessing the progress of rehabilitation after the reconstruction of the anterior cruciate ligament is the deficit of the strength of the quadriceps and the hamstrings of the operated leg. If rehabilitation is successful, all patients, after anterior cruciate ligament reconstruction, postoperatively achieve a normal or approximate ($DEF \leq 20\%$) thigh muscle strength ratio. Only the time of achieving this goal and the impact of the applied muscle strengthening techniques during postoperative rehabilitation are questionable. Studies show that six months after surgery, most patients, after reconstruction of the anterior cruciate ligament, achieve a normal gait pattern and the ratio of thigh muscle strength. (Leporace at al., 2013). Immediately after surgery, quadriceps hypotrophy occurs by 30% and persists until the sixth month after surgery. Quadriceps hypotrophy occurs abruptly after an anterior cruciate ligament injury and is noticeable in the early postoperative period after reconstruction. The period of the first three months is critical due to the physiology of graft healing. (Shelbourne at al., 2012). In literature, we find that the deficit of the strength of hamstrings, i.e. knee flexor of the injured leg ranges from 10-30% three months after surgery, which is similar in our study. (Thomas at al., 2016). Although the relationship between quadriceps strength and physiological mobility of the knee was controversial at one time, there is now strong evidence that strong quadriceps stabilizes the knee during walking and other more demanding physical activities, especially in sports, in patients after anterior cruciate ligament reconstruction. The strength of the quadriceps is reduced to a greater extent than the

hamstrings after the reconstruction of this ligament due to the neuromuscular imbalance caused by damage to the proprioceptive elements and the phenomenon of “quadriceps sparing” when moving. (Mayer et al., 2003). In our study, the subjects of the isokinetic group showed significantly greater progress compared to the classical group when it comes to increasing the torque of the quadriceps, as well as reducing the deficit of the torque of the quadriceps. A group of researchers published similar results. (Garcia et al., 2020; Eitzen et al., 2016) A group of authors proved in one study that the value of the torque of the quadriceps at an angular velocity of 60 °/s in the sixth month after reconstruction of the anterior cruciate ligament was statistically significantly lower than expected and that the subjects who participated in this study could not be recommended to return to sports activities. The reason may be the choice of rehabilitation protocol. (Kline et al., 2015). In this paper, we demonstrate the advantages of the isokinetic protocol as a better choice for rehabilitation.

Lee et al. analysed the effect of an intensive rehabilitation protocol lasting 12 weeks and determined by isokinetic measurement that there was no statistically significant improvement in the strength of the quadriceps three months after surgery in patients from the examined sample. This result is positively correlated with the results of our research, i.e. with our initial measurements. (Lee, Kim, Park, 2013). Researchers from Poland also demonstrated a positive effect of isokinetic exercises performed as part of a rehabilitation program in the period of 16-24 postoperative weeks, which was reflected in a statistically significant improvement in quadriceps torque at an angular velocity of 60 °/s. (Czamara et al., 2011). The knee flexors (hamstrings) protect the anterior cruciate ligament of the knee because on the one hand they reduce the anterior translation of the tibia in relation to the femur, and on the other hand they reduce the load on the ligament itself. The strength of hamstrings is related to the functioning of the knee and has a significant impact on rehabilitation after anterior cruciate ligament reconstruction. The strength of hamstrings is also important in the prevention of anterior cruciate ligament injuries. (DeFazio et al., 2020; Matsuo et al., 2020). When reconstructing the anterior cruciate ligament with a hamstrings graft (tendons of the m.semitendinosus and m.gracilis), it is expected that the hamstrings will weaken due to the choice of the graft. A group of researchers found that after taking a hamstring graft for anterior cruciate ligament reconstruction, the strength of hamstrings weakened by 17%. (Lee & Lee, 2020). We find similar results in our research on the initial measurement.

Our study showed that patients from the isokinetic group who underwent rehabilitation using the isokinetic rehabilitation protocol had significantly better values of quadriceps and hamstrings torque at an angular velocity of $60^\circ / s$ after three and six weeks of rehabilitation than patients rehabilitated by the classical rehabilitation protocol. . Confirmation of these facts is found in numerous studies because the weakness of the quadriceps after ligamentoplasty of the anterior cruciate ligament is a well-documented area. (Cristiani et al., 2019; Zwolski et al., 2015; Lieber, Silva & Daniel, 1996; Suijkerbuijk et al., 2015). We found no studies that refuted the results of this study. Karanikas et al. report that the strength and endurance of hamstrings after ligamentoplasty of the anterior cruciate ligament with the soft tissue graft of the hamstrings is in a smaller deficit compared to the quadriceps, but that they remain after one year from the operation. (Karanikas, Arampatzis & Brüggeman, 2005). In our study, we found a somewhat slower and weaker regeneration of the torque deficit of flexors of the operated knee compared to the non-operated one, which is to be expected considering that the graft was taken from the tendon of these muscles. Many authors have also confirmed this phenomenon. Choi et al. showed that patients after anterior cruciate ligament ligamentoplasty with a hamstrings graft, where the graft spot is not well regenerated, have more than four times greater deficit of hamstrings muscle strength compared to patients with well-regenerated tendons. A correlation was found between the number of regenerated tendons and the deficit functioning level. (Choi et al., 2012). Our work has addressed the effects that this regeneration leaves on the torque deficit of muscle strength, and we have obtained very similar results as many other researchers. (Takeda et al., 2006; Piussi et al., 2020; Snow et al., 2012). A group of authors reported progressive recovery of thigh muscle strength deficit after anterior cruciate ligament reconstruction. They found that 70% of the strength and endurance of thigh muscles of the operated leg was achieved in relation to the non-operated one in the first year after the ligamentoplasty of the anterior cruciate ligament. (Ko et al., 2012). Hewwet et al. conducted the largest comparative study of the difference in isokinetic strength in relation to the gender of subjects. They found that in female subjects there was no adequate response of hamstrings to an increase in the strength of quadriceps contraction during changes in flexion rate within physiological values. They expressed the opinion that the basis for the difference in the ratio of hamstring / quadriceps contractions when changing the speed of movement of the lower leg, which exists in subjects of different genders, is a consequence of different ways of development

during puberty. Thus women athletes more often and easily injure the anterior cruciate ligament. In fact, male athletes after puberty, faster and more easily increase the strength of the contraction of hamstrings with an increase in the speed of flexion of the thigh and thus have a preventive effect on possible overload of the anterior cruciate ligament. (Hewett, Myer & Zazulak, 2008).

Appreciating that long-term monitoring and evaluation of the rehabilitation course of patients after LCA reconstruction is the direction of further research, we believe that our research has confirmed these facts when it comes to rehabilitation within five months of surgery.

V. CONCLUSION

This paper confirms that isokinetic training is a very advanced method in achieving strength and compensating for muscle deficit of the operated leg in patients after LCA reconstruction compared to isotonic training, but there are certain differences in the rate of repair of hamstrings, especially in females. As already mentioned, the increase in the performance of the thigh muscles of the injured leg is accompanied by a decrease in the torque deficit of muscles (DEF), which is a part of successful rehabilitation after reconstruction of the anterior cruciate ligament (LCA). This progress should be accompanied by maintaining and increasing the level achieved. This especially refers to the restoration of the muscular activity of the injured leg, but during training we do not neglect a healthy leg, so that, if possible, as rehabilitation progresses, training an injured leg is essentially no different from training a healthy leg. If we take this fact into account, the conclusion is that the reduction of the deficit of the monitored isokinetic parameters of the injured leg is not always what we think. It is necessary to monitor all isokinetic parameters, first of all the peak torque of muscles of both legs and compare its progress, and not rely only on the deficit of the torque of muscles of the operated leg. Isokinetic training is a very advanced method in achieving muscle strength and power and compensating for the deficit of muscle strength of the operated leg in patients after LCA reconstruction compared to classical (isotonic) training, but there are certain differences in the rate of repair of hamstrings, especially in females. These would also be directions for

further research. This research also contributes to the creation of protocols in rehabilitation treatment after reconstruction of the anterior cruciate ligament.

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