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Biomechanics assessment of long term consequences of talocrural joint sprain in conservatively treated males

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The aim of the study was an assessment of isometric torque (IT) values under static conditions and relative torque (RT) for the plantar flexion muscles (PFM) and dorsal flexion muscles (DFM) and their mutual relations in males 5 years after talocrural joint sprain. IT measurements in PFM and DFM were performed using Biodex System 3. Group I consisted of 20 males on average 5 years after the sprain of the talocrural joint. Group II comprised 23 males with no history of talocrural joint injuries. The angles of measurement were: –15° of dorsiflexion (DF) and 0°, 15°, 30° and 45° for plantar flexion (PF) of the foot. In group I, the IT and RT obtained from PFM of involved leg were statistically significantly lower for most of the measured values of foot angle as compared to the contralateral joint and the results of the control group. The increase in the PF angle resulted in the decrease in IT values obtained from PFM, in favour of DFM. The IT values for PFM and DFM depend on the angle of foot and are represented by two different curves.

Key words: *dorsiflexion muscles (DFM), isometric torque (IT), plantar flexion muscles (PFM), talocrural joint*

1. Introduction

The complex construction of the foot and the talocrural joint is an interesting and important element of the human motor organ [1]–[3]. Foot and its numerous structures enable the human being contact with the ground. Thanks to muscle function and a well-organized neuromotor coordination, the talocrural joint plays an important role in body stability and actively participates in different forms of locomotion [4]–[7]. New information about the role of the talocrural joint and foot in human locomotion, including the biomechanic functions of the muscles affecting this joint, is necessary for accurate assessment of their role in normal functioning of the motor organ [8]–[13]. An answer is also sought to the question: what are the mutual relations and proportions of the studied biomechanic parameters and the level of neuromotor coordination advancement? [14], [15]. In the related literature there are no earlier study results which would definitely confirm or exclude the usefulness of isometric torque (IT) measurement under static conditions in the muscles acting in the sagittal plane for the wide range of the angle of foot positioning towards the shin in the assessment of talocrural joint injuries.

The main goal of this study was the analysis of IT values in muscles for five ranges of PF and DF angles in males, on average after five years after talocrural joint sprain (I, I/II or II degree), who had undergone conservative treatment.

The additional goal of the study was the comparison of the results obtained from the males who sustained talocrural joint injuries with the reference values obtained from the males with no injuries.

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2. Materials and methods

The study was approved by the College's Committee of Bioethics and Research. The study was carried out and financed at the College of Physiotherapy in Wrocław (Institute of Physiotherapy). Each subject was presented the goal of the study and the measurement approach to be used. The subjects signed their informed consent form to participate in the study.

2.1. Inclusion and exclusion criteria

The randomly selected 300 subjects were asked the following question: "Have you ever sustained talocrural joint injuries?" The inclusion criteria for the study were: age between 20 and 30 years, unilateral sprain of the talocrural joint (I, I/II or II degree), conservative treatment and no additional motor organ injuries. 44 subjects (15%) answered "yes". 24 subjects were excluded from the study as they did not meet the inclusion criterion (16 females and 4 males after bilateral sprain of the talocrural joint, 2 males after fibular fracture, 1 male after tibial fracture and 1 male after surgical correction of club feet – talipes equinovarus). Eventually, 20 males were selected for group I. The subjects sustained a I, I/II or II degree unilateral talocrural joint sprain five years earlier (minimum 2 years, maximum 8 years) and underwent conservative treatment, which was confirmed in the documentation of the orthopaedic examination. 23 males aged 20–30 years who volunteered for the study and did not have any injuries of the talocrural joint, as confirmed by orthopaedic examination, were selected for the study.

Table 1. Basic data of the study groups

Basic data of the study groups	Group I $n = 20$		Group II $n = 23$		p
	x	SD	x	SD	
Body height (cm)	181.00	5.93	183.52	4.42	0.125
Body mass (kg)	79.10	7.89	79.44	10.86	0.981
Age (years)	23.40	2.21	23.17	1.50	0.909

Table 1 presents basic data on the body height (cm), body mass (kg) and the subjects' age (years). No significant differences in anthropometric parameters between groups were noted. The subjects were office employees, entrepreneurs, physiotherapists and students. The anamnesis revealed occasional and unsystematic involvement in recreational physical activities after working hours.

2.2. Therapeutic procedures

Based on the anamnesis and the medical documentation it was found that in the group I the therapeutic procedure used by leading physician was as follows. Firstly, the injured joint was immobilized for 2–3 weeks with partial unloading, depending on the degree of injury. A standard pharmacotherapy was applied (antithrombotic, anti-inflammatory and analgesic treatment). On removal of the plaster cast (immobilization), the patients underwent standard ambulatory physiotherapy (near their homes) including cryotherapy, magnetic field and laser treatment for about 2 weeks. Next, they exercised from 1 to 2 weeks with a physiotherapist and at the end they were instructed how to perform exercises at home. On completion of this treatment stage, the patients did not systematically undergo subsequent stages of specialist physiotherapy [16].

2.3. IT measurement

Isometric torque (IT) measurements under static conditions of PFM and DFM were performed in both groups using Biodex System 3 from 2011 to 2012 (Fig. 1). Biodex System 3 was produced in the year 2008 and it accommodates measurement and rehabilitation facilities (Manufacturer: Biodex Medical Systems SHIRLEY, N.Y. 11967 USA. Model 333-250. Software – Biodex Advantage) [17].

Fig. 1. The measurement of IT using Biodex System 3

Prior to IT measurements, the subjects performed a 12 minute warm-up on a cycle ergometer with a constant speed of 60 revolutions per minute (rpm). The load was 50 watt (W) within the first 6 minutes. Next, without interrupting the warm up, the load was increased every 2 minutes in 5–10 W increments. The warm-up was followed by a 5 minute rest period. After the break, the IT values obtained from PFM and then from DFM were measured (in the sagittal plane) in both lower extremities. In group I, the measurements were started from the uninvolved leg. In group II, the measurements started from the right leg.

The IT measurements were performed under static conditions (isometrics) for five angles of foot positioning towards the shin. The measurements started from foot dorsiflexion (DF) for the angle 15° in the talocrural joint, next for the neutral position (NP) involving 0° flexion (foot in 90° flexion towards the shin) and next for 15°, 30° and 45° plantar flexion (PF). During the measurements, the patients assumed a supine position in the measuring chair. The measurements were taken in the sagittal plane. The knee joint was in 30° flexion and the angle of hip joint flexion was 70°.

Calibration of the measuring system, stabilization of the patient and positioning of the dynamometer as well as measurement length arm were in conformity with the methodology presented by the manufacturer [17]. The measurements comprised the range of movements (ROM) in the studied joints using Biodex System 3. The foot was placed in the same line in the sagittal plane as the shin and the thigh. The IT measurement of each position of foot flexion angle involved alternate performance of maximal isometric contractions of PFM and DFM. On the "start" command, the subject performed a maximal isometric contraction of foot muscles and ended it on the "stop" command. The duration of a single isometric contraction was minimum 6 s. Between subsequent isometric contractions there were 10 s rest intervals. After performing the measurements in one angle, there was a 90 s break and next the foot positioning angle towards the shin changed. The change was automatic and the angles of foot positioning were in accordance with the preset sequence of foot positioning, introduced into the computer. The subjects from both groups underwent the measurement in each position for each muscle group three times. The highest IT values for a given angle of foot positioning were chosen for the right and left legs. In order to exclude the effect of possible differences in body mass between the studied groups on the result of the comparison of the values obtained, the relative torque (RT) value was calculated for the maximal isometric contraction by dividing the obtained IT value by the subject's body mass (Nm/kg bm).

2.4. Statistical analysis

The mean value (x) and standard deviation (SD) were calculated for the results obtained from the biomechanical tests. The results obtained from the involved and uninvolved legs of subjects from group I were compared with the results obtained from group II. To study the distribution, the Shapiro–Wilk test was performed. The variables under study had both a normal distribution as well as the distribution showing some abnormalities. For the comparison of the dependent samples, the parametric Student-t test or the nonparametric Wilcoxon's test was used. For independent samples the parametric t-test for independent samples or the nonparametric Mann–Whitney U test was applied. The significance level was accepted as $p < 0.05$. The results were next subjected to statistical analysis using the IBM SPSS Statistics v. 19 program.

3. Results

On average five years after talocrural joint sprain, the IT values for PFM, measured in the involved legs for 4 angles (–15°, 0° 15° and 45°) of foot positioning, were significantly lower as compared to contralateral, uninvolved legs (Table 2). The highest significance level for the differences ($p < 0.001$) was noted for the 2 extreme ranges of foot positioning angle, namely for 45° of PF (deficit 34%) and 15° DF with 19% deficit (Table 2). The IT values produced by the foot muscles in DF in the involved leg were significantly lower at 45° PF (deficit at the level of 26 %) as compared to the contralateral, uninvolved legs (Table 2).

Table 3 shows that the highest IT values for PFM, obtained from group II, were noted for 15° dorsal flexion of the foot, namely $x = 163.16$ Nm and $x = 158.1$ Nm for the right and left leg, respectively. The asymmetry of the parameter studied involved a 3% difference between both legs. Subsequently, for 0° angle the IT values decreased in the right ($x = 122.12$ Nm) and left ($x = 119.66$ Nm) leg, respectively, indicating 2% asymmetry. Next, with the increase in the PF angle in both legs, IT values further decreased, even eight times at a 45° angle to $x = 22.53$ Nm and $x = 22.1$ Nm for the right and left leg respectively, as compared to the values obtained from the measurement in the 1st position of the foot. The asymmetry between both legs was 1%. Generally, in group II, no significant differences in IT values were found between the right and left leg in PFM for the same angles of foot positioning

Table 2. Comparison of IT values produced by PFM and DFM
of the involved leg and uninvolved leg in group I

IT of PFM and DFM in group I (Nm)						
The angle of foot positioning towards the shin (°) and measured muscle group	Involved leg		Uninvolved leg		*p*	Deficit (%)
	–	SD	*x*	SD		
–15° PFM	133.61	42.26	165.22	39.30	0.001	19
–15° DFM	36.02	9.95	36.77	9.11	0.741	1
0° PFM	98.07	29.17	116.59	28.96	0.003	16
0° DFM	46.50	12.49	48.51	8.99	0.492	4
15° PFM	66.29	20.93	77.17	18.10	0.037	14
15° DFM	48.25	12.44	50.51	8.13	0.794	4
30° PFM	39.49	16.18	45.22	16.95	0.071	13
30° DFM	40.78	14.75	42.52	13.50	0.904	4
45° PFM	14.30	11.90	21.76	12.82	0.001	34
45° DFM	26.01	15.35	35.35	12.47	0.046	26

Table 3. Comparison of IT values produced by PFM and DFM of the right leg and left leg in group II

IT of PFM and DFM in group II (Nm)						
The angle of foot positioning towards the shin (°) and measured muscle group	Right leg		Left leg		*p*	Deficit (%)
	x	SD	*x*	SD		
–15° PFM	163.16	39.10	158.10	41.17	0.343	3
–15° DFM	39.22	9.36	39.10	8.10	0.946	0
0° PFM	122.11	26.40	119.65	29.47	0.447	2
0° DFM	50.30	8.82	49.36	8.37	0.473	2
15° PFM	83.97	15.38	79.96	19.25	0.273	5
15° DFM	51.64	9.70	51.19	8.54	0.831	1
30° PFM	48.74	11.36	49.27	12.05	0.811	1
30° DFM	47.07	8.17	47.88	8.52	0.496	2
45° PFM	22.53	11.32	22.09	10.75	0.724	2
45° DFM	38.85	6.75	39.10	7.95	0.822	1

Table 4. Comparison of IT values of PFM and DFM of the involved leg in group I
to the values obtained from the right and left leg in group II

IT of PFM and DFM in group I and group II (Nm)								
The angle of foot positioning towards the shin (°) and measured muscle group	Group I Involved leg		Group II Right leg		*p*	Group II Left leg		*p*
	x	SD	*x*	SD		*x*	SD	
–15° PFM	133.61	42.26	163.16	39.10	0.022	158.10	41.17	0.062
–15° DFM	36.02	9.95	39.22	9.36	0.284	39.10	8.10	0.269
0° PFM	98.07	29.17	122.11	26.40	0.007	119.65	29.47	0.021
0° DFM	46.50	12.49	50.30	8.82	0.251	49.36	8.37	0.376
15° PFM	66.29	20.93	83.97	15.38	0.003	79.96	19.25	0.031
15° DFM	48.25	12.44	51.64	9.70	0.635	51.19	8.54	0.779
30° PFM	39.49	16.18	48.74	11.36	0.034	49.27	12.05	0.029
30° DFM	40.78	14.75	47.07	8.17	0.091	47.88	8.52	0.061
45° PFM	14.30	11.90	22.53	11.33	0.025	22.09	10.75	0.029
45° DFM	26.01	15.35	38.85	6.75	0.003	39.10	7.95	0.004

towards the shin and the highest level of asymmetry did not exceed 5% (Table 3). In group II, IT characteristics for DFM indicated that the highest values were three times lower than the best values obtained from PFM, both for the right and left legs. Moreover, the highest IT values for the studied muscle group were

Table 5. Comparison of the RT values obtained from PFM and DFM in group I
and the corresponding values obtained from group II

RT of PFM and DFM in group I and group II (Nm/kg bm)												
The angle of foot positioning towards the shin (°) and measured muscle group	Group I Involved leg		Group II Right leg		*p*	Deficit (%)	Group I Involved leg		Group II Left leg		*p*	Deficit (%)
	x	SD	*x*	SD			*x*	SD	*x*	SD		
–15° PFM	1.72	0.60	2.10	0.62	0.051	18	1.72	0.60	2.02	0.59	0.111	15
–15° DFM	0.45	0.12	0.49	0.11	0.314	8	0.45	0.12	0.49	0.11	0.280	8
0° PFM	1.26	0.40	1.57	0.42	0.032	20	1.26	0.40	1.53	0.43	0.028	8
0° DFM	0.59	0.15	0.63	0.08	0.240	6	0.59	0.15	0.62	0.08	0.384	5
15° PFM	0.84	0.27	1.08	0.27	0.026	21	0.84	0.27	1.02	0.28	0.050	17
15° DFM	0.61	0.15	0.65	0.07	0.669	6	0.61	0.15	0.64	0.08	0.807	6
30° PFM	0.50	0.20	0.62	0.15	0.047	18	0.50	0.20	0.62	0.16	0.098	19
30° DFM	0.52	0.18	0.59	0.05	0.077	12	0.52	0.18	0.60	0.07	0.066	13
45° PFM	0.18	0.14	0.28	0.14	0.024	36	0.18	0.14	0.27	0.13	0.027	36
45° DFM	0.33	0.19	0.48	0.04	0.001	33	0.33	0.19	0.49	0.07	0.001	33

also obtained for other angles of foot positioning, namely for 0° and 15° PF. The lowest values were noted for 15° DF and 45° PF. The level of IT asymmetry between the right and the left leg (maximum 2%) was statistically insignificant (Table 3).

The IT values produced by PFM in group I were significantly lower for all five measured angles of foot positioning as compared to the values obtained from the right leg in group II and the four angle ranges obtained from the left leg in group II (Table 4). Moreover, the IT values obtained from DFM of the involved leg were significantly lower at 45° PF as compared to group II results.

In group I, the RT values obtained from PFM were lower for the 4 studied angles of foot positioning (0°, 15°, 30° and 45°) as compared to the right foot and for the 3 angle ranges as compared to the left talocrural joint in group II (Table 5). The DFM of the involved talocrural joint obtained significantly lower IT values as compared to those obtained from the right and left talocrural joint in group II at 45° PF. Table 5 also presents the percentage values of RT deficit level for PFM and DFM. In group I, 8% to 36% deficit for PMF and 5% to 33% deficit in DFM were noted in the involved talocrural joints for different values of foot positioning angle as compared to the values obtained from the same muscle groups affecting the right and left talocrural joints in group II. In the involved legs the greatest deficits were noted for both muscle groups at 45° PF (Table 5).

4. Discussion

Monitoring of the treatment of talocrural joint injuries is carried out by an orthopaedist [1], [3]. The clinical anamnesis and physical examination is most often complemented by a functional assessment of the patients. One of the components of functional assessment is the analysis of muscle strength.

The study involved biomechanical comparative assessment of IT and RT in the muscles affecting the talocrural joint in the sagittal plane, under static conditions (isometrics) in males with the history of talocrural joint sprain (I, I/II and II degree), sustained on average five years prior to the study; the latter subjects had also undergone conservative treatment. In this group, the IT values obtained from the two muscle groups were significantly lower in involved leg compared to uninvolved leg, especially for the borderline values of foot positioning angle in plantar flexion (PF) and dorsiflexion (DF) (Fig. 2a). For PFM, significant IT deficits were noted for 4 of 5 ranges of the measurement angle as compared to the corresponding values obtained from the uninvolved legs in the same males. It was particularly visible for 45° PF angle where the deficit was 34% and for 15° DF angle where the deficit was 19%. Significantly lower IT values for DFM were noted in the involved leg at 45° PF angle (26% deficit) as compared to the uninvolved leg.

A group of males with no history of talocrural joint injury were also studied. The results obtained from this group revealed essential information about the IT and RT values produced by the muscle groups under study and were used as model, reference values. The IT values obtained from PFM and DFM separately changed from 15° dorsiflexion to 45° PF and formed 2 different curves (Fig. 2b). PFM produced the highest IT values at –15° of DF and were three times as high as the IT produced by DFM. The increase in the values of PF resulted in a decrease in IT for PFM in favour

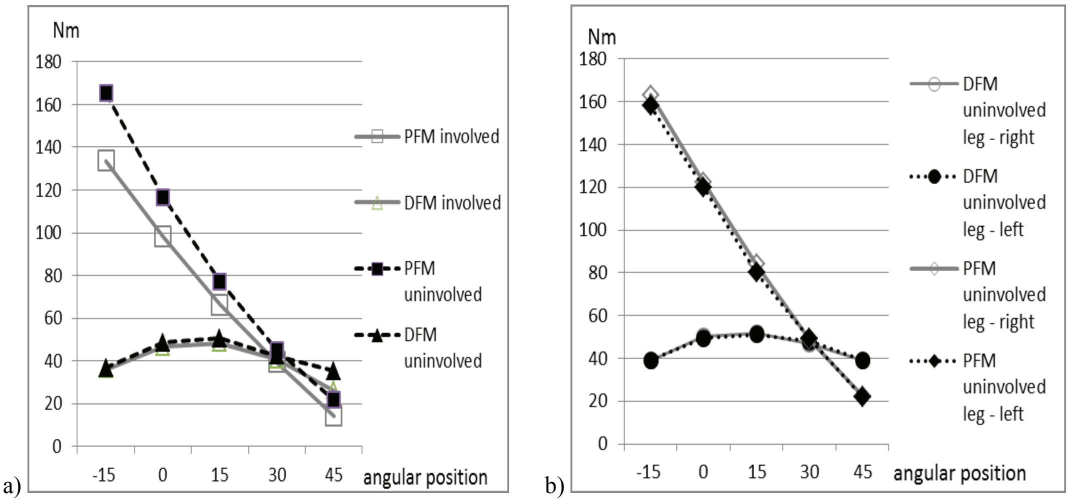

Fig. 2. IT values of PFM and DFM depending on the angle of foot positioning towards the shin in group I (a) and group II (b)

of IT increase for DFM. IT balance between PFM and DFM was obtained at 30° of PF angle. For 45° PF angle the lowest IT values were found for both muscle groups, however, apparently in favour of the DFM. The level of asymmetry in the IT values obtained separately for each muscle group between the right and the left side did not exceed 5%.

Similarly, the analysis of RT values in group I showed the same trend of deficits of IT converted into kg of body mass in the involved talocrural joints for the muscle groups presented above.

Probably the main reason for such a large deficit in IT and RT in group I was the short and incomplete physiotherapeutic procedure. The anamnesis and the analysis of patients' documentation indicated that most of the subjects in group I did not undergo the 3rd and 4th stages of physiotherapy program [16]. Most of them did not undergo kinesiotherapy based on functional training and did not perform systematic proprioceptive exercises at different levels of difficulty, joint stabilization exercises and the neighboring kinematic chains. Most of them did not perform exercises aimed at direct muscle strength recovery in the muscle groups being studied. Subsequent factors that might have affected the results obtained after basic treatment included low physical activity level at work and occasional involvement in recreational physical activity within the average 5 year period after talocrural joint injury.

Based on the results obtained we can assume that the biomechanical tests conducted are useful in distant evaluation of deficits in IT values obtained from the studied muscle groups at the side of talocrural joint sprain.

Generally, in the literature there are no papers assessing the usefulness of IT value measurement in shin muscles affecting the foot after talocrural joint sprain under static conditions (isometrics). Peak torque (PT) values are most often measured under isokinetic conditions in the muscles affecting the talocrural joint in the sagittal plane and evertor and invertor muscles of the foot for a given angular velocity. Isokinetic measurements are carried out under condition of open and closed kinematic chain during concentric, eccentric and concentric-eccentric exercises and the other way round [18]. Isokinetic exercises resemble natural everyday human activities performed at work and in sports. Isokinetic tests, carried out in concentric conditions provide us with information about the submaximal torque produced depending on the preset angular velocity. Collado et al. (2010), in their isokinetic tests, obtained better PT values from foot evertor muscles in patients who underwent rehabilitation with extended eccentric training as compared to the patients who underwent concentric training [9]. Kamiński et al. (2003) performed PT measurements in evertor (E) and invertor (I) muscles prior to and after different six-week trainings. They did not note any significant effect or any significant differences in PT and E/I ratio in the studied groups of muscles between the group involved in strength training and the group involved in strength training combined with proprioception [19]. Goharpey et al. (2007) in isokinetic tests, during eccentric exercises (angular velocities of 60°/s and 120°/s) showed that PT measurements, normalized for the body mass were more useful in assessment of PT deficits in foot invertor muscles in patients with chronic functional instability of the talocrural joint as compared with the standard PT measurement under concentric and eccentric conditions [11]. Hadzic et al. (2009) showed that too high PT values, produced by PFM in isokinetic conditions and a disturbed ratio to DFM with limited foot dorsiflexion significantly increase the risk of further talocrural joint injuries [20]. Möller et al. (2002) compared the results of isokinetic measurements for PFM and DFM in patients with the history of Achilles tendon injuries, who had undergone conservative and surgical treatment. Concentric and eccentric tests were carried out at two angular velocities. The studies carried out after 6, 12 and 24 months generally did not show any differences in PT values between the study groups. However, after 2 years they still noted significant deficits in PT of the PFM (from over 12% to about 27%) when they compared the results obtained from the involved and uninvolved legs [21].

Studies carried out in static conditions (maximal isometric contraction) allow essential information to be obtained about the evoked isometric torque (IT) of the studied muscle groups for different angles in the joint. Adequate organization of such studies, stabilization of the patient as well as adequately selected ranges of joint angles depending on the clinical case, qualify this kind of measurements as safe with a small measurement error. Moreover, such studies are most often less expensive. They were combined with electrophysiological measurements for the comparison of the results obtained from younger and older patients [22], [23]. Such tests make it possible to obtain information on IT behaviour for a defined value of angle in the joint under condition of an isolated measurement. However, using a proper equipment enables simultaneous measurement of the parameters studied for several large groups of muscles affecting two or more joints [24], [25]. On the other hand, 2 or 3 attempts of IT measurement for each of the several ranges of values of the angle in the joint, separately for each muscle group in the right and left leg are time consuming, which makes the measurements less attractive under static conditions. Also errors in EMG records are possible during the tests of isometric muscle contractions [26]. However, as far as physiological conditionings of muscles are concerned, it should be emphasized that they perform alternate body stabilizing functions (isometric contractions) and dynamic functions, namely locomotion, thanks to the changes in their contractility and specialized neuromuscular coordination. Therefore, 2 kinds of tests should be conducted in due time in patients with the history of motor organ injuries and 2 kinds of training restoring the strength in weakened muscles should be applied in the process of rehabilitation, adequately to the clinical condition, in order to restore reciprocal biomechanical characteristics, both quantitative and qualitative ones.

This thesis can be carefully confirmed (due to the studied different muscle groups and other clinical cases) by the results of the study of the knee joint after anterior cruciate ligament (ACLR) reconstruction. Czamara (2008) showed that the patients systematically involved in physiotherapy obtained IT values from the extensor and flexor muscles of the involved leg similar to those obtained from the uninvolved leg in the 6th month after ACLR [27]. Similarly, Czamara et al. (2011) showed that similar IT values could be obtained from the involved and uninvolved leg in another group of patients after ACLR. However, the isokinetic study, carried out in this sample for the same muscle groups showed at the end of the 6th month significant PT deficits in some patients from the operated knees for the angular velocity of 60°/s [28]. In a subsequent study, Czamara et al. (2011) compared the IT values responsible for internal and external tibial rotation in ACLR patients during the 6th month of systematic physiotherapy as compared to the patients who did not undergo systematic physiotherapy after 12 months from the injury. The study showed a higher effectiveness of IT measurements (under static conditions) as compared to isokinetic measurements [29]. Based on the cited reports, we can assume that restoring strength parameters under static conditions and speed-strength parameters under dynamic conditions in the muscle groups studied is not simultaneous and it is not characterized by one level of the restored IT values for both conditions.

The future measurements should be carried out both under static and isokinetic conditions. Obtaining new information about biomechanical parameters in the studied muscle groups may add new values to complex assessment of treatment results in patients with the history of talocrural joint injuries [3], [9], [30]–[34].

5. Conclusions

1. In males averagely five years from the talocrural joint sprain significant deficits in isometric torque values obtained from the studied muscle groups were noted, particularly in the muscles responsible for plantar flexion, as compared to the results obtained from the contralateral joint and those obtained from the males with no history of talocrural joint injuries.

2. The highest deficit in isometric torque values obtained from both muscle groups under study as compared to the results obtained from the contralateral joint was noted at a 45° plantar flexion.

3. The highest isometric torque values were obtained from plantar flexors in foot dorsiflexion and with the increase in plantar flexion angle they decreased in favour of dorsal flexors.

4. In the group of males with no history of talocrural joint injury the isometric torque values obtained from the studied muscle groups are characterized by a low level of asymmetry in the comparison between the right and the left leg.

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