Acta of Bioengineering and Biomechanics
Vol. 23, No. 4, 2021

Original paper
DOI: 10.37190/ABB-01918-2021-03

Changes in postural stability on balance platform in patients after meniscal repair – two years follow up

KINGA ŻMIJEWSKA[1, 2]*, ALICJA FĄFARA[3, 4], JAROSŁAW FELUŚ[5], MAGDALENA MIKOS[1, 2], JOLANTA NAWARA[6], ARTUR GĄDEK[1, 2]

[1] Department of Orthopedics and Physiotherapy, Jagiellonian University Medical College, Kraków, Poland.
[2] Trauma and Orthopaedics Clinical Department, University Hospital, Kraków, Poland.
[3] Faculty of Health Science, Institute of Physiotherapy, Jagiellonian University Medical College, Kraków, Poland.
[4] Arthrogryposis Treatment Center, University Children's Hospital of Cracow, Poland.
[5] Department of Orthopedics, University Children's Hospital of Cracow, Poland.
[6] Orthopädie Liesing, Wien, Austria.

Purpose: The aim of this work was to evaluate postural stability on the balance platform averagely 2 years following meniscal repair. *Methods*: This is a retrospective, case-control comparative analysis of patients who underwent surgical repair for the isolated longitudinal traumatic meniscal tear versus matched healthy controls. The study group consisted of 30 patients (mean age 29.93 years; averagely 2.3 years after surgery) and the control group – of 30 people. Following physical examination and completion of the IKDC, and the Lysholm questionnaires, the evaluation of the postural stability using two single-leg stabilometry tests was performed. In the static test, the analyzed variables included deviations from the horizontal, vertical axes and the length of the balance path travelled. In the dynamic test, the length of the path travelled and the time to complete task were recorded. Between-limb and between-groups comparison of collected stabilometry tests were performed. Additionally, the IKDC and the Lysholm questionnaires scores were compared between the study and heathy groups. *Results*: No abnormalities were found on clinical examination in the study group nor any differences between the operated and contralateral knee ($p > 0.05$). In stabilometry: (1) in the study group, the operated extremity scored worse than the contralateral limb (length of path traveled in: A) static test $x = 56.7$ cm SD = 37.91 cm vs. $x = 21.6$ cm SD = 9.06 cm; $p = 0.002$ and B) dynamic test $x = 82.57$ cm, SD = 50.43 cm vs. $x = 53.32$ cm, SD = 13.82 cm; $p = 0.003$); (2) In the control group, no leg-related differences were noted ($p > 0.05$); (3) Between-group comparison revealed that the study group scored worse than the control group (length of path traveled in: A) static test $x = 56.7$ cm, SD = 37.91 cm vs. $x = 17.23$ cm, SD = 3.39 cm; $p = 0.001$ and B) dynamic test $x = 82.57$ cm, SD = 50.43 cm vs. $x = 32.13$ cm, SD = 9.41 cm; $p < 0.001$). Study group scored worse on IKDC scores ($p < 0.001$) but not on Lysholm score ($p > 0.05$). *Conclusions*: Postural stability deficit persists despite a successful meniscal repair.

Key words: *meniscal repair, postural stability, knee function*

1. Introduction

In recent years, the interest in sports has been clearly increasing. With the increasing number of people leading an active lifestyle, the incidence of injuries has also increased [7]. Sport-related injuries frequently concern the knee joint structures, with meniscal tears being one of the most common issues in sports medicine [7], [16], [25], [26], [30], [39]. The meniscal injuries are predominantly situated in the posterior horn, that contains the highest number of mechanoreceptors. The presence of mechanoreceptors indicates the participation of the meniscus in the reception of proprioceptive stimuli acting on the knee joint and the sense of joint positioning. The receptors are responsible for receiving information regarding the position or movement of the joint, which is con-

* Corresponding author: Kinga Żmijewska, Faculty of Health Sciences, Jagiellonian University Medical College, ul. Michałowskiego 12, 31-126 Kraków, Poland. Phone: + 48 12 632 48 81, +48 507 306 361, e-mail: kinga.zmijewska@uj.edu.pl

Received: August 23rd, 2021
Accepted for publication: November 26th, 2021

verted into afferent neural stimulation [9], [22], [31], [32]. This, in turn, by muscular response, helps to maintain postural stabilization and to adopt the knee to the changing dynamic environment [22], [31]. Thus, the menisci among other functions play a role of dynamic stabilizers of the knee joint [3], [20], [24], [38]; their injury as well as removal were reported to result in impaired knee proprioception [4], [31].

Owing to long-term consequences associated with meniscectomy, arthroscopic surgical repair is considered the first-line treatment for traumatic meniscal tears in young, active individuals [37]. This approach is presently gaining increasing popularity, given its favorable long-term effects, i.e., prevention or delaying the development of early-onset osteoarthritis [21], [34], [39]. In view of the essential roles played by the menisci in the knee joint, the practice of performing total meniscectomies is being abandoned [7], [21], [39]. Keeping up with the ”save the meniscus” principle, the obligatory tendency is to repair the meniscus preserving as large fragment of the structure as possible [19], [27], [38], [39]. One of the key factors in avoiding repeated injuries is appropriate static and dynamic knee stabilization [6]. However, there is scant information regarding the effect of the isolated meniscal tear repair on the postoperative knee joint proprioception and postural stability. Most of the reported series concerns meniscectomy and/or meniscal repair along with concomitant ACL reconstruction [2], [5], [17], [22], [24].

Several methods of studying proprioception and neuromuscular control of the joint have been described. The first one, feeling the position of the joint, consists of recreating the position of the limb set by the therapist. The difference between the initial position and the position of the patient’s limb is measured in angles. It is not a reliable method as it only tests the sense of the position of the joint. The second method relates to the sense of passive limb movement. The patient’s limb should be moved passively at a speed of 0.5 °/sec. The patient, with eyes closed, is to pinch when he feels movement. The distance traveled by the limb and the moment of detecting the movement are compared. This method assesses kinesthesia. Another method is to measure muscle activation and delay responses to muscle reflex stimuli. A widely recognized and used method is the assessment of balance and stabilometry (e.g., using a balance platform), which can be successfully used to study postural control as well as proprioception and neuromuscular control [5], [15].

The main objective of this study was to analyze whether the postural stability deficit persisted after successful surgical repair of an isolated meniscus injury in patients averagely 2 years after surgery. We analyzed the clinical outcomes, the IKDC and Lysholm questionnaires and the stabilometric results on the balance platform to examine a group of patients (operated vs. contralateral limb) and compared their characteristics with the matched control group. It has been hypothesized that a postural stability deficit is observed after the repair of the meniscus.

2. Materials and methods

This study was approved by the Bioethics Committee of the Jagiellonian University of Cracow (nr 1072.6120.50.2020). Written consent was obtained from each patient prior to the investigation. The study was conducted in 2019 at the University Hospital in Kraków.

Characteristics of participants being studied

The group of patients consisted of people invited to the study and operated by one surgeon. The group of healthy people consisted of willing volunteers who volunteered to participate.

The inclusion criteria were: minimum of 1 year follow-up, no meniscal tear symptoms on clinical examination (full, painless range of motion of the affected knee including deep squatting, no pain on palpation, no mechanical symptoms, Apley and McMurray tests negative), no quadriceps deficit (<1 cm difference of the thigh circumference and no difference in the quadriceps strength as compared to the contralateral side), no other clinical abnormalities of the examined or contralateral extremity. Additionally, the healthy group included matched healthy volunteers with no trauma history. Detailed data on the groups are presented in Table 1. The time interval from surgery to assessment of postural stability was 1–3.5 years (2.3 years on average).

Surgical repair

The patients underwent successful surgical repair for an isolated longitudinal, traumatic meniscal tear in the red-red zone. All the injuries were located in the posterior horn of the meniscus and the posterior part of the meniscal body or encompassed this region as a part of a bigger tear. All the patients were operated by a single, high volume (>100 meniscal repairs per year), fellowship-trained knee surgeon with >10 years of experience in reconstructive knee surgery. The meniscal repair was done using all-inside devices (ultra FAST-FIX – Smith & Nephew and/or Sequent – ConMed)) for the posterior horn, and in-out technique (Zone Specific II Meniscal Repair System (ConMed/Linvatec)/absorbable monofilament stitches) for the meniscal body. Both meniscal surfaces (femoral and tibial) were repaired with vertical/oblique mattress sutures in 1.0–1.5 cm intervals.

Postoperative physiotherapy

After the surgery, the patients and physiotherapists were provided with information on rehabilitation. Up to 6 weeks after surgery, patients were on crutches with partial weight-bearing and flexed the knee from 0 to 60 degrees. Patients were provided with a clock orthosis. The techniques of patella mobilization and myofascial relaxation were used, work was done on maintaining extension and activating the muscles of the lower limb. After the 6th week, intensive muscle strengthening, gait re-education and increasing the range of motion began. Rehabilitation lasted 6 months [7], [36].

Investigative tools

Prior to functional testing, the subjects were questioned as to their age, physical activity return to sport, past injuries, and pain involving the knee joint. Next physical examination of both lower extremities was conducted to confirm a full painless range of motion, adequate ligamentous stability, absence of knee effusion, and absence of meniscal symptoms in the Apley and McMurray tests. Quadriceps circumference was measured 15 cm proximally to the joint line, and muscle strength was determined by the Lovett scale. The patients were asked to complete the subjective form of the International Knee Documentation Committee (IKDC) and Lysholm Knee Scoring Scale questionnaires [10], [13]. Then, a study was carried out on the balance platform: static and dynamic tests.

The static test is illustrated in Fig. 1. The geometric center of the board had to be held at the designated point for 60 seconds, allowing for examining the deviation of the body center of gravity along the *X* (horizontal) and *Y* (vertical) axes. During the test, the patient watched the current location of a point in the screen in front of the platform. When the task was completed, the investigator obtained information on the mean deviation values from the *X* and *Y* axes, as well as the length of the path traveled [cm].

The dynamic test is presented in Fig. 3. In the initial phase, the examined foot was again positioned centrally on the platform, which was reflected on the screen as a center of the circle composed of 8 circumferentially dispersed points. The test consisted in reaching sequentially highlighting peripheral points in the screen and going back to the center of the circle each time. Upon completion of the test, it was possible to obtain records of the exercise duration and length of the traveled path [cm].

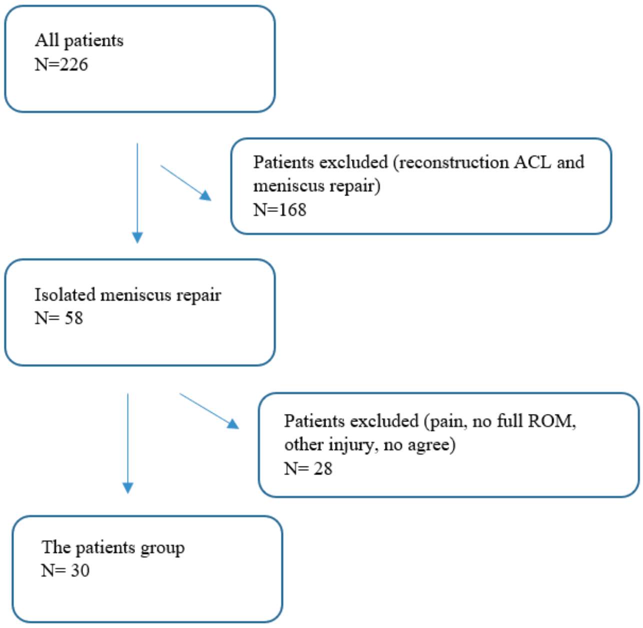

Fig. 1. The flowchart of the study

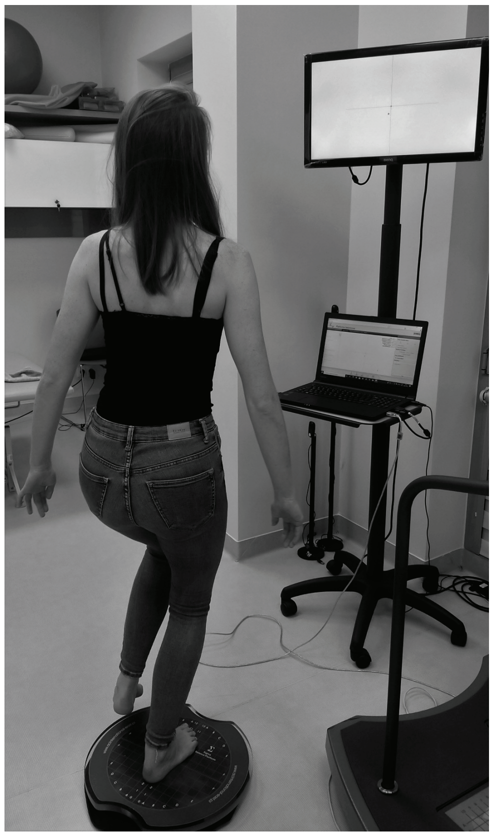

Fig. 2. The static test

The stabilometry examination was carried out using the Sigma balance platform with biofeedback (AC International East Ltd., Knurów, Poland). Two tests were selected for this purpose, namely, the static test (1 min) and the dynamic test (one repetition). Each test was performed on a platform set with a moderate difficulty level, separately for the right and left lower extremity. Supporting one's body with the free hand was not allowed. A training period before commencing the proper part of the project consisted in executing an additional exercise allowing the subject to get familiar with the opportunities offered by the board. The participants performed both tests twice. The first repetition was familiarization with the platform and the task. The results of the second replicate were taken into account in the study. The foot was positioned centrally on the platform with the median vertical coordinate passing underneath the second metatarsal and the median horizontal coordinate transecting the middle of the antero-posterior dimension of the foot. This position was checked prior to every exercise in order to compare the results. Before each test, brief instructions were given and the balance platform was calibrated.

Both tests were done separately for the right and left lower limbs for every participant. In the patient group, the results were compared between the affected and contralateral extremity and also between medial and lateral meniscus repair. In the heathy group the differences between the dominating and non-dominating extremities were analyzed. Finally, the results from the patient group (affected extremity) were compared to the findings observed in the heathy group (arithmetic average for both limbs).

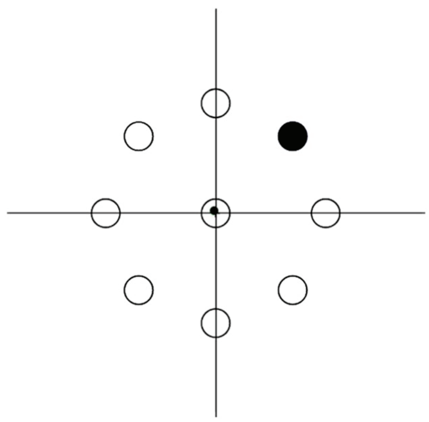

Fig. 3. The dynamic test

Statistical analysis

The Statistica 13.1 program was used for statistical analysis. The differences between the deviation from the X and Y axes [cm] as well as the length [cm] of the path traveled in the static test as well as the time [s] and length [cm] of the path traveled were examined. The normality of the distribution of variables was tested using the Shapiro–Wilk test. The results were not normally distributed and were statistically analyzed by the Mann–Whitney U-test (for independent samples) and Wilcoxon signed-rank test (for dependent samples). The sample size was 17, with a power of 0.08 and an α level of 0.05. The adopted significance level was $\alpha = 0.05$.

3. Results

Overall, sixty participants fulfilled the inclusion criteria and were enrolled – 30 in the patient group and 30 in the heathy group. There were no statistically significant demographic differences between the groups ($p > 0.05$) (Table 1).

Table 1. Demographic data of the study group and the control group

	Study group		Control group		p
	x	SD	x	SD	
Age [years]	29.93	9.82	25.73	7.36	0.143
Body mass [kg]	75.93	12.54	69.33	13.41	0.367
Height [cm]	177.11	8.68	171.33	9.68	0.187
BMI	25.17	5.23	23.6	4.78	0.279
Thigh circumference	50.7	5.57	54.64	4.05	0.493
	N	%	N	%	
Sex:					
• male	18	60	16	53.33	0.461
• female	12	40	14	46.67	0.376
Sport activity >2 twice/week	24	80	26	86.67	0.482
Damaged meniscus:					
• medial	23 (6 BHT)	76.67	–	–	–
• lateral	7 (2 BHT)	23.33			
Affected limb:					
• right	19	63.33	–	–	–
• left	11	36.67			

N – participants; x – mean; SD – standard deviation; p – p-value, BHT – bucket-handle tear.

Clinical assessment

All the patients in the patient group completed their postoperative physical therapy regimen and considered their recovery finalized. All of them returned to recreational sports activities. On physical examination, all the subjects were asymptomatic and no objective differences were found between the operated and contralateral extremity.

Functional questionnaires

The IKDC questionnaire showed in all domains worse results in the patient group as compared to the heathy group. When the Lysholm Knee Scoring Scale was used, no statistically significant differences were noted (Table 2).

Table 2. IKDC and Lysholm Knee Scoring Scale questionnaires scores in the study group and the controls

Questionnaire		Study group		Controls		*p*
		x	SD	*x*	SD	
IKDC	Symptoms	28.67	6.06	35.93	1.95	**0.004***
	Physical activity	31.67	9.68	39.1	1.2	**0.001***
	Functioning	7.38	1.52	9.8	0.23	**0.015***
	Total points	71.46	17.81	98.23	4.12	**<0.001***
Lysholm Knee Scoring Scale		91	15.29	98.7	1.67	0.068

IKDC – the International Knee Documentation Committee, *x* – mean, SD – standard deviation; *p* – *p*-value; * – statistically significant ($p < 0.05$).

Stabilometry tests

a) Study group

The affected extremity scored worse than the contralateral limb on both the static and dynamic tests for all the analyzed variables (Table 3).

b) Control group

The results obtained from the dominant and non-dominant extremity revealed no significant differences between the extremities in the static or dynamic tests (Table 4).

c) Intergroup comparison

The patient group (affected extremity) scored worse than the heathy group (the arithmetic mean for both

Table 3. Stabilometry tests, study group – operated versus non-operated extremity

		Operated extremity		Non-operated extremity		*p*
		x	SD	*x*	SD	
Static test	Deviation from *X* axis [cm]	0.06	0.04	0.03	0.03	**0.03**
	Deviation from *Y* axis [cm]	0.03	0.02	0.02	0.01	**0.019**
	Length of path traveled [cm]	56.7	37.91	21.6	9.05	**0.02**
Dynamic test	Time of path traveling [s]	118.19	57.39	80.49	31.45	**0.001**
	Length of path traveled [cm]	82.57	50.43	53.32	13.84	**0.002**

x – mean; SD – standard deviation; *p* – *p*-value; * – statistically significant ($p < 0.05$).

Table 4. Stabilometry tests, dominant versus non-dominant extremity in study group

		Non-dominant extremity		Dominant extremity		*p*
		x	SD	*x*	SD	
Static test	Deviation from *X* axis [cm]	0.04	0.04	0.04	0.03	0.728
	Deviation from *Y* axis [cm]	0.04	0.03	0.03	0.03	0.065
	Length of path traveled [cm]	41.06	14.76	38.23	12.11	0.487
Dynamic test	Time of path traveling [s]	119.72	61.01	95.46	53.86	0.734
	Length of path traveled [cm]	91.07	53.01	68.04	32.11	0.311

x – mean; SD – standard deviation; *p* – *p*-value; * – statistically significant ($p < 0.05$).

Table 5. Stabilometry tests, study group versus controls

		Study group		Control group		*p*
		x	SD	x	SD	
Static test	Deviation from *X* axis [cm]	0.06	0.04	0.02	0.02	**0.019***
	Deviation from *Y* axis [cm]	0.03	0.02	0.02	0.02	0.219
	Length of path traveled [cm]	56.7	37.91	17.23	3.39	**0.001***
Dynamic test	Time of path traveling [s]	118.19	57.39	54.19	14.88	**<0.001***
	Length of path traveled [cm]	82.57	50.43	32.13	9.41	**<0.001***

x – mean; SD – standard deviation; *p* – *p*-value; * – statistically significant ($p < 0.05$).

limbs) on both the static and dynamic tests for most of the analyzed variables (except for the *Y* axis deviation in the static test) (Table 5).

4. Discussion

While interpreting the results obtained by the IKDC questionnaire, it should be emphasized that the document is subjective and – in order to complete it – the subject needed to analyze not only the present functional status, but also the consequences of a meniscal injury and/or surgery. When answering the questions, every responder from the patient group noted motor limitations compared to the heathy group, despite a long time lapse after surgery, completed postoperative rehabilitation, and an absence of abnormalities in the objective clinical exam. The results obtained when the other questionnaire – the Lysholm Knee Scoring Scale – was employed showed a similar trend, but no significant intergroup differences. Both questionnaires are commonly used in research studies that evaluate functional status following knee reconstructive treatment.

The analysis of the data obtained while studying proprioception in the repaired and non-repaired extremities in the patient group demonstrated significant differences. Better results were achieved for the non-repaired limb both in the static and dynamic tests. Additionally, the patient group performed worse than the heathy group. This phenomenon may indicate the effect of meniscal tear and/or repair on stabilization of the knee joint in motor control that may be of importance not only in the rehabilitation process, but also in further functioning of the patient. It is known that joint stability is affected by several factors. The ability to sense the joint position (proprioception) is an interplay of passive capsuloligamentous restraint, as well as dynamic musculotendinous units to maintain the joint within the physiologic range during motion and to prevent exceeding the safe limits [12]. In the present study the recruitment criteria included intact passive capsuloligamentous stability (isolated meniscal tear, with no concomitant ligament injury), along with a <1 cm difference in thigh circumference between the repaired and non-repaired extremity (what supports the notion that the muscle balance has been successfully restored). This may lead to the conclusion that it was the impaired proprioception that jeopardized the functional results in the patient group.

For many years, much attention has been paid to restoring proprioception after anterior cruciate ligament (ACL) reconstruction, as it is well known how important it is for proper knee functioning [29]. Studies suggest that decreased ability in the field of knee joint proprioception may increase the risk of a reinjury [14], while injuries and surgical procedures may negatively affect the function of the mechanoreceptors [1]. Rehabilitation protocols addressing ACL reconstruction include training of deep sensibility, with exercises aiming at joint stabilization. On the contrary, when the therapy of patients subjected to meniscal repair is introduced, attention is paid to mobilizing the tissues and the patella, increasing the range of motion as well as strengthening the muscle and providing gait reeducation in order to restore complete dexterity of the body [18], [23], [36]. Decidedly less time is devoted to stabilization exercises [28].

The reason for that is that, despite the detailed structure of the menisci, their biomechanical properties and function have been well understood, the role of the menisci in the knee joint proprioception still remains a poorly investigated and underestimated field. Al-Dadah [2] reported the presence of mechanoreceptors both in the anterior and posterior horns. According to Brindle [6] and Karahan [17], mechanoreceptors are present solely in the meniscal horns. Fox [12] pointed to a higher density of those structures in the posterior horns. Some studies demonstrated not only the Ruffini cells and Pacinian corpuscles in the meniscal structure, but also the Golgi tendon organs and free nerve endings; all of them are responsible for maintaining balance and knee joint stabilization what as a consequence affects the body posture [12], [38]. Suprisingly, the analysis of research databases has not disclosed any study that would address the effect of isolated meniscal repair on knee joint proprioception. Predominating, although scant, reports describe the effect of meniscectomy [2], [17], [23]. Al-Dadah found that partial meniscectomy negatively affected the proprioception of the knee joint [2]. Karahan [17] addressed the position sense of the lower limb following partial meniscectomy. Patients after partial resection of the meniscus obtained worse results compared to the heathy group. The number of publications concentrating on patients after meniscectomies studied with the use of a balance platform is extremely low. Matyas [24] studied the effects of meniscus tear and partial meniscectomy on balance using a platform. Balans was disturbed after both meniscal damage and partial meniscectomy. The observations also focus on the effects of partial meniscectomies and damage of ACL and the menisci and their correlation with proprioception. Basar [5] compared proprioception in patients subjected to two surgical procedures: ACL reconstruction and meniscal repair or meniscectomy. The obtained results indicate better function of the knee joint and proprioception in the group of patients who underwent repair of the meniscus.

The results from the present study are supplementary to the aforementioned findings. Our data support the hypothesis that meniscal injury, even if repaired, may still have a long-lasting consequences for knee joint proprioception. Such injuries most often involve the posterior horn of the meniscus that contains the highest number of mechanoreceptors responsible for the transmission of proprioceptive stimuli (Ruffini cells, Pacinian corpuscles and Golgi tendon organs). It is the very destruction of mechanoreceptors and/or afferent nerves (passing along with the vessels) that may affect joint function. Proprioception is responsible for the sense of joint movement and position; when preserved, it allows not only for functional joint stability but also plays a significant role in knee joint protection. This is especially the case as the individual approaches the maximal motion range. Information from the mechanoreceptors may also affect the degree of the anterior and posterior translation of the femoral condyles on the tibial plateau [17]. Thus, awareness of the impaired knee proprioception following meniscal repair is meaningful from the practical viewpoint. While executing postoperative management, the physiotherapist should obligatorily employ and emphasize the proprioception training as it is done following ACL reconstruction. The use of a dedicated rehabilitation protocol after meniscal repair that takes the type and extent of injury, meniscal biomechanics, and the important role of the menisci in preserving proprioception into consideration may allow for achieving optimal postoperative results.

In summary, the present analysis shows that meniscal repair affects knee joint stabilization in motor control, even though the differences demonstrated to occur between the repaired and non-repaired extremity are small. This may become yet another argument for the postoperative protocol following meniscal repair. When selecting exercises, apart from taking the principles of tissue healing and unloading the repaired area into consideration, at the same time the physiotherapist should from the very beginning focus attention on proprioception exercises. At the present state of knowledge, the inclusion of proprioceptive training is a necessity.

There were some limitations of the present study that need to be mentioned. First, one may argue that the meniscal healing status was not confirmed routinely by MRI prior to the investigation. This might theoretically result in underdiagnosed persistent tears/re-tears that jeopardized the outcomes. However, despite the fact that standard MRI is the method of choice for diagnosis of the primary meniscal injuries, it must be remembered that its accuracy in the detection of unhealed/re-torn menisci is far lower, approaching 66–80% and not exciding the accuracy of the clinical examination [4], [8], [33], [35]. All the patients in the patient group reported no complaints and were asymptomatic on clinical examination and the authors considered this a sufficient criterion for inclusion in the present analysis. Second, because the patients were receiving post-operative physiotherapy in their own environment, it is possible that the protocols used differed from those recommended. This may affect the level of functional recovery in some patients. However, even if this is the case, it further supports the necessity to optimize the treatment regimens following meniscal repair. Third, the patient group is relatively small and the results may be underpowered, what may be reflected by the lack of significant differences in some clinical data. Fourth, the present analysis, as a pilot study, addresses only postural stability. To achieve comprehensive results, further studies on proprioception following meniscal repair are warranted; it is also necessary to perform tasks blindfolded. Lastly, the character of the present study did not make it possible to distinguish between meniscal injury itself and surgical damage of the meniscal ultrastructure during repair as a causative factor for impairment of proprioception. However, as a surgical repair is the treatment of choice for amenable meniscal tears, they both should be rather seen in conjunction. The limitations of the study also include the lack of validation of the Sigma balance platform used and the lack of the minimally clinically meaningful difference.

5. Conclusions

The findings of this study suggest that the postural stability deficit may be expected following meniscal repair. Proprioception training should be included as an integral part of the postoperative protocol in meniscal injuries.

References

[1] AHMED M.M., MUSSALLEM D.M., KHAIRET S.M., ISMAIL T.A., HAMIDO F.A., AL-BUSAIRI W.A., *Evaluation of dynamic posturography in anterior cruciate ligament injury patients*, Maced. J. Med. Sci., 2011, 15, 167–173.

[2] AL-DADAH O., SHEPSTONE L., DONELL S.T., *Proprioception following partial meniscectomy in stable knee*, Knee Surg. Sports Traumatol. Arthrosc., 2011, 19 (2), 2007–2013.

[3] ANDREWS S., SHRIVE N., RONSKY J., *The shocking truth about menisci*, J. Biomech., 2011, 44 (10), 2737–2740.

[4] BAKER J.C., FRIEDMAN M.V., RUBIN D.A., *Imaging the postoperative knee meniscus: an evidence-based review*, Am. J. Roentgenol., 2018, 211 (3), 519–527.

[5] BAŞAR B., BAŞAR G., AYBAR A., KURTAN A., BAŞAR H., *The effects of partial meniscectomy and meniscal repair on the knee proprioception and function*, J. Orthop. Surg., 2020, 28 (1), 2309499019894915, DOI: 10.1177/2309499019894915.

[6] BRINDLE T., NYLAND J., JOHNSON D.L., *The meniscus: review of basic principles with application to surgery and rehabilitation*, J. Athl. Train., 2011, 36 (2), 160–169.

[7] CAVANAUGH J.T., KILLIAN S.E., *Rehabilitation following meniscal repair*, Curr. Rev. Musculoskelet Med., 2012, 5 (1), 46–58.

[8] CHAPIN R., *Imaging of the postoperative meniscus*, Radiol. Clin. North Am., 2018, 56 (6), 953–964.

[9] CHIVERS M.D., HOWITT S.D., *Anatomy and physical examination of the knee menisci: a narrative review of the orthopedic literature*, J. Can. Chiropr. Assoc., 2009, 53 (4), 319–333.

[10] COLLINS N.J., MISRA D., FELSON D.T., CROSSLEY K.M., ROOS E.M., *Measures of knee function: International Knee Documentation Committee (IKDC) Subjective Knee Evaluation Form, Knee Injury and Osteoarthritis Outcome Score (KOOS), Knee Injury and Osteoarthritis Outcome Score Physical Function Short Form (KOOS-PS), Knee Outcome Survey Activities of Daily Living Scale (KOS-ADL), Lysholm Knee Scoring Scale, Oxford Knee Score (OKS), Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), Activity Rating Scale (ARS), and Tegner Activity Score (TAS)*, Arthritis Care Res (Hoboken), 2011, 63 Suppl. 11 (0 11), S208–28.

[11] DAY B., MACKENZIE W., SHIM S.S., LEUNG G., *The vascular and nerve supply of the human meniscus*, Arthroscopy, 1985, 1, 58–62.

[12] FOX A.J., BEDI A., RODEO S.A., *The basic science of human knee menisci: structure, composition and function*, Sports Health, 2012, 4 (4), 340–351.

[13] GREVNERTS H.T., TERWEE C.B., KVIST J., *The measurement properties of the IKDC – subjective knee form*, Knee Surg. Sports Traumatol. Arthrosc., 2015, 23 (12), 3698–3706.

[14] HENRIKSSON M., LEDIN T., GOOD L., *Postural control after anterior cruciate ligament reconstruction and functional rehabilitation*, Am. J. Sports Med., 2001, 29, 359–66.

[15] HEWETT T.E., PATERNO M.V., MYER G.D., *Strategies for enhancing proprioception and neuromuscular control of the knee*, Clin. Orthop. Relat. Res., 2002, (402), 76–94.

[16] JAUREGUI J.J., WU Z.D., MEREDITH S., GRIFFITH C., PACKER J.D., HENN R.F., *How should we secure our transplanted meniscus? A meta-analysis*, Am. J. Sports Med., 2018, 46 (9), 2285–2290.

[17] KARAHAN M., KOCAOGLU B., CABUKOGLU C., AKGUN U., NURAN R., *Effect of partial medial meniscectomy on the proprioceptive function of the knee*, Arch. Orthop. Trauma Surg., 2010, 130 (3), 427–431.

[18] KOCH M., MEMMEL C., ZEMAN F., PFEIFER CH.G., ZELLNER J., ANGELE P. et al., *Early functional rehabilitation after meniscus surgery: Are currently used orthopedic rehabilitation standards up to date?*, Rehabil. Res. Pract., 2020, DOI: 10.1155/2020/3989535.

[19] KOPF S., BEAUFLS P., HIRSCHMANN M.T., ROTIGLIANO N., OLLIVIER M., *Management of traumatic meniscus tears: the 2019 ESSKA meniscus consensus*, Knee Surg. Sports Traumatol. Arthrosc., 2020, 28 (4), 1177–1194.

[20] KRYCH A.J., BERNARD C.D., LELAND D.P., CAMP C.L., JOHNSON A.C., FINNOFF J.T., STUART M.J., *Isolated meniscus extrusion associated with meniscotibial ligament abnormality*, Knee Surg. Sports Traumatol. Arthrosc., 2019, 28, 3599–3605.

[21] LEE D.W., HA J.K., KIM J.G., *Medial meniscus posteriori root tear: a comprehensive review*, Knee Surg. Relat. Res., 2014, 26 (3), 126–134.

[22] LEE J.H., HEO J.W., LEE D.H., *Comparative postural stability in patients with lateral meniscus versus medial meniscus tears*, Knee, 2018, 25 (2), 256–261.

[23] LIND M., NIELSEN T., FAUNØ P., LUND B., CHRISTIANSEN S.E., *Free rehabilitation is safe after isolated meniscus repair: a prospective randomized trial comparing free with restricted rehabilitation regimens*, Am. J. Sports Med., 2013, 41 (12), 2753–2758.

[24] MAGYAR M.O., KNOLL Z., KISS R.M., *Effect of medial meniscus tear and partial meniscectomy on balancing capacity in response to sudden unidirectional perturbation*, J. Electromyogr. Kinesiol., 2012, 22 (3), 440–445.

[25] MOSICH G.M., LIEU V., EBRAMZADEH E., BECK J.J., *Operative treatment of isolated meniscus injuries in adolescent patients: a meta-analysis and review*, Sports health, 2018, 10 (4), 311–316.

[26] MUTSAERTS E., ECK C., DE GRAAF V., DOORNBERG J.N., DEN BEKEROM M., *Surgical interventions for meniscal tears: a closer look at the evidence*, Arch. Orthop. Trauma Surg., 2016, 136, 361–370.

[27] NAKAYAMA H., KANTO R., KAMBARA S., KUROSAKA K., ONISHI S., YOSHIYA S., YAMAGUCHI M., *Clinical outcome of meniscus repair for isolated meniscus tear in athletes*, Asia Pac. J. Sports Med. Arthrosc. Rehabil. Technol., 2017, 10, 4–7.

[28] O'DONELL K., FREEDMAN K.B., TJOUMAKARIS F.P., *Rehabilitation protocols after isolated meniscal repair: a systematic review*, Am. J. Sports Med., 2016, 45 (7), 1687–1697.

[29] OGRODZKA-CIECHANOWICZ K., CZECHOWSKA D., CHWAŁA W., ŚLUSARSKI J., GĄDEK A., *Stabilometric indicators as an element of verifying rehabilitation of patients before and after reconstruction of anterior cruciate ligament*, Acta Bioeng. Biomech., 2018, 20 (1), 101–107.

[30] PALMER-GREEN D., *Epidemiology of sports injuries and illnesses*, ABC of sports and exercise medicine 4th Edition 1, 2015.

[31] PARK J.H., JEONG W.K., LEE J.H., CHO J.J., LEE D.H., *Postural stability in patients with anterior cruciate ligament tears with and without medial meniscus tear*, Knee Surg. Sports Traumatol. Arthrosc., 2013, 23 (1), 240–245.

[32] PARUS K., LISIŃSKI P., HUBER J., *Body balance control deficiencies following ACL reconstruction combined with medial meniscus suture. A preliminary report*, Orthop. Traumatol. Surg. Res., 2015, 101 (7), 807–10.

[33] PATHAK S., BHARADWAJ A., PATIL P. et al., *Functional outcomes of arthroscopic combined anterior cruciate ligament reconstruction and meniscal repair: a retrospective analysis*, Arthrosc. Sports Med. Rehabil., 2020, 2 (2), e71–e76.

[34] ROBINSON J.R., JERMIN P.J., *Meniscal root tears: current concepts*, Asian J. Arthrosc., 2016, 1 (2), 35–46.

[35] RUSSO A., CAPASSO R., VARELLI C. et al., *MR imaging evaluation of the postoperative meniscus*, Musculoskelet Surg., 2017, 101 (Suppl. 1), 37–42.

[36] SPANG R.C., NASR M.C., MOHAMADI A., DEANGELIS J.P., NAZARIAN A., RAMAPPA A.J., *Rehabilitation following me-*

niscal repair: a systematic review, B.M.J. Open Sport Exerc. Med., 2018, DOI: 10.1136/bmjsem-2016-000212.

[37] THORLUND J.B., JUHL C.B., INGELSRUD L.H., SKOU S.T., *Risk factors, diagnosis and non-surgical treatment for meniscal tears: evidence and recommendations: a statement paper commissioned by the Danish Society of Sports Physical Therapy (DSSF)*, Br. J. Sports Med., 2018, 52 (9), 557–565.

[38] WESTERMANN R.W., DUCHMAN K.R., AMENDOLA A., GLASS N., WOLF Br., *All-inside versus inside-out meniscal repair with concurrent anterior cruciate ligament reconstruction: a meta-regression analysis*, Am. J. Sports Med., 2017, 45 (3), 719–724.

[39] YOON K.H., PARK K.H., *Meniscal repair*, Knee Surg. Relat. Res., 2014, 26 (2), 68–76.