Post-Arthroscopy Osteonecrosis of the Knee: With Special Reference to Meniscal Extrusion before and after the Medial Meniscectomy

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1 **Post-Arthroscopy Osteonecrosis of the Knee: With Special Reference to Meniscal** 2 **Extrusion before and after the Medial Meniscectomy**

3 4 **Abstract**

5 **Background:** Post-arthroscopic osteonecrosis of the knee (PAONK) is a rare disorder
6 condition. In addition, no studies have analyzed the relationship between the meniscus
7 extrusion and PAONK. The purposes of this retrospective study are to report 10 cases of
8 PAONK and to evaluate location of the MM in the joint space, including the meniscus
9 extrusion, before and after the meniscectomy in these 10 knees.

10 **Methods:** Ten knees with PAONK were found in 876 knees which had undergone
11 arthroscopic partial meniscectomy of the medial meniscus (MM). We retrospectively
12 collected the clinical, surgical, and radiological data of these 10 patients. To evaluate
13 intraarticular location of the menisci in the joint space, Extrusion width and Inner width
14 were defined on magnetic resonance images, and they were statistically compared.

15 **Results:** In the 10 patients (2 men and 8 women; the age ranged between 60 and 80 years),
16 knee pain recurred within 12 weeks after the meniscectomy. Preoperatively, the Extrusion
17 width of the MM (the mean, 4.7 mm) was significantly greater ($P<0.0001$) than that of
18 the LM (0.2 mm). At the time of diagnosis of PAONK, the Extrusion width of the MM

significantly increased by 1.2 mm and the Inner width was significantly reduced by 3.9 mm, compared with the preoperative values ($P<0.0001$).

Conclusion: This is the first report that, in each of the 10 knees with PAONK, the MM had been extruded before the meniscectomy, and then, the Inner width of the MM almost disappeared postoperatively due to not only the increased meniscal extrusion but the partial meniscal resection. This study suggested that the intraarticular abnormal location of the MM, including the meniscal extrusion, is a critical factor that should be evaluated in future studies to clarify causative factors of PAONK.

Keywords: Osteonecrosis of the Knee, Arthroscopic meniscectomy, Meniscal extrusion, Meniscal location, Medial meniscus, Posterior root tear, Radial tear.

Background

Osteonecrosis of the knee was reported by Ahlbäck et al. [1] in 1968. Currently, it has been classified into 3 categories, spontaneous osteonecrosis (SPONK), secondary osteonecrosis, and post-arthroscopic osteonecrosis of the knee (PAONK). [8] Concerning PAONK, Brahme et al. [5] described the first report entitled “osteonecrosis of the knee after arthroscopic surgery” in 1991. Later, similar pathological conditions were reported as “postmeniscectomy osteonecrosis” [9, 23, 24]. In 2007, Pape et al. [22] reviewed previously reported cases of these pathological conditions, and they named them “PAONK”. Thus, PAONK is defined as a type of knee osteonecrosis that occurs in patients who underwent arthroscopic knee surgery. Clinical diagnosis of PAONK is made with magnetic resonance imaging (MRI), while findings on the MRI are the same as those for SPONK. [8] An important criterion in diagnosing PAONK is to confirm that any signs of osteonecrosis were not observed in the MRI taken prior to the meniscectomy. [8]

PAONK is a rare disorder condition so that the incidence has been reported to be 0.2-1.5% of the knees which underwent arthroscopic surgery. [23, 24] Therefore, the etiology of PAONK has not been fully clarified. To clarify the etiology, it is needed to increase the patient database on PAONK. For example, previous studies concerning PAONK have not focused on the meniscus location in the joint space before and after

arthroscopic surgery. Particularly, no studies have analyzed the relationship between the meniscus extrusion and PAONK. Recently, Oda et al. [21] reported that there was a significant correlation between the meniscal extrusion and the SPONK. Therefore, it is required to analyze a relationship between the meniscal extrusion and the PAONK.

In our clinical practice, we found 10 knees with PAONK in 876 knees which had undergone arthroscopic partial meniscectomy of the medial meniscus (MM). The first purpose of the present study is to report the clinical status of the 10 patients in detail to increase the database of PAONK. The second purpose is to clarify whether these 10 knees had abnormal location of the MM in the joint space, including the meniscus extrusion, before and after the arthroscopic partial meniscectomy.

Methods

1) Diagnosis of PAONK

PAONK was diagnosed with MRI examinations using the following criteria (Johnson 2000, Di Caprio 2017) [8, 12] : (1) The patient complained of serious pain in the knee which had undergone arthroscopic surgery within the past 12 months. (2) The MRI showed osteonecrosis in the femoral condyle or the tibial plateau at the ipsilateral side of the arthroscopic surgery. (3) Retrospectively, the MRI taken immediately before the

arthroscopic surgery did not show any evidence of bone marrow edema (BME) or osteonecrosis. Then, the diagnosis of osteonecrosis was made, based on the following findings in the T1- and T2*-weighted MRI. [4, 17, 18] (1) In the early stages, a necrotic lesion was observed in the femoral condyle or tibial plateau as a low signal area surrounded by an extensive BME area. (2) At the margin of the necrotic lesion, a high signal line was often observed, delineating the necrotic area from the adjacent area of BME. Commonly, the BME is gradually reduced by approximately 3 months. (3) In the late stage, bone sequestration or segmentation was sometimes observed with a surrounding high signal rim in the flattened femoral condylar.

2) Patients

In our hospital (##### Hospital, #####, #####), arthroscopic partial meniscectomy was performed in 876 knees between 2010 and 2015. In following up these patients postoperatively for 1 year in our outpatient clinic, we found 10 cases (2 men and 8 women) of PAONK. Concerning these 10 patients, we retrospectively collected the clinical, surgical, and radiological data and added statistical analyses. The study design was accepted by the Ethical Review Board in our hospital.

3) Evaluations with radiograms and MRI examinations

The radiological stage of osteoarthritis (OA) was evaluated using the Kellgren and Lawrence (KL) grades [13]. The radiological stage of osteonecrosis of the knee was evaluated using Koshino's classification [14] (Table 2). In the present study, the MRI was taken with 0.2-T MRI (Aris; Hitachi, Tokyo, Japan). For T1-weighted images, the protocol included both sagittal and coronal spin-echo sections with TR/TE values of 550 per 27 milliseconds. For T2*-weighted images, we used gradient-echo sections with TR/TE of 660 per 17 milliseconds (FA of 30 degrees). Section thickness was between 4 and 5 mm with 4-mm intervals. An extremity coil was used with a field of view of 150 mm, 256 x 256 matrix.

The location of the MM in the joint space, including the degree of extrusion of the MM, was quantified using the following method, which was created by modification of Costa's method [7]. On the coronal image of the MRI at the midpoint of the medial femoral condyle, a vertical line intersecting the peripheral margin of the medial tibial plateau was drawn (Figure 1). Osteophytes were excluded in determining the medial margin. Then, the second and third lines, which were parallel to the first line, were drawn at the outer (peri-articular) and inner (intra-articular) margins of the meniscus, respectively (Figure 1). We measured the distance between the first and second lines,

which was defined as “Extrusion width”, and the distance between the first and third lines, which was defined as “Inner width” (Figure 1). Each width was quantified in millimeters. This method was applied to the lateral joint space in the same manner to quantify the location of the lateral meniscus (LM). Locations of the MM and LM in the joint space was measured before the arthroscopic surgery and at the time when the diagnosis of PAONK was made.

4) Statistics

Statistical comparisons were made using the paired or unpaired t-test. The significance level was set at $P < 0.05$.

Results

1) Characteristics of the patients before meniscectomy

Patients characteristics before meniscectomy are shown in Table 1. The age of the 10 patients (2 men and 8 women) at the time of the arthroscopic meniscectomy ranged between 60 and 80 years (average 67.5 years). The body mass index averaged 25.9%. In arthroscopic observation, not only MM injury but also chondromalacia on MFC were found in all the 10 knees. In addition, chondromalacia on the medial tibial plateau (MTP)

was observed in 8 knees. Two knees showed grade-1 OA and 7 knees showed grade-2 OA, while the remaining one knee showed no osteoarthritic changes. The preoperative femorotibial angle (FTA) ranged between 168 and 182 degrees (average 176 degrees).

2) Characteristics of the performed meniscectomy

Characteristics of the performed meniscectomy are shown in Table 2. In the 10 knees, 5 knees had a posterior root tear of the MM, and the other 5 knees had a radial tear at the posterior horn of the MM. Three radial tears and 2 posterior root tears involved horizontal tears at the posterior horn. For these MM tears, arthroscopic partial meniscectomy at the torn portion was performed. The LM simultaneously underwent trimming at the limited lesion in 2 of the 10 knees and meniscal repair in 1 knee. Total width of the MM was resected around the torn site in 8 knees, while approximately half width of the MM was resected in 2 knees. The time needed for surgery ranged between 25 and 55 minutes (the average of 34.5 minutes). Intraoperatively, an air tourniquet was used in 7 knees, while it was not used in the remaining 3 knees.

3) Characteristics in the post-operative course

Characteristics in the post-operative course are shown in Table 3. After arthroscopic

meniscectomy, 9 of the 10 patients returned to their usual daily activities, although 3 of the 9 patients felt some mild pain in the ipsilateral knee while walking. In these 9 patients, serious knee pain recurred 3 to 12 weeks (the mean, 5.7 weeks) after the meniscectomy so that each patient visited the outpatient clinic of our hospital. The remaining one patient continuously felt moderate knee pain after the meniscectomy. The 10 patients underwent an MRI examination 3 to 21 weeks (the mean, 12.0 weeks) after the meniscectomy. The MRI showed that an osteonecrosis lesion with BME was found at the MFC in 8 knees and at both the MFC and the MTP in 2 knees. The osteonecrosis lesions were classified as Stage 1 in 4 knees, Stage 2 in 4 knees, and Stage 3 in 2 knees, according to Koshino's classification. The KL grade of knee osteoarthritis was advanced by 1 grade in 3 knees and by 2 grades in 1 knee, when compared with the grade evaluated before the meniscectomy, while 6 knees showed no changes in the KL grade. The FTA showed no significant difference compared with the pre-operative FTA.

4) Intraarticular location of the menisci

Before the arthroscopic meniscectomy, the MRI showed that the intraarticular location of the MM was abnormal in each of the 10 patients, while that of the LM was normal (Table 4). In the measurements, the Extrusion width of the MM averaged 4.7 mm with a range

between 2.8 and 6.8 mm, which was significantly greater ($P<0.0001$) than that of the LM (the mean, -0.2 mm). The Inner width of the MM averaged 4.4 mm with a wide range between 0.0 and 7.1mm, which was significantly less ($P<0.0001$) than that of the LM (the mean, 9.1 mm). The MRI, which was taken at the time of diagnosis of PAONK, showed that the degree of the Extrusion of the MM increased and the Inner width decreased in all the patients. In the measurements (Table 4), the Extrusion width of the MM averaged 5.9 mm, which was significantly greater ($P<0.0001$) than that of the LM (the mean, -0.2 mm), and it was slightly but significantly increased by 1.2 mm ($P<0.0001$) in comparison with the width measured before the meniscectomy (Figure 4). The Inner width of the MM averaged 0.6 mm, which was significantly less ($P<0.0001$) than that of the LM (the mean, 8.9 mm), and it was significantly reduced by 3.9 mm ($P<0.0001$) in comparison with the width measured before the meniscectomy (Figure 4).

5) Representative cases

Case 1: 62-year old woman (Patient No. 6 in Tables). She had suffered from pain in the left knee during walking for 3 months, before she visited our outpatient clinic. The radiograms showed grade-1 OA (Figure 2-A). The MRI examination showed a posterior root tear of the MM with degenerative changes in the posterior horn, while it did not show

any findings of osteonecrosis or BME (Figure 2-B, C, D). The Inner width and the Extrusion width of the MM were 6.1 mm and 3.5 mm, respectively. Conservative therapy was not effective so that she underwent arthroscopic partial meniscectomy of the degenerated portion. Postoperatively, she returned to unrestricted daily life activity within one month. Then, she felt severe pain in the ipsilateral knee while walking 2 months after the meniscectomy, and she visited our outpatient clinic 3 months postoperatively. The radiograms indicated stage-3 osteonecrosis in the medial femoral condyle (MFC), in which a radiolucent lesion with a calcified plate was observed (Figure 2-E). MRI showed a necrotic lesion (T1-low, T2*-high) in the MFC, which was surrounded by an osteosclerotic zone and a wide BME area (Figure 2-F, G, H). The Inner width of the MM decreased to 1.4 mm, and the Extrusion width slightly increased to 6.1 mm. The severe knee pain continued in spite of conservative treatment so that unilateral knee arthroplasty was performed.

Case 2: 64-year old man (Patient number 2 in Tables). He had suffered from pain in the right knee while walking for a period of 2 months, before he visited our outpatient clinic. The radiograms indicated grade-2 OA (Figure 3-A). The MRI examination showed a degenerative radial tear at the posterior horn of the MM, while it did not show any findings of osteonecrosis or BME (Figure 3-B, C, D). The Inner width and the Extrusion

width of the MM were 6.9 mm and 4.1 mm, respectively. Conservative therapy was not effective so that he underwent arthroscopic partial meniscectomy of the torn portion. Postoperatively, he returned to unrestricted daily life activity within one month. Three months after the meniscectomy, he felt severe pain in the ipsilateral knee while walking. He revisited our outpatient clinic 4 months after the meniscectomy. The radiograms indicated stage-2 osteonecrosis in the MFC, in which we could observe a bone-absorbed lesion surrounded by an osteosclerotic zone (Figure 3-E). MRI showed a necrotic lesion (T1-low, T2*-high) in the MFC, which was surrounded by an osteosclerotic zone (Figure 3-F, G, H). The Inner width of the MM decreased to 1.2 mm, and the Extrusion width slightly increased to 4.2 mm. Although conservative treatments were applied, the knee pain gradually increased. Subsequently, high tibial osteotomy with autologous osteochondral transplantation was performed 15 months after the meniscectomy.

Discussion

The first purpose of the present study was to report the clinical status of the 10 patients in detail in order to increase the database of PAONK. Previous studies have pointed out that orthopaedic surgeons should have sufficient knowledge on PAONK [8, 9, 22]. Pape et al. [22] reported the following clinical characteristics of PAONK in their review study:

First, there was no difference in the incidence between men and women. Secondly, the average age at the onset in their 47 cases was 58 years, which was younger compared with that for SPONK. Thirdly, PAONK occurred after medial meniscectomy in 87% and after lateral meniscectomy in 13%. Fourthly, PAONK occurred at the MFC in 83% of the cases, at the lateral femoral condyle in 8.5%, at the MTP in 4.3%, and at the lateral tibial plateau in 4.3%. Fifthly, articular cartilage injuries were found in 65% of the patients. In the present study, the clinical characteristics of the 10 patients with PAONK almost agreed with those reported by Pope except for the following points: (1) The age of our patients (67.5 years in average) was higher by approximately 10 years in comparison with Pape's report. (2) Cartilage injuries were observed before the meniscectomy in all patients. These differences may reflect a fact that the aging rate in Japan, currently 27.3%, is the highest in the world. In the present study, 90% of the patients with PAONK felt severe pain within 6 months after MM resection. Therefore, it is recommended that, when a patient who returned to daily life after meniscectomy complains of acute knee pain during walking, the orthopaedic surgeon should examine the patient with MRI to check for a potential onset of PAONK.

The most important finding in the present study was obtained by achieving the second purpose of this study. Namely, in each of the 10 knees with PAONK, the MM had

been obviously extruded before and after the arthroscopic meniscectomy, and the degree of the extrusion significantly increased at the period of diagnosis of PAONK. Furthermore, the Inner width of the MM was extremely reduced at the time of diagnosis of PAONK. Figure 4 shows two facts. First, in the 10 patients with PAONK, the Inner width of the MM almost disappeared even though the meniscectomy was partial. This means a complete loss of meniscal functions. Secondly, the disappearance of the Inner width of the MM was caused by not only the decrease of the total meniscal width due to meniscectomy but also the meniscal extrusion, which had existed before the meniscectomy and then increased following it. No studies have reported the abnormal location of the MM in the knees with PAONK. Therefore, the present study provided new important information to the research field to clarify the etiology of PAONK. In addition, the present study suggests that, when orthopaedic surgeons follow up a patient who underwent arthroscopic partial meniscectomy of the extruded MM, the surgeons should pay special attention to a high risk of PAONK.

Then, we considered the relationship between the abnormality on the intraarticular location of the MM and the onset of PAONK. In the 10 patients of the present study, it is noted that, first, the MM extrusion had existed prior to the arthroscopic meniscectomy. The meniscal extrusion is caused by root tear, radial tear, and degeneration

of the meniscus [6, 7, 25], resulting in an increase of the contact stress [16]. Secondly, the Inner width of the MM almost disappeared at the time of diagnosis of the PAONK due to not only the partial resection of the meniscus tissue but also the increase of the meniscal extrusion. This meniscal status means that the normal meniscal function, which is to reduce the joint contact stress, was almost completely lost [2, 15]. It is known that loss of the meniscal function results in an increase of the joint contact stress, leading to a progression of knee osteoarthritis [3, 25]. Recently, Oda et al. [21] reported that there was a significant correlation between the meniscal extrusion and the SPONK. Therefore, there is a high possibility that, in the present study, the abnormal location of the MM in the joint space might induce an insufficiency fracture of the subchondral bone of the femoral condyle or the tibial plateau, resulting in PAONK. This possibility is supported by the fact that the BME lesion, which commonly shows existence of insufficiency fracture, was observed in each knee with PAONK. However, the present study could not clarify whether the decrease of the Inner width of the MM due to the meniscal extrusion and the partial meniscal resection was one of the causes of PAONK, because we had no comparative data. However, this study is of value because it suggested that the intraarticular abnormal location of the MM, including the meniscal extrusion, is a critical factor that should be evaluated in future studies to clarify causative factors of PAONK.

266 Concerning the essential pathology of PAONK, various hypotheses have been
267 proposed [8]. However, recent studies have shown that an essential pathology of PAONK
268 is a subchondral bone fracture, and that the necrotic bone lesion is a secondary condition
269 of the fractured bone [10, 18, 20]. For example, Higuchi et al. [10] performed a
270 histological examination in 6 cases of PAONK. In the results, subchondral bone fracture
271 was observed in all 6 knees, but necrotic lesion was not detected at all in 4 of the 6 knees.
272 MacDessi et al. [18] carried out histological examination in 8 knees with PAONK. In their
273 results, subchondral bone fracture with a callus formation was observed in all the 8 knees,
274 but a necrotic bone tissue, which appeared to be a secondary lesion to the fracture, was
275 found in only two knees. Then, in the 10 knees of the present study, the MRI taken in the
276 early phase after recurrence of the knee pain showed that the BME lesion, which is
277 commonly seen around an insufficiency fracture lesion, was widely observed in the MFC
278 and/or the MTP. In the late phase after recurrence of the knee pain, a low intensity zone
279 in both the T1- and T2*-weighted images, which showed osteonecrosis, was observed at
280 only a localized area in the subchondral bone. These findings in the present study
281 supported the above-described histopathological studies.

282 Then, we discuss about pathological difference between PAONK and SPONK.
283 In 2000, Yamamoto et al. [26] reported that the primary event leading to SPONK is a

subchondral insufficiency fracture, and that the localized necrosis of the bone tissue seen in association with SPONK is a secondary lesion following the fracture of the subchondral bone tissue. It is noted that this pathology of SPONK is the same as the above-described pathology of PAONK. Recently, Hussain et al. [11] conducted a pathological review study and concluded that SPONK and PAONK have the same histopathology. In addition, recent clinical studies reported that meniscal extrusion causes SPONK [21, 27]. The present study also suggested that a decrease of the Inner width of the MM with an increase of the meniscal extrusion might cause PAONK. These facts support the concept that SPONK and PAONK have the same histopathological condition. Therefore, we consider that, although PAONK has been classified as a different type of osteonecrosis from SPONK in the clinical field, [5, 9, 22] the classification of osteonecrosis of the knee should be revised to precisely understand this pathological condition and to appropriately treat it.

This is a report dealing with 10 rare cases of PAONK. Therefore, there are limitations in the present study. First, the number of patients was insufficient. Secondly, there were no control data to clarify the effect of the abnormal location of the MM on occurrence of PAONK. However, we believe that this report will contribute to future studies, because this is the first report that abnormal location of the MM, including

meniscal extrusion, was observed in each of the 10 patients not only at the time of diagnosis of PAONK but before the prior meniscectomy.

Conclusion

Ten knees were diagnosed as PAONK in 876 knees which had undergone arthroscopic partial meniscectomy of the MM. In the 10 patients, the MM had been extruded (the mean, 4.7 mm) before the meniscectomy, and then, the Extrusion width significantly increased ($P<0.0001$) and the Inner width of the MM was significantly reduced ($P<0.0001$) at the time of diagnosis of PAONK. This is the first report that, in each of the 10 knees with PAONK, the MM had been extruded before the meniscectomy, and then, the Inner width of the MM almost disappeared postoperatively due to not only the increased meniscal extrusion but the partial meniscal resection. This study suggested that the intraarticular abnormal location of the MM, including the meniscal extrusion, is a critical factor that should be evaluated in future studies to clarify causative factors of PAONK.

List of abbreviations

BME: bone marrow edema, FTA: femorotibial angle, KL: Kellgren and Lawrence, LM: lateral meniscus, MFC: medial femoral condyle, MM: medial meniscus, MRI:

magnetic resonance imaging, MTP: medial tibial plateau, OA: osteoarthritis, PAONK:
post-arthroscopic osteonecrosis of the knee, SPONK: spontaneous osteonecrosis.

Declarations

- Ethical approval and consent to participate

Ethical approval was given by the Ethical Review Board in Yagi Orthopaedic Hospital,
Sapporo, Japan. A written consent was obtained from all participants prior to this study.

- Consent of publication

Not applicable.

- Availability of data and materials

The datasets generated and/or analysed during the current study are available from
the corresponding author on reasonable request.

- Competing interest

The authors declare that they have no competing interest.

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- **Author contributions**

JY collected the data, made the analysis, and prepared to draft the work. KYasuda designed this study and completed the draft. DU, KYabuuchi, and JO supported the data collection and statistical analysis. EK, NI, and MS interpreted the data and revised the draft critically. TY conducted this study and supervised the data analysis. All authors have read and approved the manuscript.

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Legends of Figures

Fig. 1 Measurement of the location of the medial meniscus (MM) on the coronal image of the MRI. A vertical line intersecting the peripheral margin of the medial tibial plateau (MTP) was drawn. Then, the second and third lines, which were parallel to the first line, were drawn at the outer and inner margins of the meniscus, respectively. We measured the distance between the first and second lines, which was defined as “Extrusion width (EW)”, and the distance between the first and third lines, which was defined as “Inner width (IW)”. Each width was quantified in millimeters.

Fig. 2 62-year old woman. Preoperatively, the radiogram (A) showed grade-1 OA. The MR images (B and C: T2*, D: T1) did not show any findings of osteonecrosis or bone marrow edema (BME). The Inner width (IW) and the Extrusion width (EW) of the MM were 6.1 mm and 3.5 mm, respectively (B). At 3 months postoperatively, the radiograms (E) indicated stage-3 osteonecrosis in the medial femoral condyle (MFC). MR images (F and G: T2*, H: T1) showed a necrotic lesion (T1-low, T2*-high) in the MFC, which was surrounded by an osteosclerotic zone and a wide BME area. The IW decreased to 1.4 mm, and the EW increased to 6.1 mm (F).

Fig. 3 64-year old man. Preoperatively, the radiogram (A) showed grade-2 OA. The MR images (B and C: T2*, D: T1) did not show any findings of osteonecrosis or bone marrow edema (BME). The Inner width (IW) and the Extrusion width (EW) of the MM were 6.9 mm and 4.1 mm, respectively (B). At 4 months postoperatively, the radiograms (E) indicated stage-2 osteonecrosis in the medial femoral condyle (MFC). MR images (F and G: T2*, H: T1) showed a necrotic lesion (T1-low, T2*-high) in the MFC, which was surrounded by an osteosclerotic zone. The IW decreased to 1.2 mm, while the EW was 4.2 mm (F).

Fig. 4 A: Comparison of the medial meniscus (MM) locations measured before the meniscectomy (Preop) and at the time of diagnosis of PAONK (@Diagnosis). The Extrusion width (EW) and the Inner width (IW), the definition of which is shown in a schematic picture (B), were significantly ($P < 0.0001$) changed between the 2 periods. This bar graph also shows that the disappearance of the IW of the MM was caused by not only the decrease of the total meniscal width due to meniscectomy but also the meniscal extrusion.

Table 1 Characteristics of the 10 patients with PAONK concerning the preoperative factors. F: female, M: male, R: right, L: left, BME: bone marrow edema, MMT: medial meniscus tear, LMT: lateral meniscus tear, CM: chondromalacia, MFC: medial femoral condyle, MTP: medial tibial plateau, LTP: lateral tibial plateau, PF: patellofemoral, OA: osteoarthritis, FTA: femorotibial angle.

Patient No.	Age Sex	Side	Body weight (Kg)	BMI (%)	Period between the onset and the preop MRI	BME or osteonecrosis in MRI	Diagnosis (MRI, Arthroscopy)	OA grade	FTA
1.	73, F	L	70	30.3	12 wks	None	MMT, CM@MFC&MTP&PF	2	175°
2.	64, M	R	61	22.4	10 wks	None	MMT, CM@MFC&MTP	2	176°
3.	66, F	L	75	33.3	10 wks	None	MMT, CM@MFC&MTP	2	182°
4.	74, F	L	50	22.8	2 wks	None	MMT, CM@MFC&MTP	2	174°
5.	66, F	R	50	20.3	4 wks	None	MMT, CM@MFC&MTP<P&PF	2	178°
6.	62, F	L	52	21.6	14 wks	None	MMT, LMT, CM@MFC&PF	1	177°
7.	67, F	R	71	32.4	8 wks	None	MMT, CM@MFC&MTP	2	178°
8.	80, M	R	58	25.8	2 wks	None	MMT, CM@MFC&MTP	1	176°
9.	60, F	R	58	23.2	32 wks	None	MMT, LMT, CM@MFC<P&PF	2	168°
10.	63, F	R	64	26.6	31 wks	None	MMT, LMT, CM@MFC&MTP	0	178°
Mean (SD)	67.5 (5.94)		60.9 (8.53)	25.9 (4.43)	12.5 (10.17)		MMT: 10 CM@MFC: 10 CM@MTP: 8	G2: 7 G1: 2 G0: 1	176.2 (3.43)

Table 2 Characteristics of the 10 patients with PAONK concerning the surgical factors. F: female, M: male, MM: medial meniscus, RT: radial tear, PH: posterior horn, HT: horizontal tear, PRT: posterior root tear, PMM: partial medial meniscectomy, PLM: partial lateral meniscectomy, LMR: lateral meniscus repair

Patient No.	Age Sex	Type of MM tear	Surgery Done	Resected width of MM	Tourniquet Time	Surgery Time
1.	73, F	RT at PH (with HT)	PMM	Total	30 min	55 min
2.	64, M	RT at PH	PMM	Half	0 min	35 min
3.	66, F	PRT	PMM	Total	30 min	30 min
4.	74, F	PRT (with HT)	PMM	Total	30 min	30 min
5.	66, F	PRT (with HT)	PMM	Total	0 min	25 min
6.	62, F	PRT	PMM, PLM	Total	18 min	26 min
7.	67, F	RT at PH	PMM	Half	14 min	51 min
8.	80, M	RT at PH (with HT)	PMM	Total	0 min	25 min
9.	60, F	PRT	PMM, PLM	Total	8 min	30 min
10.	63, F	RT at PH (with HT)	PMM, LMR	Total	26 min	38 min
Mean		5 PRT	10 PMM	8 Total	15.6	34.5
(SD)		5 RT	2 PLM 1 LMR	2 Half	(12.35)	(10.09)

Table 3 Clinical characteristics of the 10 patients with PAONK concerning the post-operative course and the diagnosis. PMM: partial medial meniscectomy, ON: osteonecrosis, MFC: medial femoral chondyle, MTP: medial tibial plateau, BME: bone marrow edema, OA: osteoarthritis, UKA: unicompartmental knee arthroplasty, TKA: total knee arthroplasty, OATS: osteochondral autograft transfer system, HTO: high tibial osteotomy

Patient No.	Age Sex	Residual pain in daily life	Time @ recurrence of pain	Time @ MRI diagnosis	Location of a necrotic lesion	Area of BME	Necrosis stage (Koshino)	OA grade (KL)	FTA	Subsequent Treatment
1.	73, F	None	8 wks	12 wks	MFC	Narrow	S-2	G-2	176	TKA
2.	64, M	None	12 wks	19 wks	MFC	Moderate	S-2	G-3	178	HTO, OATS
3.	66, F	None	2 wks	4 wks	MFC	Wide	S-2	G-2	181	UKA
4.	74, F	+ (mild)	4 wks	6 wks	MFC	Narrow	S-1	G-3	175	UKA
5.	66, F	None	8 wks	9 wks	MFC	Narrow	S-2	G-2	179	UKA
6.	62, F	+ (mild)	6 wks	11 wks	MFC	Moderate	S-3	G-1	177	UKA
7.	67, F	None	7 wks	21 wks	MFC	Wide	S-3	G-3	177	UKA
8.	80, M	+ (mild)	7 wks	19 wks	MFC&MTP	Narrow	S-2	G-3	178	TKA
9.	60, F	None	3 wks	5 wks	MFC	Narrow	S-1	G-2	169	TKA
10.	63, F	+ (moderate)	Unclear	3 wks	MFC&MTP	Moderate	S-1	G-0	178	UKA
Mean (SD)		Returned: 9 Not: 1	5.7 (3.32)	12.1 (7.93)	MFC: 8 MFC+MTP: 2	Narrow: 5 Moderate: 3 Wide: 2	S-1: 3 S-2: 5 S-3: 2	G-0: 1 G-1: 1 G-2: 4 G-3: 4	177 (3.03)	UKA: 6 TKA: 3 HTO: 1

Table 4 The Extrusion width (EW) and the Inner width (IW) of the medial meniscus (MM) and the lateral meniscus (LM), which were measured before meniscectomy and at the time when PAONK was diagnosed, and changes of the EW and the IW between the 2 periods, in which plus and minus values show an increase and a decrease of the width, respectively. a: comparison between the MM and the LM (unpaired t-test). b: comparison between the 2 periods (paired t-test).

Patient No.	Age Sex	Before meniscectomy				At the time of diagnosis of PAONK				Changes between the 2 periods			
		EW (mm)		IW (mm)		EW (mm)		IW (mm)		EW (mm)		IW (mm)	
		MM	LM	MM	LM	MM	LM	MM	LM	MM	LM	MM	LM
1.	73, F	7.1	0.0	2.0	8.0	8.0	0.0	-1.6	7.9	0.9	0.0	-3.6	- 0.1
2.	64, M	4.1	-0.6	6.9	10.8	4.2	-0.6	1.2	11.0	0.1	0.0	5.7	0.2
3.	66, F	4.4	0.4	4.9	8.1	5.1	0.4	3.5	8.1	0.7	0.0	1.4	0.0
4.	74, F	6.8	-0.4	2.9	8.6	6.8	-0.4	0.0	8.5	0.0	0.0	2.9	-0.1
5.	66, F	5.4	-0.6	0.0	8.1	6.6	-0.6	-1.2	8.5	1.2	0.0	1.2	0.4
6.	62, F	3.5	1.3	6.1	7.2	6.1	1.3	1.4	7.0	2.6	0.0	4.7	0.2
7.	67, F	5.8	0.0	1.7	7.2	6.1	0.0	-2.1	7.8	0.3	0.0	3.8	0.6
8.	80, M	3.7	-1.1	6.5	12.7	5.9	-1.3	0.6	13.3	2.2	-0.2	5.9	0.6
9.	60, F	2.8	-1.8	6.1	10.6	4.8	-1.8	1.6	7.9	2.0	0.0	4.5	-2.7
10.	63, F	3.4	0.6	7.1	9.4	4.9	0.8	2.2	9.0	1.5	0.2	4.9	-0.4
Mean		4.7	-0.2	4.4	9.1	5.9	-0.2	0.6	8.9	1.2	0.0	3.9	-0.2
(SD)		(1.4)	(0.8)	(2.4)	(1.7)	(1.1)	(0.9)	(1.7)	(1.8)	(0.9)	(0.1)	(1.5)	(0.9)
P value		P<0.0001 ^a		P<0.0001 ^a		P<0.0001 ^a		P<0.0001 ^a		P=0.0031 ^b	N.S. ^b	P<0.0001 ^b	N.S. ^b

Figures

Figure 1

Measurement of the location of the medial meniscus (MM) on the coronal image of the MRI. A vertical line intersecting the peripheral margin of the medial tibial plateau (MTP) was drawn. Then, the second and third lines, which were parallel to the first line, were drawn at the outer and inner margins of the meniscus, respectively. We measured the distance between the first and second lines, which was defined as “Extrusion width (EW)”, and the distance between the first and third lines, which was defined as “Inner width (IW)”. Each width was quantified in millimeters.

Figure 2

62-year old woman. Preoperatively, the radiogram (A) showed grade-1 OA. The MR images (B and C: T2*, D: T1) did not show any findings of osteonecrosis or bone marrow edema (BME). The Inner width (IW) and the Extrusion width (EW) of the MM were 6.1 mm and 3.5 mm, respectively (B). At 3 months postoperatively, the radiograms (E) indicated stage-3 osteonecrosis in the medial femoral condyle (MFC). MR images (F and G: T2*, H: T1) showed a necrotic lesion (T1-low, T2*-high) in the MFC, which was surrounded by an osteosclerotic zone and a wide BME area. The IW decreased to 1.4 mm, and the EW increased to 6.1 mm (F).

Figure 3

64-year old man. Preoperatively, the radiogram (A) showed grade-2 OA. The MR images (B and C: T2*, D: T1) did not show any findings of osteonecrosis or bone marrow edema (BME). The Inner width (IW) and the Extrusion width (EW) of the MM were 6.9 mm and 4.1 mm, respectively (B). At 4 months postoperatively, the radiograms (E) indicated stage-2 osteonecrosis in the medial femoral condyle (MFC). MR images (F and G: T2*, H: T1) showed a necrotic lesion (T1-low, T2*-high) in the MFC, which was surrounded by an osteosclerotic zone. The IW decreased to 1.2 mm, while the EW was 4.2 mm (F).

Figure 4

A: Comparison of the medial meniscus (MM) locations measured before the meniscectomy (Preop) and at the time of diagnosis of PAONK (@Diagnosis). The Extrusion width (EW) and the Inner width (IW), the definition of which is shown in a schematic picture (B), were significantly ($P < 0.0001$) changed between the 2 periods. This bar graph also shows that the disappearance of the IW of the MM was caused by not only the decrease of the total meniscal width due to meniscectomy but also the meniscal extrusion.