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Complex Meniscus Tears Treated with Collagen Matrix Wrapping and Bone Marrow Blood Injection: A 2-Year Clinical Follow-Up

Tomasz Piontek[1], Kinga Ciemniewska-Gorzela[1], Jakub Naczk[1], Roland Jakob[1], Andrzej Szulc[†], Monika Grygorowicz[1], and Michal Slomczykowski[2]

Abstract

Objective. To collect and analyze the 2-year follow-up clinical and MRI results of patients treated with an arthroscopic technique of collagen membrane-based meniscus repair. *Design*. 53 consecutive patients with combined (horizontal and radial or longitudinal component) and complex meniscal tears (tear extended through avascular zones or/and composed with two or more morphological tear pattern) were treated with an "all-inside" arthroscopic suture of meniscus and wrapping with a collagen membrane (Chondro-Gide) technique with bone marrow blood injection. The IKDC 2000 subjective score, IKDC 2000 clinical evaluation score, Lysholm score and Barret clinical criteria of meniscal healing were recorded. All patients were examinated by MRI 2 years postoperatively, using modified WORMS criteria for meniscal integrity. *Results*. The 2 year follow-up was achieved in 50 cases. Of these, 2 patients were excluded from the evaluation due to incomplete data and 2 patients underwent partial meniscectomy and were classified as failures. In 46 patients (86.8% of the intended to treat cases), a statistically significant improvement in IKDC 2000 subjective, Lysholm scores and IKDC 2000 clinical assessment between preoperative and the 2-year follow-up time points were obsereved. Barret criteria demonstrated an improved clinical outcome between pre- and post-operative values. MRI revealed a non-homogeneous signal without meniscal tear (WORMS grade 1) in 76% of the operated menisci (13% WORMS grade 2). *Conclusions*. The 2-year follow-up data demonstrate that this technique is safe and can offer an additional tool to save the meniscus in the patients otherwise scheduled for meniscal removal. Level of evidence IV

Keywords

meniscus wraping, collagen membrane, arthroscopic, complex, combined

Introduction

Meniscal injuries located in the low or nonvascularized zones (red-white and white-white zones) are often treated with partial or total meniscectomy. Although meniscectomy is a relatively simple and quick surgery with good immediate postoperative clinical outcomes, the long-term results are poor.[1,-3] These poor outcomes are not surprising since many studies have demonstrated the importance of the meniscus for the knee function.[1,5-10] It has also been accepted that surgeons should preserve as much meniscal tissue as possible. Both complete and partial meniscectomy are associated with early degenerative osteoarthritis.[7-11] To preserve function of the knee joint, it is now suggested that meniscal tears should be treated by meniscal repair instead of meniscectomy whenever possible.[1,2,6,9,12,13]

Various augmentation techniques for meniscal repair have been described. They include use of a fibrin clot, platelet-rich plasma, pro-inflammatory cytokines, and application of growth factors.[14-19] Further progress in meniscus healing has been made possible by the innovative use of cells and scaffolds.[20] Improved methods to isolate and concentrate mesenchymal stem cells from autologous sources (e.g., bone marrow or adipose tissue) allows the evaluation of the role of cell-based techniques to augment healing. Furthermore, the development of advanced scaffold materials and associated techniques has contributed to creating an intracapsular biological environment for improved meniscus healing. Notably, Jakobi and

[1]Rehasport Clinic, Poznan, Poland
[2]Geistlich Pharma AG, Wolhusen, Switzerland
[†]Clinic of Pediatric Orthopedic Surgery UM Poznań, Poland

Corresponding Author:
Kinga Ciemniewska-Gorzela, Rehasport Clinic, Górecka 30, Poznan, 60-201, Poland.
Email: kinga@rehasport.pl

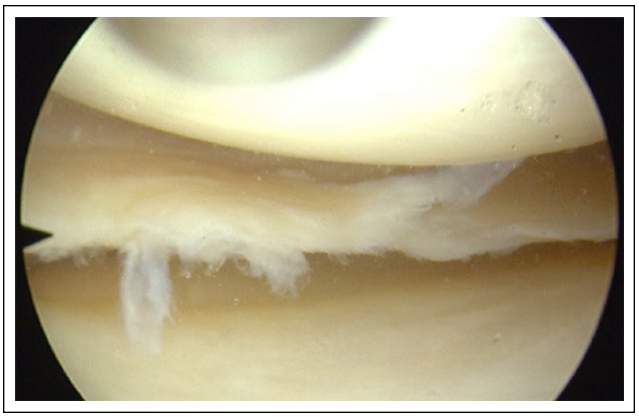

Figure 1. An example of meniscus injury treated as a part of this study.

Figure 2. Schematic drawing of a meniscus injury treated as a part of this study.

Jakob[17] tested 30 patients with the treatment of meniscal tears by suturing and wrapping the repair in a collagen matrix. The results obtained were encouraging, but the surgical technique, an inside-out suturing, presents some challenges since it can be time-consuming and requires an additional surgical approach. In a goat animal study, Jülke *et al*.[21] showed that a transient, short-term guided tissue regeneration of avascular meniscal tears occurs when a collagen membrane is used. The addition of expanded autologous chondrocytes supports more sustainable long-term tear healing in the goat model.

Inspired by those advances in the treatment of injured menisci, in 2010 a fully arthroscopic technique has been developed to treat combined (possessing horizontal and radial or longitudinal component) and complex (tear extended through all vascular zones or/and composed with 2 or more morphological tear pattern) meniscal tears. Conceptually, the surgical technique, is a modification of the historical Henning's and Jakob procedure,[17,22] included suturing and wrapping the menisci in a collagen matrix, followed by the injection of liquid bone marrow collected from the tibial proximal epiphysis, into the area of the meniscal lesion. A detailed description of the surgical method had been published by Piontek *et al*.[23] in 2012. By using this surgical technique in patients sustaining complex and/or combined meniscal injuries, meniscus resection could be avoided in these tear patterns cases that otherwise would have been treated with meniscetomy.

We hypothesized that complex and combined meniscal tears occurring in white-white and white-red zones can safely and successfully be treated arthroscopically by meniscal suturing and wrapping in the collagen matrix, instead of being partially or totally resected.

The purpose of this work is to present a 2-year follow-up of clinical and magnetic resonance imaging (MRI) results from a prospective consecutive case series of patients treated with a newly developed, fully arthroscopic technique of collagen matrix-based meniscus repair (AMMR) and the injection of bone marrow aspirate into the area of the meniscal lesion.

Materials and Methods

This clinical study has been approved by the Institutional Review Board committee of the Medical University of Poznan, Poland, and has been performed according to the ethical standards laid down in the 1964 Declaration of Helsinki. All participants provided their written informed consent to participate in this study.

Study Design

The study was designed as a case series, a level IV clinical study.

Inclusion criteria for the procedure comprised (1) full-thickness, combined meniscal tear greater than 20 mm in length, (2) horizontal and radial tear, (3) tear location reaching more than 6 mm from the meniscocapsular junction including the avascular zone, or (4) both degenerative and non-degenerative meniscus (i.e., horizontal and radial tears, involving the white-white and red-white zones, as well as extensive tears of the bucket-handle type). An example of meniscus injury treated as a part of this study is shown in **Figure 1** and as a schematic drawing in **Figure 2**.

Patients were excluded from the procedure if (1) full-thickness combined meniscus tear was larger than 85% of the meniscus body or (2) meniscus tear with fibrillation extended in all area of tear which was not able to be stabilized with a suture (meniscus lesion beyond repair).

Time to surgery was defined as a time elapsed between injury or patient decision to seek orthopaedic treatment to the AMMR surgical intervention. The length of the meniscal tear was measured during arthroscopic procedure by using arthroscopic ruler. Degenerative meniscus was in most cases defined as a adipose (fat) degeneration or significant fibrillations not exceeding 85% body of the meniscus.

The primary outcome of the study defined as a result of a clinical of the knee joint and meniscus related symptoms before and after treatment (at 2-year follow-up). The safety

of the procedure was assessed based on pass-fail criteria's and adverse events related to the procedure or medical device used (Chondro-Gide collagen matrix).

The clinical results were assessed and evaluated by the number of different scoring systems based on patient reported outcomes and clinical findings. The following information were recorded at each assessment point: International Knee Documentation Committee (IKDC) 2000 subjective score, IKDC 2000 clinical evaluation score, Lysholm score, and Barrett clinical criteria of meniscal healing.[15]

Based on original Barrett criteria score, we have developed a converted method (described in details in Appendix A) to allow for statistical analysis. The aim of this calculation is to convert the four clinically meaningful signs (pain, effusion, clicking/locking, McMurray test), which are coded binary (0 = absence and 1 = presence) into a numerical notation. The final values may vary from 0 to 15 and each value represents the discreet stage of the knee joint with respect to the initial Barrett's evaluation criteria.

In an attempt to lower the confounding influence of the concomitant knee diseases in the patients included in the study, the analysis of the subgroup of patients with isolated meniscus injury was performed. Data from 14 patients were available for the analysis.

Secondary outcome included an MRI evaluation at 24 months postoperatively.

Magnetic resonance imaging scans were acquired with a 1.5-tesla whole-body scanner using a commercial circumferential knee coil. Imaging sequences included, axial T1-weighted spin-echo (SE: 700/11 [TR ms/TE ms], 20 cm field of view (FOV), 5 mm/1 mm [slice thickness/interslice gap], 256 × 192 matrix, frequency encoding [FE] anterior-posterior, one excitation), coronal T1-weighted SE (600/11, 16 cm FOV, 4 mm/0.5 mm, 256 × 192, FE superior-inferior, 2 excitations averaged), sagittal T1-weighted SE (600/11, 16 cm FOV, 4 mm/0.5 mm, 256 × 192, FE anterior-posterior, 2 excitations averaged), sagittal T2-weighted fast spin echo (FSE: 2500/90; echo train length (ETL) of 8; 14 cm FOV, 4 mm/0 mm, 256 × 192, FE superior-inferior, 2 excitations averaged) with fat suppression (frequency-selective presaturation), and sagittal fat-suppressed T1-weighted 3-dimensional (3D) spoiled gradient echo (FS-3DSPGR: 58/6, 40° flip angle, 14 cm FOV, 256 × 128 matrix, 60 contiguous 2-mm slices covering all articular cartilage plates in the knee, FE, superior-inferior, one excitation, frequency-selective fat saturation, superior-inferior saturation bands to minimize pulsation artifacts).

All images were transferred to the Osirix v.5.8.5 DICOM viewer software (Pixmeo SARL, Bern, Switzerland). Images were scored with respect to modified Whole Organ MRI Score (WORMS) criteria for medial and lateral meniscal integrity.[24] Image assessments were performed independently by 2 orthopedic surgeons (TP, KC-G). Readers used all images to evaluate each feature. Problematic cases were assessed by both readers at the same time to achieve consensus.

The anterior horn, meniscal body segment, and posterior horn of the medial and lateral menisci were scored separately on the scale from 0 to 4 based on both the sagittal and coronal images: 0 = intact; 1 = nonhomogeneous signal but not a meniscal tear (in original WORMS scale minor radial tear or parrot-beak tear); 2 = nondisplaced tear or prior surgical repair; 3 = displaced tear or partial resection; 4 = complete maceration/destruction or complete resection. A cumulative grade for each meniscus was determined using the following scheme: 0 = all 0; 1 = at least one 1, but no >1; 2 = 2 in only one region; 3 = 2 in more than one region; 4 = 3 in one or more regions; 5 = 4 in only one region; 6 = 4 in more than one region. These modifications were introduced in order to accurately describe MRI scans.

In this study, the following pass-fail criteria were used:

1. Failure if at the follow-up process patient underwent partial/complete meniscectomy or knee replacement after AMMR procedure
2. Pass was defined as an overall grade of A or B at final follow-up with clinical IKDC 2000 assessment.
3. Pass was also defined if the patient exhibited no pain at rest or with activity and a negative McMurray's test.

Patients who did not met the aforementioned criteria were characterized as "poor" with regard to their latest clinical follow-up.

Additionally, a WORMS cumulative grade 2 and more classified patients in the poor MRI results group.

Collagen Matrix

The Chondro-Gide Collagen Matrix (Geistlich Pharma AG, Wolhusen, Switzerland) was used for meniscus wrapping. This is a non–cross-linked collagen type I/III matrix, with a 2-layer (bilayer) structure. The porous layer (placed facing the defect) allows the in-growth of cells and a newly formed tissue. The compact layer acts as a scaffold to prevent cells being flushed out of the meniscal site defect.

Surgical Technique

A diagnostic knee arthroscopy was performed to identify other pathologies, such as ligament or cartilage lesions. All cartilage and ligament lesions were repaired during surgery. The extent and type of meniscal lesion was evaluated to determine whether or not the meniscal lesion meets the study inclusion criteria.

Lesions were reduced and meniscal fragments were fixed with a meniscal fixing device (Fast-Fix, Smith & Nephew, Andover, MA, USA).

The matrix, usually of the size 30 × 20 mm, was prepared by addition of nonabsorbable suture loops (Ethibond

2, Ethicon Inc), passing through the surface of the matrix on both sides. The matrix was then inserted into an applicator.

Using direct arthroscopic vision, the loops of threads running through the meniscal posterior horn and the meniscal body were passed with a special suture shuttle (Accupass, Smith & Nephew, Andover, MA, USA) at the level of the anterior border of the tear.

Ethibond 2, matrix-passing sutures, were inserted to the meniscal posterior horn and to the anterior part of the lesion. The applicator with the collagen matrix was introduced into the knee joint. The matrix was inserted into the knee joint with smooth surface facing cartilaginous surfaces of the tibia and femur and with porous part directed to the meniscal surface.

After assuring that the matrix adhered to the meniscus from the tibial side the scaffold was fixed to the meniscus, with arthroscopic simple knotted sutures. As a result, the meniscus was wrapped by the collagen matrix on both sides, and the matrix was fixed into the meniscus in a stable way. Additionally, 1 to 4 (3 on average, depending on the extension of the tear) Fast-Fix sutures were inserted into the meniscus wrapped with the matrix for a better stabilization of the meniscal tear and for an increased tightness between the meniscus and the matrix.

An example of suture placement and meniscus wrapping with collagen matrix is shown in **Figure 3** and as a schematic drawing in **Figure 4**.

The bone marrow aspirate was obtained from the tibial proximal epiphysis of the operated knee. Approximately 5 mL of liquid bone marrow was aspirated. The bone marrow aspirate was injected between the Chondro-Gide matrix and the meniscus, under direct arthroscopic control and carried out in 'dry arthroscopy' conditions.

The surgery was completed by closing the wounds without a drainage the knee joint. No knee-stabilizing orthosis was used. An extensive surgical description of the technique has been published by Piontek *et al*.[23] in 2012.

Postoperative Physiotherapy Protocol

Patients began postoperative treatment from toe touch crutch walking and a range of motion exercises on the first postoperative day, for a period of 4 weeks. Over the next 2 to 4 weeks the patients were allowed to walk with partial weight-bearing. The patients were encouraged to return to their daily activity by 12 weeks. Sports activity was possible after 6 months postsurgery. Detailed rehabilitation guidelines used in our center have been presented in Appendix B.

Statistical Evaluation

Statistical evaluation included descriptive statistics to compare the pre- and postoperative indexed values.

The comparison between preoperative (time 0) and postoperative (24 months follow-up) values of IKDC 2000 clinical, IKDC subjective, and Lysholm separately had been calculated by nonparametric Wilcoxon test.

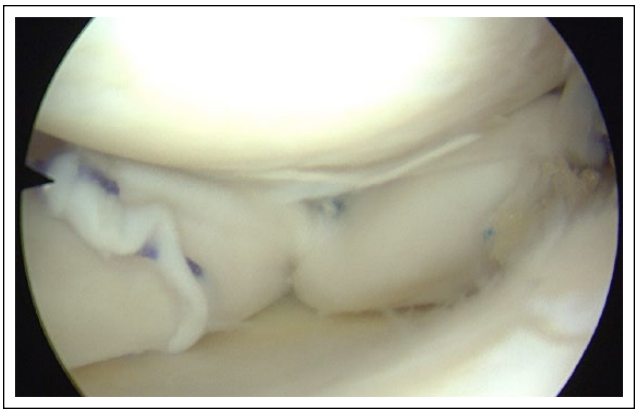

Figure 3. An example of suture placement and meniscus wrapping with collagen matrix.

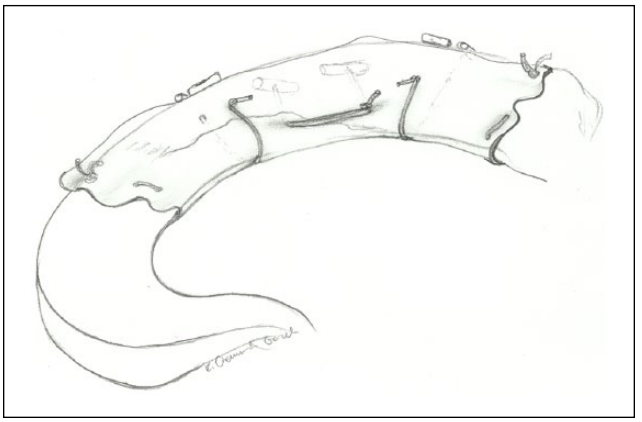

Figure 4. Schematic drawing of a suture placement and meniscus wrapping.

The statistical significance of values between the preoperative and 2-year follow-up values of IKDC 2000 clinical, IKDC 2000 subjective, and Lysholm scores with respect to the WORMS MRI cumulative score were performed using Kruskal-Wallis test.

Spearman's rank coefficient test was used to calculate the correlation coefficients between IKDC 200, IKDC subjective, and Lysholm score preoperatively and at 2-year follow-up and against WORMS MRI cumulative score.

The cut off level of $P < 0.05$ was used for statistical significance.

Computations were done with Statistica data analysis software system version 10 (Statsoft Inc, 2011).

Results

The comprehensive data, including demographics, pre- and postoperative data of the patients participating in the study, are summarized in **Table 1**.

Between April 2010 and November 2011, 53 consecutive patients (40 male and 13 female, age 18-59 years) meeting

Table 1. Summary of Patients and Outcomes Data.

Notes	Count	Sex	Age (Years)	TTS (Months)	BMI (kg/m^2)	Length (mm)	Barrett Pre/2-year FU Value	IKDC Clinical Pre/2-year FU	Lysholm score Pre/ 2-year FU	IKDC Subjective Pre/2-y FU	MRI Cumulative Scoring[a]
	1	M	46	2	32	30	15/0	D/A	68/90	26.4/73.6	1
	2	M	33	28	27	30	11/1	C/B	40/64	40/70	1
	3	M	51	24	23	30	15/1	C/B	63/77	36/41.1	1
	4	M	18	26	24	30	15/0	D/A	85/90	69/83.3	1
	5	M	35	7	27	30	15/0	D/A	74/95	46/89.7	1
	6	M	59	36	22	30	15/0	D/A	31/100	21/90.8	1
	7	F	29	48	20	40	15/0	D/A	37/94	37/82.8	0
	8	F	50	60	22	30	15/0	C/A	36/100	36/90.8	1
	9	F	46	10	27	25	15/0	C/A	72/90	41.4/66.7	1
	10	M	22	6	24	30	15/0	D/C	79/94	44.8/89.7	1
	11	F	46	2	22	20	15/0	C/A	62/95	32/86.2	1
	12	M	44	24	29	25	15/0	C/A	50/99	37/87.4	1
	13	M	50	3	32	30	15/0	D/A	67/85	39.1/75.9	1
	14	M	57	24	26	30	15/0	D/A	89/100	57.5/90.8	1
	15	M	31	18	27	40	15/1	C/B	51/53	26/52.9	2
	16	F	25	6	25	20	11/0	C/A	50/87	31/55.2	1
	17	M	18	3	24	30	15/0	D/A	70/95	42/95.4	1
	18	M	32	36	27	20	11/0	D/A	90/95	56/96.5	1
	19	M	35	24	30	30	15/0	D/A	81/100	52.9/100	1
	20	M	23	2	26	30	15/0	C/B	94/89	58/80.5	0
	21	M	26	1	27	40	15/0	C/A	67/100	44/100	1
	22	M	27	8	25	30	11/0	C/A	29/80	16/78.2	1
	23	M	50	3	27	30	15/1	D/B	89/60	79.3/63.2	1
	24	M	58	36	35	30	15/0	D/A	49/89	29/73.6	1
	25	M	44	24	24	35	15/0	D/A	73/89	59/89.7	1
	26	M	34	2	23	30	9/0	D/A	89/100	61/95.4	1
	27	F	48	10	27	30	15/6	D/A	42/33	31/37.9	1
	28	F	20	24	21	20	15/0	D/A	68/95	53/93.1	1
	29	M	49	18	24	30	11/0	C/A	80/85	41/64.4	2
Failure	30	M	30	18	24	25	15/N/A	C/N/A	N/A	N/A	N/A
	31	F	57	60	27	30	15/1	D/C	57/50	32/46	1
	32	M	33	1	25	15	15/0	D/A	85/95	62/95.4	2
	33	M	39	36	28	25	15/0	D/A	82/76	50.6/75.9	2
	34	M	48	2	28	30	15/0	D/A	78/95	42/89.7	1
	35	F	37	60	18	30	13/0	D/A	87/81	52/81.8	1
	36	F	23	4	21	30	15/0	D/A	85/81	60/80.5	1
	37	M	23	120	24	30	15/0	D/A	66/94	57.5/92	1
	38	F	36	28	21	30	11/0	D/B	61/74	29/57.5	1
	39	M	18	2	26	35	15/0	D/A	64/100	48.3/95.4	1
	40	M	41	12	27	35	13/0	D/A	56/73	51.7/50.6	0
Data partly missing	41	M	47	60	30	35	15/0	D/A	Missing/92	Missing/92	1
	42	M	40	60	27	30	15/0	C/A	90/85	62/85.1	2
	43	F	49	24	23	30	15/0	D/A	71/89	29.9/70.1	0
	44	M	19	4	27	30	15/0	D/A	35/94	32.2/87.4	0
Failure	45	M	33	3	27	30	15/0	D/B	52/57	39/54	NA
	46	M	19	4	29	30	15/0	C/A	57/100	32.2/87.4	2
MRI missing	47	M	39	2	24	30	15/0	D/A	70/95	58.6/88.5	Missing
	48	M	28	36	22	30	15/0	D/A	70/77	64.4/70.1	1

Abbreviations: BMI, body mass index; F, female; FU, follow-up; IKDC, International Knee Documentation Committee; M, male; N/A, not aapplicable; TTS, time to surgery; Barrett scores, binary value for pain, effusion, clicking/locking, McMurray test; Barrett values, converted Barrett scores (Att.1).
[a]MRI cummulative based on WORMS modified criterias.[24]

inclusion criteria were included in the study and treated with the AMMR method. In total, 32 right and 21 left knees have been assessed in the study. Degenerative meniscus tears were treated in 30 cases and nondegenerative in 23 cases. Lesions were observed in 38 medial and 15 lateral menisci.

Meniscal lesions were associated with other knee joint surgeries for concomitant lesions in 32 cases, and are reported in **Table 2**.

The overall study participants distribution is depicted on CONSORT Case Series diagram in **Figure 5**.

Table 2. Concomitant Knee Joint Surgical Treatment Provided at the Time of Indexed Procedure.

	Concomitant Knee Joint Condition	Concomitant Knee Joint Treatment
n = 9	ACL rupture	ACL autologous graft reconstruction
n = 7	Chondral lesion grade IV	AMIC MFC
n = 4	Medial meniscus tear	Medial meniscus suture
n = 7	ACL rupture	ACL autologous graft reconstruction
	Medial meniscus tear	Partial medial meniscetomy
n = 2	Post–ACL reconstruction, poor clinical result	Revision ACL autologous graft reconstruction
n = 3	ACL rupture	ACL autologous graft reconstruction
	Chondral lesion grade III or IV	AMIC MFC

Abbreviations: ACL, anterior cruciate ligament; AMIC, autologous matrix-induced chondrogenesis; MFC, medial femoral condyle.

Two-year follow-up period was achieved in 50 cases, 3 (5.7%) patients being lost to follow-up. In addition, 2 patients were completely excluded from the evaluation due to the incomplete pre- or postoperative data.

Two patients (4.2%) underwent partial meniscectomy and according to the pass-fail criteria were classified as failures. Based on pass-fail criteria used in this study, 46 patients were successfully treated. This value represents 95.8% of the cases entered the prospective evaluation and 86.8% of the intended to treat cases.

IKDC 2000 subjective and Lysholm scores pre and postop comparison (**Table 3**) indicated a statistically significant improvement ($P = 0.0001$, Wilcoxon test).

The analysis of the IKDC clinical scores after 2 years (**Table 4**) demonstrated that 96% patients achieved A or B scores, compared with none of the patients present in either category preoperatively. A statistically significant improvement in IKDC 2000 clinical assessment was also observed between preoperative and 2-year follow-up ($P = 0.0001$, Wilcoxon test).

The clinical assessment based on Barrett criteria (calculated using the method described in Appendix A) is presented in **Table 5**, panels A and B. Calculated values demonstrate a tendency for the patients to score low (good clinical outcome) at the 24-month follow-up. Significant improvement for Barrett's clinical score assessment between pre and postoperative values was observed ($P = 0.0001$, Wilcoxon test).

In the subgroup of isolated meniscal injuries, the IKDC 2000 subjective and Lysholm scores were slightly lower preoperatively than in the overall study population, but the results were in the range of the general study population after 2 years (**Tables 6** and **7**). An improvement in IKDC 2000 subjective and Lysholm scores in this subgroup of patients was observed on average and in patient by patient assessments (data not included in this article).

In 11 patients, an isolated horizontal cleavage tear of the menisci were observed (average age 41 years, range 20-59 years). In this group of patients, an average improvement of subjective IKDC (from 47 to 72) and Lysholm (from 79 to 89) outcomes were observed. None of those 11 cases had undergone any additional surgical knee treatment and had their meniscus saved. The worst results were obtained among patients suffering from cartilage damage (grade IV) irrespective of age. The remaining patients with additional damage to the knee (mainly posttraumatic), obtained very good and excellent results. No significant difference in the rate of meniscal repair failure was noted for anterior cruciate ligament–intact, compared with anterior cruciate ligament–deficient knees.

In the 2 failures, a second-look arthroscopy was performed. In 1 case, the meniscal healing in arthroscopic assessment was found but due to persisting pain symptoms, a partial meniscectomy was performed 12 months after initial treatment. Postoperatively the patient still complaint about the pain localized in the region of the medial tibial condyle. Subsequent MRI evaluation demonstrated stress fracture of the medial tibial condyle. After appropriate treatment, the patient reported pain-free knee and full knee joint function. The second patient did not comply with the physiotherapy protocol and returned to full physical activity 3 months postoperatively, despite the doctor's recommendations. As a result, he developed a second injury of the treated meniscus leading to partial meniscectomy 6 months after indexed procedure.

Analysis of the follow-up MRI images revealed 85% of good meniscus outcomes based on the WORMS classification (cumulative score ≤1) (**Table 1**).

In the MRI examination at 2 years postoperatively, 76% of all operated menisci showed meniscal abnormalities corresponding to a nonhomogeneous signal without meniscal tear and were classified as grade 1 according to WORMS classification. Eleven percent of menisci had been classified as grade 0, with a fully regenerating meniscal cartilage with homogenous MRI signal. The WORMS cumulative grade 2 was established in 6 out of 45 patients (13%) and they were classified as a poor MRI results.

The analysis of the MRI results and clinical findings at 2 years FU demonstrated that in this case series the cumulative WORMS results did not correlate with either clinical (clinical IKDC 2000 and Barrett score) or subjective scores (IKDC 2000 subjective and Lysholm score) (**Table 8**).

Notably, in 29 (62%) of the cases, MRI revealed the presence of a cyst located in the vicinity of the T-fix anchor. The presence of the cyst had no correlation with clinical (IKDC 2000 clinical, $P = 0.47$; and Barrett criteria) or cumulative WORMS results. Additionally, no correlation was found between the number of used T-fix anchors and

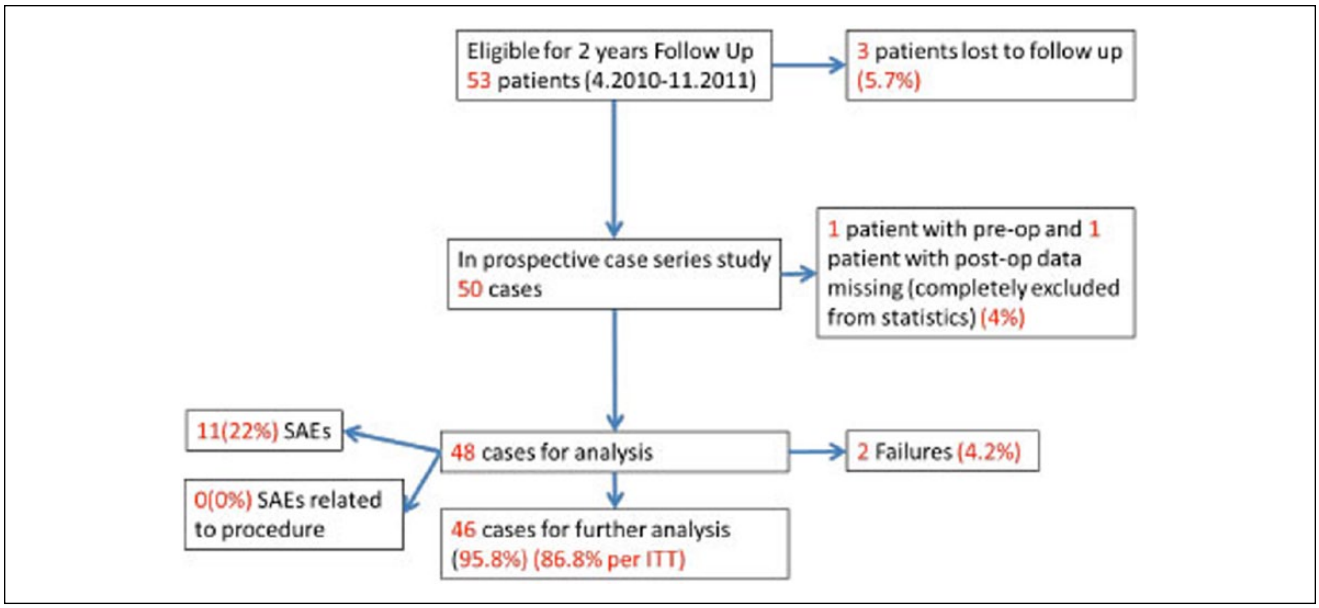

Figure 5. CONSORT (Consolidated Standards of Reporting Trials) case series diagram. SAE, severe adverse event (according to ISO 14155).

Table 3. The Subjective IKDC and Lysholm Scores Preoperative and 24 Months Postoperative Follow-Up Results.

	n	Average	Minimal	Maximal	95% CI	*P* Value (Wilcoxon Test)
IKDC subjective preoperative	46	44.5	16.0	79.3	5.2	0.0001
IKDC subjective 24-month FU	46	79.1	37.9	100.0	9.1	
Lysholm preoperative	46	66.1	29.0	94.0	6.2	0.0001
Lysholm, 24-month FU	46	86.4	33.0	100.0	5.1	

Abbreviations: CI, confidence interval; FU, follow-up; IKDC, International Knee Documentation Committee.

Table 4. The IKDC 2000 Clinical Results.

	Preoperative		24-Month FU		
IKDC 2000 Clinical Score	Number of Cases	%	Number of Cases	%	*P* Value (Wilcoxon Test)
A	0	0.0	38	82.6	
B	0	0.0	6	13.0	0.0001
C	15	31	2	4.4	
D	33	69	0	0.0	

presence or absence of the cyst ($P = 0.22$) and with cumulative WORMS results ($r = -0.08$; $P = -0.62$, Spearman's rank coefficient test, Kruskal-Wallis test).

Figure 6A–D illustrates the MRI history of one representative case of a 50-year-old man who had undergone medial meniscus repair with AMMR technique and cartilage regeneration of medial femoral condyle with arthroscopic AMIC procedure in a one-stage knee arthroscopy.

In our series, 13 serious adverse events (including 2 failures) were registered. However, none of these events were related to either the indexed procedure or material used. The summary of adverse events is presented in **Table 9**.

Discussion

The data obtained demonstrate that combined and complex meniscal tears located in the white-white and white-red zones can be treated arthroscopically safely and with clinical success treated by meniscal suturing and wrapping in the collagen matrix. All patients participating in this study

Table 5. Results of Barrett's Clinical Score of Criteria of Meniscus Healing.[a]

A: Barrett's Clinical Score Preoperative	Number of Patients	%
No symptoms (score 0)	0	0.0
Pain or joint line tenderness + clicking or locking (score 9)	1	2.0
Pain or joint line tenderness + effusion + positive McMurray's test (score 11)	6	12.5
Pain or joint line tenderness + clicking or locking + positive McMurray's test (score 13)	2	4.2
Pain or joint line tenderness + effusion + clicking or locking + positive McMurray's test (score15)	39	81.3
B: Barrett's Clinical Score, 24-Month Follow-Up	**Number of Patients**	**%**
No symptoms (score 0)	40	87.0
Pain or joint line tenderness (score 1)	5	10.9
Effusion + clicking or locking (score 6)	1	2.1

[a]$P = 0.0001$ (Wilcoxon test). No patient was presented with positive McMurray test.

Table 6. Results of IKDC 2000 Subjective Scores for the Patients with Isolated Meniscal Injuries.

	n	Average	Minimal	Maximal	95% CI
Preoperative	14	37.6	16.0	64	(85.9 to 74.61)
24 months	14	79	41	96.5	(79.42 to 89.58)

Table 7. Results of Lysholm Scores for Patients with Isolated Meniscal Injuries.

	n	Average	Minimal	Maximal	95% CI
Preoperative	14	58	29	90	(73.88 to 85.92)
24 months	14	88	64	100	(86.52 to 94.48)

Table 8. Correlation Analysis Between MRI Findings and Clinical Results.

MRI Cumulative Value vs.	*n*	Correlation Coefficient *r* (Spearman's Rank Coefficient Test)	*P* Value (Kruskal-Wallis test)
IKDC 2000 at 24 months postoperative	47	−0.0348	0.8165
IKDC subjective at 24 months postoperative	47	0.07	0.6401
Lysholm at 24 months postoperative	47	0.0114	0.9336
Barrett at 24 months postoperative	47	−0.0294	0.8444

Abbreviations: IKDC, International Knee Documentation Committee; MRI, magnetic resonance imaging.

would have had their menisci partially or totally resected otherwise.

The present results, demonstrate that the specially developed "all-inside" technique of suture wrapping of the lesion with a collagen membrane and in situ administration of blood bone marrow aspirate through an arthroscopic technique, is feasible. It presents, in our opinion, an alternative to total or partial meniscectomies in cases of combined tears located in the red-white and white-white zones. As previously suggested, the collagen scaffold may facilitate healing by providing an appropriate biological environment for cells and bone marrow blood to facilitate the process of natural healing and regeneration.

The primary outcome results of our 2-year follow-up data indicate not only possibility for meniscus preservation but also increase in the IKDC subjective score from 44 to 79 and in the Lysholm score from 66 to 86 on average preoperatively and at 2-year follow-up, respectively. IKDC 2000 clinical and Barrett scores were also improved at 24 months postsurgery.

In the subgroup of 11 cases of horizontal tear we were able to save the meniscus in all cases with 82% of good to excellent clinical results, and 64% of very good and excellent subjective score assessment.

In our case series, we have used an "all inside" surgical technique. It provides good access to the operating site, is simple and was preferred by the operating surgeon. There is, however, no reason to restrict the surgical technique to the one approach only. The goal is to fix the torn meniscus and wrap it in to the collagen membrane.

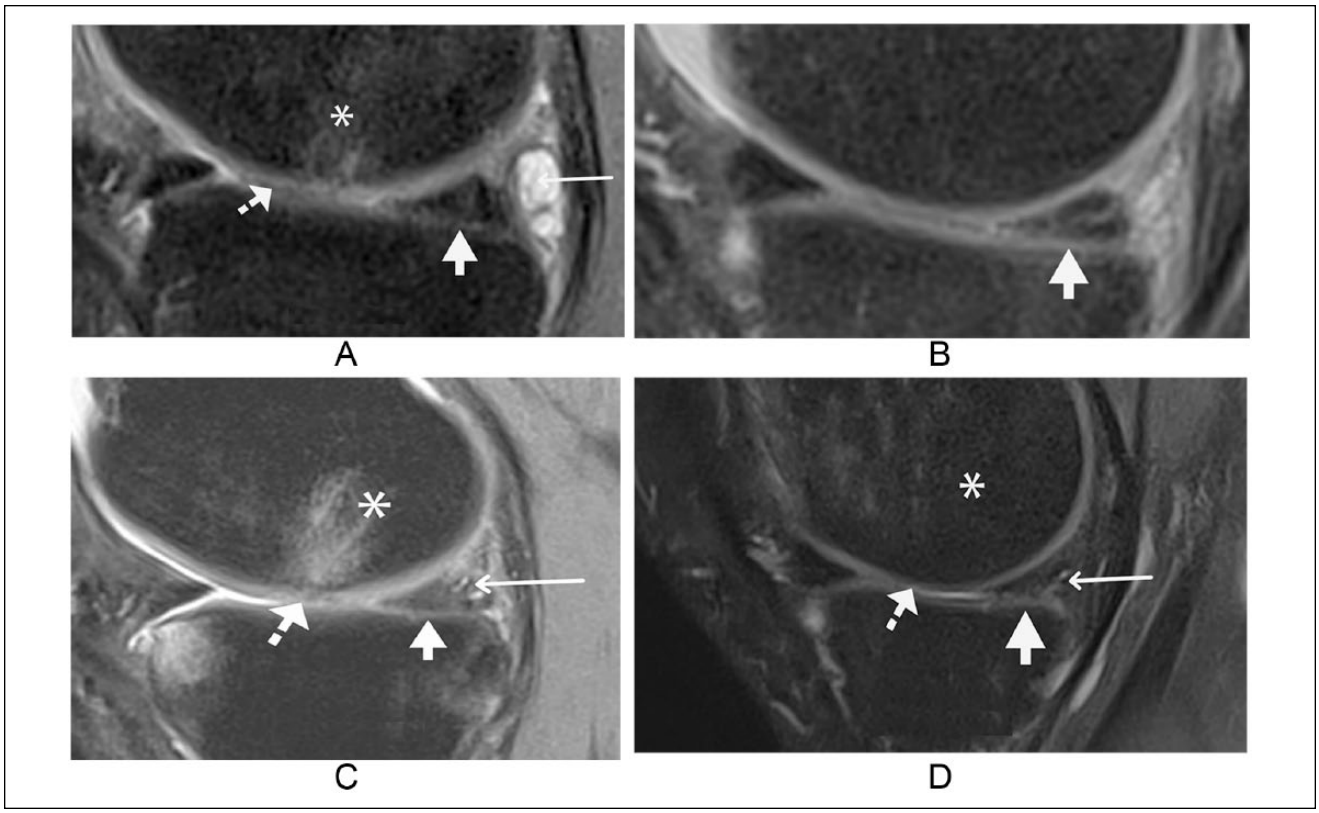

Figure 6. An example of sagittal proton density–weighted fat-saturated image magnetic resonance iamging (MRI) of a 50-year-old man who had undergone medial meniscus regeneration with arthroscopic technique of collagen matrix-based meniscus repair (AMMR) and cartilage regeneration of medial femoral condyle with arthroscopic autologous matrix-induced chondrogenesis (AMIC) procedure in one-stage knee arthroscopy. (**A**) Six-month follow-up. Abnormal signal of the medial meniscus (thick arrow), bone marrow edema (asterisk), a parameniscal cyst (thin arrow), and abnormal signal from regenerated cartilage area (dotted line arrow). (**B**) Six-month follow-up. Abnormal signal extending to the superior surface of the body of the medial meniscus (thick arrow). (**C**) Twenve-month follow-up. Normal signal of the medial meniscus (thick arrow), a parameniscal small cysts containing Fast-Fix anchors (thin arrow), bone marrow edema (asterisk), and abnormal signal from regenerated cartilage area (dotted line arrow). (**D**) Twenty-four-month follow-up. Normal signal of the medial meniscus with scar tissue (thick arrow), Fast-Fix anchors with small cysts (thin arrow), normal signal from bone marrow (asterisk) and normal signal from the regenerated cartilage area (dotted line arrow).

Collagen membrane use to protect the cartilage healing after micro fracture is an established procedure since almost 10 years.[25,26] Recently, Jülke *et al*.[21] described encouraging results of collagen membrane use for short-term guided tissue regeneration of avascular meniscal tears on the goat model, especially if the autologous chondrocytes were applied.

Autologous bone marrow aspirate can be obtained in a relatively simple and inexpensive method, and is known as a source of stem cells as well as growth factors. Although alternative sources of stem cells are described in the literature, there is currently no evidence of superiority one over the other source or method of preparation.

After reviewing the clinical results of the series, we found no reason to limit the method to the patients presented with absent signs of an advanced arthrosis of the knee, neither to the patients of the young age. Based on our experience great care needs to be taken in patients with grade IV cartilage lesions which scored lowest in our case series. Additional research on a larger population may help in finalizing the indications for the proposed method of treatment.

Our study protocol includes MRI assessment as a secondary outcome. While there are number of publications indicating MRI as the imaging modality of choice for diagnosis of primary meniscal injuries, to date there is no suitable scoring system offering the assessment classification and allowing for an objective analysis of the MRI data after meniscus repair. Conventional MR accuracy for detection of meniscal recurrent tears status post-surgery has been previously reported as 66% to 82%.[27,28]

In the absence of established MRI scoring system for assessment of meniscal repair, we have chosen the WORMS score as the classification best suited for the purpose of this study.[24]

We found a higher prevalence of increased signal in the posterior horn of the treated meniscus in 35 cases (73%) in which degeneration and tears are most frequently found, and

Table 9. Details of Serious Adverse Events Not Related to the AMMR Procedure.

No.	Patient ID	Serious Adverse Events	Treatment
1	46	Acute compartment syndrome ipsilateral leg	Fasciotomy
2	11	Medial meniscus injury ipsilateral leg (indexed meniscus—lateral)	Second-look arthroscopy—partial medial meniscectomy
3	9	Medial meniscus injury contralateral leg	None
4	24	Brain aneurysm	Embolization
5	12	Medial meniscal injury contralateral leg	Arthroscopy—meniscus regeneration with Chondro-Gide and 2× Fast-Fix (AMMR)
6	23	Acute medial meniscus injury contralateral leg	Arthroscopy—medial meniscus suture
7	8	Arthrofibrosis ipsilateral leg, pain due to femoral screw after MPFL reconstruction	Second-look arthroscopy—soft tissue release
8	13	ACL graft rupture, medial meniscus injury (indexed meniscus—medial)	Revision ACL reconstruction, medial meniscus suture
9	22	Arthrofibrosis ipsilateral leg	Second-look arthroscopy—soft tissue release
10	52	Medial meniscus injury contralateral leg	Medial meniscectomy
11	32	ACL graft failure	Revision ACL reconstruction
12	34 F	Undetected fatigue fracture of left medial tibial condyle before AMMR procedure. Persistent pain after meniscus wrapping	Partial medial menisectomy—histologically signs of regenerated meniscal tissue
13	50 F	Reinjury of ipsilateral leg: medial meniscus tear (indexed meniscus—medial). Patient did not comply with postoperative physiotherapy regime and returned to full professional activity as a firefighter	Arthroscopy—partial medial menisectomy

Abbreviations: ACL, anterior cruciate ligament; AMMR, arthroscopic technique of collagen matrix-based meniscus repair; MPFL, medial patellofemoral ligament.
[a]F indicates failure according to the pass-fail criteria for this study.

the differentiation of a high signal intensity from a meniscal tear at this site is of great clinical importance. The reason and meaning of this finding remains unclear, but it may be due to the scar formation and increased vascularization after regeneration. In 7 (15%) cases, we had found nonunion in posterior region of meniscus. Interestingly, we had observed a homogenous signal in 5 (10%) cases, which is uncommon after meniscus suturing without biological healing enhancing methods. We also had observed changes in shape of meniscus; however, this finding has been reported as sensitive but not specific for the diagnosis of recurrent tears.[28]

Similarly to Popescu *et al*.,[30] no correlation between MRI outcomes, healing outcomes and clinical scores, Barrett's criteria, patient's satisfaction, or the return to previous level of activity was found in the study. On the other hand, Morgan *et al*.[31] reported 84% asymptomatic patients after meniscal repair. Of these, 65 % had healed completely and 19 % had healed incompletely, leaving a failure of 16%. All failures remained symptomatic, while all healed and incompletely healed menisci were asymptomatic. Similar observations were described by Cannon and Vittori[32] and Pujol *et al*.[33,34]

Miao *et al*.[35] have recently compared meniscal treatment techniques, and found that strict clinical evaluation resulted in lower estimates of the healing rate compared with MRI or second-look arthroscopy. Similarly to Miao and Pujol, we are of the opinion that a thorough clinical evaluation, including medical history and physical examination, seems to remain the "gold standard" in short-term follow-up, and this may be supplemented with imaging studies when needed.[35,36]

"All-inside" suture materials, such as Fast-Fix, are now widely available. The occurrence of meniscal cyst is rather frequently related to all known suture techniques and materials.[37,38] In the present study, anchor cysts were noted in 29 (62%) menisci in follow-up MRI evaluation, without significant or clinically relevant correlation with clinical outcome.

Type of lesion, type of surgery, timing of biological healing, and the patient's symptoms determine the various types of rehabilitation protocol available for a full recovery. The optimal physiotherapy program after meniscus repair has not been established.[39-41] Specific physiotherapy treatment applicable after AMMR procedure has been designed and used for the patients of this study (see Appendix B).

The results presented in this study were collected on a consecutive case series from a single center. The present study has several limitations. By the virtue of the case series model, the study design did not include a control or comparison group. The alternative of treatment for the participants of current study would be total or partial meniscetomy. From the literature and clinical experience it is known that such treatment leads to biomechanical suboptimal condition and increases the risk of development of the arthritic changes in the knee joint.[7-11] Possibility of control group containing simple suturing of menisci was also contemplated; however, the clinical experience of menisci sutured in white-white zone were not satisfactory. It has proven to be ethically unjustified to propose the clinical study with the control group, which will evidently not be benefitting from the treatment and such proposal was in fact not considered by our institutional review board. The goal of this study was to evaluate the safety of the procedure and early clinical outcome of the preserved menisci treated with the collagen wrapping technique.

Since majority of patients in the study had additional lesions, including cartilage defects and anterior cruciate ligament deficiency. It cannot be excluded that those

concomitatnt defects affected the final clicnial outcome due to potential differences in the biology of the intrasynovial fluid.

Furthermore, neither calculation of the sample size nor power analysis was performed. Such a study design may be confounded by selection bias, which limits statements on the causality of correlations observed. The inclusion criteria based on the extent and type of meniscal lesion were assessed and operated by one surgeon. Video and photographic documentation have been however obtained for each case documenting meniscal lesion and the justification for using the collagen wrapping surgical technique according to the selection criteria of the study design.

For the recruitment for this study, the lower limb axis was not a limiting factor. Patients underwent full clinical orthopedic examination at each time point. The study objective was to assess the clinical state after applying the new technology regardless of the axis of the leg. No patient underwent any leg axis correction.

A Barrett score used for meniscus assessment is a well-established tool used for many years for research and clinical purposes.[15] The numerical representation of the Barrett score, described in detail in Appendix A was simple conversion of the single variables into the one summarized value.

Safety of the procedure was evaluated based on pass-fail criteria and adverse events recording. None of the recorded adverse events were related to the procedure or material used in the procedure. There were 2 cases of arthrofibrosis occurring postoperatively (4%). Both patients have been successfully treated and achieved full recovery and full range of motion in the knee joint. Based on the published data the frequency of arthrofibrosis of the knee joint after arthroscopic interventions is reported between 8% and 10%.[37,42]

The compartment syndrome can ouccure after arthroscopic procudre. This has been described in the literature.[43-49] We agree that an accumulation of irrigation fluid passing through a popliteal cyst into the superficial flexor compartment can be potential couseor at least should be suspected. In summary, even with an optimal perioperative management the subsequent compartment syndrome due to knee arthroscopy cannot be completely avoided.

The results of this study can be considered for "salvage" treatment of complex meniscal tears in patients who otherwise would have undergone total or partial meniscectomies. The 2-year follow-up is generally considered as a minimum time span to assess the results of the orthopedic intervention in the knee joint. In fact, the current understanding is that meniscal healing is reported to be achieved at 6 months.[50,51] The surgical technique applied in this study will be further validated through an extended follow-up for the next 3 years.

Conclusions

A clinical results at the 2-year follow-up of the patients operated by AMMR technique due to the meniscal lesions localized in the white-white and white-red zones demonstrated that presented surgical technique can offer a safe and promising additional alternative for surgeons who are willing to make an effort to save the meniscus in the patients otherwise scheduled for meniscal removal.

Appendix A

Converted Barrett score: Method of calculation of the digital representation of the Barrett's clinical criteria of meniscal healing. This scoring system applies the concept of numerical notation used in the computations.

The aim of this calculation is to convert the 4 clinically meaningful signs (pain, effusion, clicking/locking, McMurray test) that are coded binary (0 = absence, 1 = presence) into the numerical notation enabled for further processing. The final values may vary from 0 to 15 and each value represents the discreet stage of the knee joint with respect to the initial Barrett's evaluation criteria.

The following notations were adopted for the description of the Barrett's criteria:

Score	
0	No symptoms in any of all four criteria
1	Pain or joint-line tenderness
2	Effusion
3	1 + 2; pain or joint-line tenderness + effusion
4	Clicking or locking
5	1 + 4; pain or joint-line tenderness + clicking or locking
6	2 + 4; effusion + clicking or locking
7	1 + 2 + 4; pain or joint-line tenderness + effusion + clicking or locking
8	Positive McMurray's test
9	1 + 8; pain or joint-line tenderness + positive McMurray's test
10	2 + 8; effusion + positive McMurray's test
11	1 + 2 + 8; 1 + 8; pain or joint-line tenderness + effusion + positive McMurray's test
12	4 + 8; clicking or locking + positive McMurray's test
13	1 + 4 + 8; pain or joint-line tenderness + clicking or locking + positive McMurray's test
14	2 + 4 + 8; effusion + clicking or locking + positive McMurray's test
15	1 + 2 + 3 + 8; pain or joint-line tenderness + effusion + clicking or locking + positive McMurray's test

Appendix B

Physiotherapy Guidelines for Autologous Membrane Meniscus Repair.

Phase	Weeks	Sessions	Suggested Therapeutic Interventions	Progression Criteria	CPM	NMES	Weightbearing Restrictions	Additional Comments
Protection and joint activation	0-2	Home-based supervised rehabilitation	– Exercise instruction – Improved biomechanics patient education) – Cryotherapy, elevation, and compression – Calf elongation – Quadriceps isometric – Gluteal isometric – Antithrombotic exercises	– 2 weeks after surgery	No CPM exercises due to outside-facility rehabilitation	Quadriceps NMES for 15-20 minutes	Foot-to-ground contact	Recommendation for patient: – To exercise 2-3 times a day – To perform from 3 × 15 to 3 × 25 repetitions – If necessary antithrombotic stocking is applied – Range of motion limited to 60°
	3-6	2-3 times a week 50-60 minutes per session Aquatic therapy session	– Weightbearing ROM exercise – Hamstring flexibility exercises – Triceps sure flexibility exercises – Isometric gluteal, hamstring, quadriceps, triceps sure muscle exercises – Active hip exercises in lying position – Weightbearing proprioceptive exercises – Active strengthening exercises with elastic resistance performed on healthy limb – Active strengthening exercises with elastic resistance performed on operated limb – Patellar mobilizations in all directions – Knee post–isometric relaxation exercises – Functional massage – Deep massage – Fascia techniques – Manual mobilization – Knee extension exercise with external load – Stationary cycling with minimal external load – Double limb squat to 1/3 flexion ROM – Core stability exercises – Quadriceps flexibility exercises – Learning the proper limb loading on ground reaction force platform – Gait training according to weightbearing restrictions – Forward step-down and forward step-ups from an 8-inch step – Lateral step-ups within safe range of knee flexion with full weightbearing – Aquatic therapy added as soon as surgical incision is healed – Walking, jogging in aqua jogging belts and with aquatics training kickboards – Swimming freestyle and backstroke	– Minimal or no pain – Minimal or no effusion – Pain-free gait without crutches – Knee flexion ROM ≥100° – Muscular activation recovery – Recovery of normal gait cycle	Knee flexion-extension CPM movements for 15-20 minutes	Quadriceps NMES for 15-20 minutes if necessary	– 2-3 weeks—30% load – 3-4 weeks—50% load – 5-6 weeks—no crutches	– Range of motion limited to 90° for 4 weeks – Load percentage is measured on ground reaction force platform – In cases where the patient is able to walk with a locked knee one can give up crutches and walking with the knee extended

(continued)

Appendix B (continued)

Phase	Weeks	Sessions	Suggested Therapeutic Interventions	Progression Criteria	CPM	NMES	Weightbearing Restrictions	Additional Comments
Functional joint recovery	7-8	1-2 times a week 50-60 minutes per session Aquatic therapy session (with strengthening program)	– Full load proprioceptive exercises – Continuous flexibility exercises – Gait training on treadmill – Double limb squat to 90° of knee flexion on stable and unstable ground – Progressing core stability training – Gluteal, quadriceps, hamstring, hip muscles strengthening exercises progressing from concentric to eccentric load – Closed kinetic chain exercises an stable and unstable ground – Deadlift exercises – Continue stationary cycling with progressing external load – One-leg squat on stable and unstable ground – Forward lunges – Progressing forward step-down and step-ups, and lateral step-ups – Continuous aquatic therapy with hand bars, thigh weights, aquatic ankle cuffs – Continuous freestyle and backstroke with swimming fins	– Pain-free 90° of knee flexion double legs squat – No pain after high intensive exercises – No effusion after high intensive exercises	If necessary knee flexion-extension CPM movements for 15-20 minutes			– 15-minute warm up on stationary cycle – If patient feels pain after high-intensity exercises we reduce the intensity and the rehabilitation process extends – Patients are recommended to practice at home
	9-16	1-2 times a week 50-60 minutes per session Aquatic therapy session (with strengthening program—more intensive; no breaststroke technique)	– Continuous flexibility exercises – Progressing proprioception exercises from unidirectional to multidirectional, from double leg to single leg patterns – Continuous cycle and orbitrek ergometer with increasing duration – Progressing one-leg squat on stable and unstable ground with additional external load – Progressing closed kinetic chain exercises an stable and unstable ground – Progressing deadlift exercises – Forward lunges, forward step-ups, and lateral step-ups within safe range of knee flexion after full weight bearing – Progressing aquatic therapy with hand bars, thigh weights, aquatic ankle cuffs – Progressing freestyle and backstroke with swimming fins	– Side to side absolute strength difference between 15% and 20% in isokinetic test at 16th week – Side to side absolute endurance difference between 15% and 20% in isokinetic test at 16th week – Side to side load difference between 15% and 20% in ground reaction force test at 16th week – Postural Priority values between 40% and 60% in proprioceptive test at 16th week – Knee flexion ROM ≥140° – Ability to run on a treadmill at 8 km/h for more than 10 minutes				– 15-minute warm up on stationary cycle or Orbitrek – During the ground reaction force test patients perform "easier" movement patterns such as: upright position test, 90° knee squat, double leg jumps, jogging – Patients are recommended to practice at home

(continued)

Appendix B (continued)

Phase	Weeks	Sessions	Suggested Therapeutic Interventions	Progression Criteria	CPM	NMES	Weightbearing Restrictions	Additional Comments
	At 16 weeks, the functional biomechanical evaluation in every (eligible) patient. The assessment consists of (1) isokinetic knee flexion—extension tests performed at 60 deg/s (5 repetitions) and 240 deg/s (30 repetitions) angular velocity to examine strength and endurance deficits, respectively; (2) proprioception and vestibular control strategy on Postural Proprioceptive System DPPS (on stable and unstable ground with eyes open and closed, depending on testing conditions); (3) ground reaction force investigation in 4 different movement patterns.							
	This functional biomechanical evaluation is performed to verify if the patient is prepared for dynamic exercises in the next rehabilitation phase.							
Sport-specific activity	17-20	1-2 times a week 50-60 minutes per session Aqua therapy session	– Progressing exercises from previous phase – Single-leg jump – Single-leg hop – Double leg bounds – Single leg bounds – Plyometric exercises – Aerobic exercises – Treadmill running exercises	– Side to side absolute strength difference between 10% and 15% in isokinetic test at 20th week – Side to side absolute endurance difference between 10% and 15% in isokinetic test at 20th week – Side to side load difference between 5% and 10% in ground reaction force test at 20th week – Postural priority values ≥60% in proprioceptive test at 20th week – FMS test values ≥14 at 20th week – No pain during hell sitting exercises				
	At 20 weeks, the functional biomechanical evaluation in every patient is performed. The assessment consists of (1) isokinetic knee flexion—extension tests performed at 60 deg/s (5 repetitions) and 240 deg/s (30 repetitions) angular velocity to examine strength and endurance deficits, respectively; (2) proprioception and vestibular control strategy on Postural Proprioceptive System DPPS (on stable and unstable ground with eyes open and closed, depending on testing conditions); (3) ground reaction force investigation in 6 different movement patterns; (4) Functional Movement Screen test battery							
	Functional biomechanical evaluation performed at this stage is to allow sport active patients for participating in high intensity sport-specific rehabilitation phase							

(continued)

Appendix B (continued)

Phase	Weeks	Sessions	Suggested Therapeutic Interventions	Progression Criteria	CPM	NMES	Weightbearing Restrictions	Additional Comments
	21-24	1-2 times a week 50-60 minutes per session	– Continue strengthening and flexibility exercises from previous phase – Aerobic running cises – Progressive running – Acceleration-deceleration exercises – High-intensity exercises – Running with quick changes of direction – Coordination exercises – Functional sport-specific agility training – Presport conditioning training – Education and preparation for return to sport	– Side to side absolute strength difference between 10% and 15% in isokinetic test at 24th week – Side to side absolute endurance difference between 10% and 15% in isokinetic test at 24th week – Side to side load difference between 5% and 10% in ground reaction force test at 24th week – Postural priority values ≥60% in proprioceptive test at 24th week – FMS test values ≥17 at 24th week – Lack of apprehension with sport specific movements – Dynamic neuromuscular control with multi-plane activities without pain or swelling				
Final assessment	At 24 weeks, the functional biomechanical evaluation in every active patients/athletes is performed. If the tested subject meets the results obtained at 20th week, he or she is allowed to return to sport activity.							

Abbreviations: CPM, continuous passive motion; FMS, Functional Movement Screen; NMES, neuromuscular electrical stimulation; ROM, range of motion.

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Declaration of Conflicting Interests

Prof. Jakob serves as a paid consultant to Geistlich Pharma AG. Dr Slomczykowski serves as a Medical Director to Geistlich Pharma AG. The other authors do not report any conflicts of interest.

Ethical Approval

Ethical approval for this study was obtained from the IRB Committee of the Medical University of Poznan/Poland, and it has been performed according to the ethical standards laid down in the 1964 Declaration of Helsinki.

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