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Authors' contributions:

All authors have made substantial contributions to (1) the conception and design of the study, or acquisition, analysis and interpretation of data; (2) drafting the article or revising it critically for important intellectual content; (3) final approval of the version to be submitted; and (4) agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately resolved. The specific contributions of the authors are as follows:

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2. Acquisition, analysis, and interpretation of data for the work: YH(1), YH(2), NK, NM, KN, DA, TM

3. Drafting the article: YH(1)

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Abstract

Purpose To compare the postoperative rotatory knee laxity between ACL-reconstructed knees with different meniscus treatments using an electromagnetic pivot-shift measurement.

Methods Forty-six patients with unilateral ACL reconstructions were enrolled (21 males/25 females, 25±12 y.o.). Concomitant meniscus tears, if any, were repaired whenever possible during primary ACL reconstruction. At one year postoperatively, pivot-shift test was performed under anesthesia during screw removal surgery and quantitatively evaluated by tibial acceleration using an electromagnetic system. The acceleration was compared between ACL-reconstructed knees with different meniscal treatments: intact, repaired and unrepaired.

Results A concomitant meniscus tear was found in 28 knees preoperatively: lateral tears in 11 knees, medial tears in 11 knees and both medial and lateral tears in 6 knees. Postoperatively, 19 ACL-reconstructed knees had a repaired meniscus for either medial, lateral or bilateral menisci tears, and 18 knees had intact menisci pre- and post-operatively. Meanwhile, 9 lateral meniscus tears were irreparable and treated by partial menisectomy or left in situ. ACL-reconstructed knees with unrepaired lateral menisci had significantly larger pivot-shift acceleration (0.9±0.7 m/sec^2) than those with intact menisci (0.5±0.2 m/sec^2, $p<0.05$), whereas rotatory knee laxity was similar between the knees with fully repaired menisci (0.6±0.3 m/sec^2) and intact menisci (n.s.).

Conclusion An unrepaired lateral meniscus tear in an ACL-reconstructed knee could lead to remaining pivot-shift postoperatively. A concomitant meniscus tear should be repaired during ACL reconstruction to restore normal rotational laxity.

Level of evidence Therapeutic Study Level III

Keywords: Anterior cruciate ligament reconstruction, Meniscus repair, Rotatory knee laxity, Pivot-shift test, Quantitative measurement

Introduction

Meniscus tears are often accompanied with anterior cruciate ligament (ACL) injury [2, 5, 23, 27] and have been shown to affect the rotatory knee laxity in in vitro studies [16, 19, 24]. Even in clinical cases, the increase in rotatory knee laxity in ACL injured knees due to concomitant meniscus injuries have been detected by novel measurement technologies [10, 13, 20].

Ideally, every meniscus tear will be fully repaired for complete restoration of rotatory knee laxity. However, not all meniscus tears are repairable, and lateral meniscus tears are often treated by partial menisectomy or benign neglect with acceptable clinical outcomes [4, 14, 25, 26, 28]. Post-operative rotatory knee laxity could be compromised in such cases, but not detected clinically due to lack of meticulous evaluation systems.

Residual pivot-shift is a persistent problem that can be observed in ACL-reconstructed knees, even after an anatomic ACL reconstruction procedure [3]. This may be due to unrepaired meniscus tears, or meniscus repairs with insufficient restraining effect against pivot-shift in ACL-reconstructed knees. The purpose of this study was to compare the rotatory knee laxity between different meniscus conditions (intact, repaired and unrepaired) in ACL-reconstructed knees using quantitative measurements of the pivot-shift test. It was hypothesized that an unrepaired torn meniscus would induce greater pivot-shift in an ACL-reconstructed knee compared to repaired or intact menisci. The information about the effect of the unrepaired meniscus tear on the rotational laxity in the ACL reconstructed knees would be clinically important because it would promote preserving meniscus to improve the treatment of the ACL injured knee with concomitant meniscus injury.

Materials and Methods

Ethical approval was obtained from our institutional review board prior to this study (ID No. B190055). Informed consent was obtained from all individual participants. Patients aged 15-50 years who had primary ACL reconstruction at a single hospital between March 2013 and August 2016, and subsequent screw removal surgery about one year after the index ACL reconstruction were prospectively enrolled. Patients were excluded if they had concomitant fractures, severe cartilage injuries such as ICRS grade III or IV, posterolateral corner injuries, or other knee ligament injuries, including those of the medial collateral ligament and posterior cruciate ligament, in the ipsilateral or contralateral knee. Forty-six patients (21 males/25 females, 25±12 y.o.) were included in this study.

Patients were treated according to the clinical standard of care at the institution. After ACL injury was diagnosed clinically and confirmed by MRI, ACL reconstruction was performed using an anatomic reconstruction technique where the graft was finally fixed to a post screw using 6.5mm cancellous screw with washer on the tibial side [2]. Twenty-six patients underwent anatomic double-bundle reconstructions using an autograft from the hamstrings tendon, and 20 patients had anatomic single-bundle reconstructions using either hamstrings tendon autografts (18 patients) or bone-patellar-tendon bone autografts (2 patients). Concomitant meniscus tears, if any, were repaired whenever possible during the primary ACL reconstruction. Just prior to the index ACL reconstruction, the pivot-shift test was performed under anesthesia and evaluated clinically and quantitatively in ACL-deficient knees.

At one year postoperatively, the pivot-shift test was performed under anesthesia during screw removal surgery. Screw removal surgery was routinely performed at around one year after the ACL reconstruction in our facility. <u>Because remaining screw sometimes made kneeling pain or uncomfortable sensation and may become a focus of infection or cause interference if revision ACL reconstruction is needed.</u> Hardware removal surgery was covered by general health insurance in Japan and most patients agreed with the surgery prior to their primary ACL reconstructions. An electromagnetic measurement system was used to quantify the pivot-shift test by providing tibial acceleration of reduction movement as follows.

Quantitative Pivot-Shift Evaluation

The pivot-shift test was performed under general anesthesia as described above while the examiner was blinded to the meniscus status. The standardized technique [8] was used for the pivot-shift test. The pivot-shift movement was then quantitatively assessed using an electromagnetic measurement system (Fig. 1).

An electromagnetic motion-tracking device (JIMI 神戸, Arthrex Japan Inc., JAPAN) was used. This system consists of an electromagnetic tracking system, PC and analyzing software and is the same system utilized in previous studies [9, 10, 22]. Two electromagnetic sensors were secured on the thigh and shank with plastic straps. The examiner pointed seven anatomic bony landmarks of the femur and tibia with a probe with a sensor to register three-dimensional positions of the landmarks in relation to the two sensors on the skin. The seven anatomic bony landmarks were the greater trochanter, medial and lateral epicondyles, the crossing point between the medial joint line and the medial collateral ligament, fibula head, and medial and lateral malleoli. The positions of the femur and tibia were then recognized based on the spatial relationship between the anatomic bony landmarks and sensors on the skin. The anatomic coordinates of the knee were set according to the system proposed by Grood and Suntay [6]. The 6 degree-of-freedom knee kinematics were recorded during the pivot-shift test with a sampling rate of 240 Hz. Tibial acceleration (m/sec^2) during the pivot-shift test was then calculated from the data of the tibial anteroposterior translation in the same way as reported in previous studies. The accuracy of this measurement was reported as the average standard deviation of three measurements was 0.2 ± 0.1 m/sec^2. [9, 10, 22].

At the same time, clinical grade of the pivot-shift was assessed according to the International Knee Documentation Committee's guidelines, as: none (-), glide (+), clunk (++), and gross (+++) [11].

The acceleration and clinical grading of the pivot-shift test were compared between different preoperative meniscus conditions: intact, medial meniscus tear, lateral meniscus tear and bilateral menisci tears and between different postoperative conditions: intact, repaired and unrepaired.

Statistical Analysis

The clinical grade, tibial acceleration of the pivot-shift test, side-to-side difference of KT-1000 measurement with manual maximum and Lysholm score were compared between different postoperative meniscus conditions and different ACL reconstructions using a chi-square test and two-factor factorial analysis of variance (ANOVA), respectively, followed by a post-hoc Tukey HSD test for separate comparisons between two groups.

All statistical analyses were performed with SPSS Version 22 (SPSS Inc., Chicago, IL, USA). Statistical significance was set at $p<0.05$.

An a priori power analysis showed that 34 subjects were required to detect a 0.5 m/sec^2 difference in tibial acceleration, assuming a power of 0.80, significance level of 0.05, and common variance of 0.5 m/sec^2 in a two-sided Student's t-test. These parameters were based on data from previous reports [22]. If the assumption were slightly different, i.e. expected difference of 0.4m/sec^2 and statistical power of 0.85, the required sample size would be 48 which is over the current sample size.

Results

Concomitant meniscus tears were found in 28 knees during primary ACL reconstruction surgery: lateral meniscus tear in 11 knees, medial meniscus tear in 11 knees, and both medial and lateral menisci tears in 6 knees. 18 knees with intact menisci before ACL reconstruction did not exhibit additional meniscus tears during follow-up examinations. 17/17 medial meniscus tears and 8/17 lateral meniscus tears were repaired. The remaining 9 lateral meniscus tears were irreparable based on intra-operative arthroscopic finding and treated by partial menisectomy or left in situ. The types of meniscus tear and their treatment was described in Table2. Consequently, 19 knees had repaired menisci for medial, lateral or bilateral tears, whereas the remaining 9 knees had unrepaired lateral meniscus tears which were categorized in unrepaired meniscus group (Fig. 2). The demographic data of each group (intact, fully repaired and unrepaired meniscus) is shown in Table 1. The preoperative clinical and quantitative evaluations of the pivot-shift measurement were similar between groups with different postoperative meniscus conditions (n.s.) (Table 1).

The screw removal surgery was performed 14±3 months after the index ACL reconstruction surgery. The clinical grade of the pivot-shift, side-to-side difference of KT-1000 measurement and Lysholm score were not different between groups (all n.s.) (Table 3). The quantitative evaluation of the pivot-shift demonstrated that ACL-reconstructed knees with unrepaired menisci had larger pivot-shift accelerations (0.9±0.7 m/sec^2) than those with intact menisci (0.5±0.2 m/sec^2, $p<0.05$). There was no significant difference in rotatory knee laxity between knees with fully repaired menisci (0.6±0.3 m/sec^2) and intact menisci (n.s.) (Fig. 3). Comparison between different ACL reconstructions revealed that there was no statistically significant difference (n.s.) between double-bundle (n=26, 0.5±0.3 m/sec^2), single-bundle (n=26, 0.7±0.4 m/sec^2) and bone-patellar-tendon bone ACL reconstructions (n=2, both 0.4 m/sec^2). The statistical interaction between postoperative meniscus conditions and types of ACL reconstructions was not observed based on two factorial ANOVA (n.s.).

Discussion

The most important finding of this study is that unrepaired lateral meniscus tears induce a small but statistically significant increase of pivot-shift acceleration in ACL-reconstructed knees compared to knees with intact menisci. In addition, ACL-reconstructed knees with fully repaired menisci had similar rotatory knee laxity to those with intact menisci. The postoperative consequence of leaving a meniscus tear unrepaired in ACL-reconstructed knees has not been fully investigated, mainly due to lack of clinical symptoms in such cases [4, 14, 25, 26, 28]. Detailed evaluation of the rotatory knee laxity has detected a small difference of the pivot-shift [10, 20, 22], and subclinical problems in the rotatory knee laxity caused by unrepaired meniscus tear could be identified by quantitative evaluation of the pivot-shift test in this study.

The effect of meniscus repair on the pivot-shift was examined under the condition of ACL deficiency. Katakura et al [13] evaluated the pivot-shift before and after meniscus repair intraoperatively in ACL-injured knees just prior to ACL reconstruction and found significantly reduced tibial acceleration of the pivot-shift after meniscus repair using an accelerometer system [13]. However, postoperative in vivo effect of meniscus repair after the ACL reconstruction has yet to be studied.

In vivo quantitative evaluation using advanced technology is necessary to detect the small impact of the meniscus' condition on the pivot-shift. The influence of meniscus tear on the pivot-shift in the ACL deficient knee had been suggested by some in vitro studies [17, 24], but such an effect was not recognized in clinical settings due to lack of sensitive measurement of the pivot-shift. Recently, Musahl et al. [20] applied iPad pivot-shift measurement systems to detect increased anterior tibial translation of the lateral compartment during the pivot-shift in ACL-injured knees caused by a tear of the meniscus and anterolateral capsule [20].

Significant increase of the pivot-shift measurement was observed in the meniscus-unrepaired knees in this study, but it is still unknown how such an increased laxity affects clinical outcomes. In the current study, ACL reconstruction significantly reduced the rotatory knee laxity to a clinical grade of none (-) or glide (+), regardless of the meniscus conditions. Lateral meniscus tear can be left in situ or a partial menisectomy can be done, both resulting in acceptable clinical outcomes [25, 26]. However, it has been reported that remaining rotatory knee laxity may lead to osteoarthritic changes over time [12]. The clinical effect of the small increase in pivot-shift that detected in the current study needs long-term follow-up.

In the current study, repaired medial menisci seem to work similarly to intact menisci in terms of restraining pivot-shift. It is generally accepted that a medial meniscus tear has a significant impact on rotational laxity in the ACL deficient status [15, 18, 29], but there are specific tear types of the medial meniscus that do not affect anterior stability against combined rotational stress [1, 21]. Once the ACL was reconstructed, even menisectomy did not affect anterior laxity measured by KT-1000 [7]. The treatment of the medial meniscus tear, either meniscal repair or menisectomy, might not influence rotatory knee laxity in ACL-reconstructed knees.

The ACL reconstruction technique must have significant effect on the knee rotatory laxity. Double-bundle ACL reconstruction was previously reported to restore pivot-shift better than single-bundle using the same reconstruction technique and similar electromagnetic measurement [2]. In the current study, there was slightly smaller pivot-shift acceleration in double-bundle ACL reconstruction than single-bundle, but there was no statistical significance. The possible reason for this was similar distribution of ACL reconstructions in different meniscus condition groups.

This study has some limitations. First, since this is an observational study, treatment selection was not randomized. The same type of meniscus tears should be compared between repaired and unrepaired in a prospective manner. However, surgical decision on whether the meniscus tear was repairable or not was made by the surgeon based on his own experience and technique. Second, although it was determined by a sample size calculation prior to the study to provide enough power to detect the significant difference between three groups, our sample size was small. More detailed categorization based on different types of tears (horizontal, radial and longitudinal) and different locations (anterior, medial and/or posterior) would better address each specific meniscus tear seen in clinical practice. Third, the time to follow-up was only about one year (14±3 months). However, this study focuses on the biomechanical influence of the meniscus repair in ACL-reconstructed knees. Knee laxity after ACL reconstruction does not change significantly after one year postoperatively. Also, most athletes who have ACL reconstruction resume their normal activities at approximately one year after the operation. Thus, one year might be sufficient to address the biomechanical function of the knee after ACL reconstruction. Finally, postoperative assessment of the pivot-shift can only be compared under anesthesia. However, testing under anesthesia is the ideal condition for comparison of the pure knee rotatory laxity without any influence of neuromuscular reaction.

Clinical relevance of this study is that concomitant lateral meniscus tears, if any, should be repaired to inhibit pivot-shift after ACL reconstruction. Because irreparable lateral meniscus tears may lead to remaining rotatory knee laxity, even after ACL reconstruction.

Conclusions

Unrepaired lateral meniscus tears in ACL-reconstructed knees lead to remaining pivot-shift at one year postoperatively. Concomitant meniscus tears should be repaired during ACL reconstruction surgery to restore normal rotational laxity.

Authors' information

This work was presented at in the 12th Biennial ISAKOS Congress 2019, Cancun, Mexico.

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Compliance with Ethical Standards

Disclosure of potential conflicts of interest

We have no conflicts to disclose.

Research involving Human Participants

All procedures performed in our study are in accordance with the ethical standards of the institutional research committee (the Institutional Review Board of Kobe University (ID No. B190055) and with the 1964 Helsinki declaration and its later amendments or with comparable ethical standards.

Informed Consent

Informed consent was obtained from all individual participants.

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Tables

Table 1. Demographic Details of the Study Patients.

*: Ham SB – Single bundle ACL reconstruction using hamstrings tendon graft, Ham DB – Double bundle ACL reconstruction using hamstrings tendon graft, BTB – Single bundle ACL reconstruction using bone-patellar tendon-bone graft.

	Intact meniscus	**Fully repaired meniscus**	**Unrepaired meniscus**	**Total**
Patient number	18	19	9	46
Sex (Male/Female)	9/9	8/11	4/5	21/25
Age (y)	29±13	24±12	21±6	25±12
Time from injury to surgery (d)	206±252	167±146	214±336	191±231
Pivot-shift acceleration before primary operation (m/sec^2)	1.4±0.9	1.2±1.0	1.2±0.9	1.3±0.9
Number of patients for each meniscus injury status at the time of ACL reconstruction		Medial only: 11 Lateral only: 5 Both: 3	Lateral only: 6 Both: 3	
ACL reconstruction technique*	Ham SB: 9 Ham DB: 7 BTB: 2	Ham SB: 5 Ham DB: 14	Ham SB: 4 Ham DB: 5	

Table 2. Meniscus tear type and location in each repaired and unrepaired group.

*: All menisectomies were partial resections of the damaged area.

Abbreviations; Post – Posterior, Mid – Middle, Ant – Anterior.

	Medial meniscus tear only	Lateral meniscus tear only	Both meniscus tear
Fully repaired group	Total n=11 Longitudinal tear -Post part (n=5) -Mid part (n=2) -Mid-post part (n=3) -Ant-post part (n=1)	Total n=5 Longitudinal tear -Post part (n=2) -Mid-post part (n=2) Horizontal tear -Post part (n=1)	Total n=3 *Medial* Longitudinal tear -Post part (n=1) -Mid-post part (n=1) -Post part (n=1) *Lateral* Longitudinal tear -Post part (n=1) -Post-mid part (n=1) Horizontal tear -Mid part (n=1)
Unrepaired group	Total n=0	Total n=6 Longitudinal tear -Post part (n=1; Menisectomy*) Radial tear -Post part (n=2; Left in situ) (n=1; Menisectomy*) Horizontal complex tear -Post part (n=1; Menisectomy*) -Ant part (n=1; Menisectomy*)	Total n=3 *Medial(all repaired)* Longitudinal tear -Post part (n=1) -Mid-post part (n=1) *Lateral* Longitudinal tear -Post part (n=3; left in situ)

Table 3. Clinical grade of the pivot-shift test in the ACL deficient knees, side-to-side difference of KT-1000 measurement with manual maximum and Lyshom score with different meniscus conditions at around one-year follow-up

		Intact meniscus	Fully repaired meniscus	Unrepaired meniscus
Pivot-shift grade	None (-)	17	16	8
	Glide (+)	1	3	1
	Clunk or Gross (++ or +++)	0	0	0
Side-to-side difference of KT-1000 measurement		0.6±1.4mm	1.0±1.1mm	0.9±1.3mm
Lysholm score		95±7	93±7	95±4

Figure legends

Fig. 1 Quantitative assessment of the pivot-shift using an electromagnetic measurement system (JIMI 神戸, Arthrex Japan Inc., Tokyo, JAPAN) The left knee is examined with the pivot-shift test and movement of the knee is evaluated with the electromagnetic system. Two electromagnetic sensors are attached to the thigh and shank, and an electromagnetic transmitter is placed within the range of the electromagnetic wave.

Fig. 2 Transition of meniscus condition pre- and post- ACL reconstruction surgery

Fig. 3 Tibial acceleration during the pivot-shift test in ACL-injured knees with different meniscus conditions A statistically significant difference was observed only between the meniscus-intact and the unrepaired meniscus groups.

Fig1

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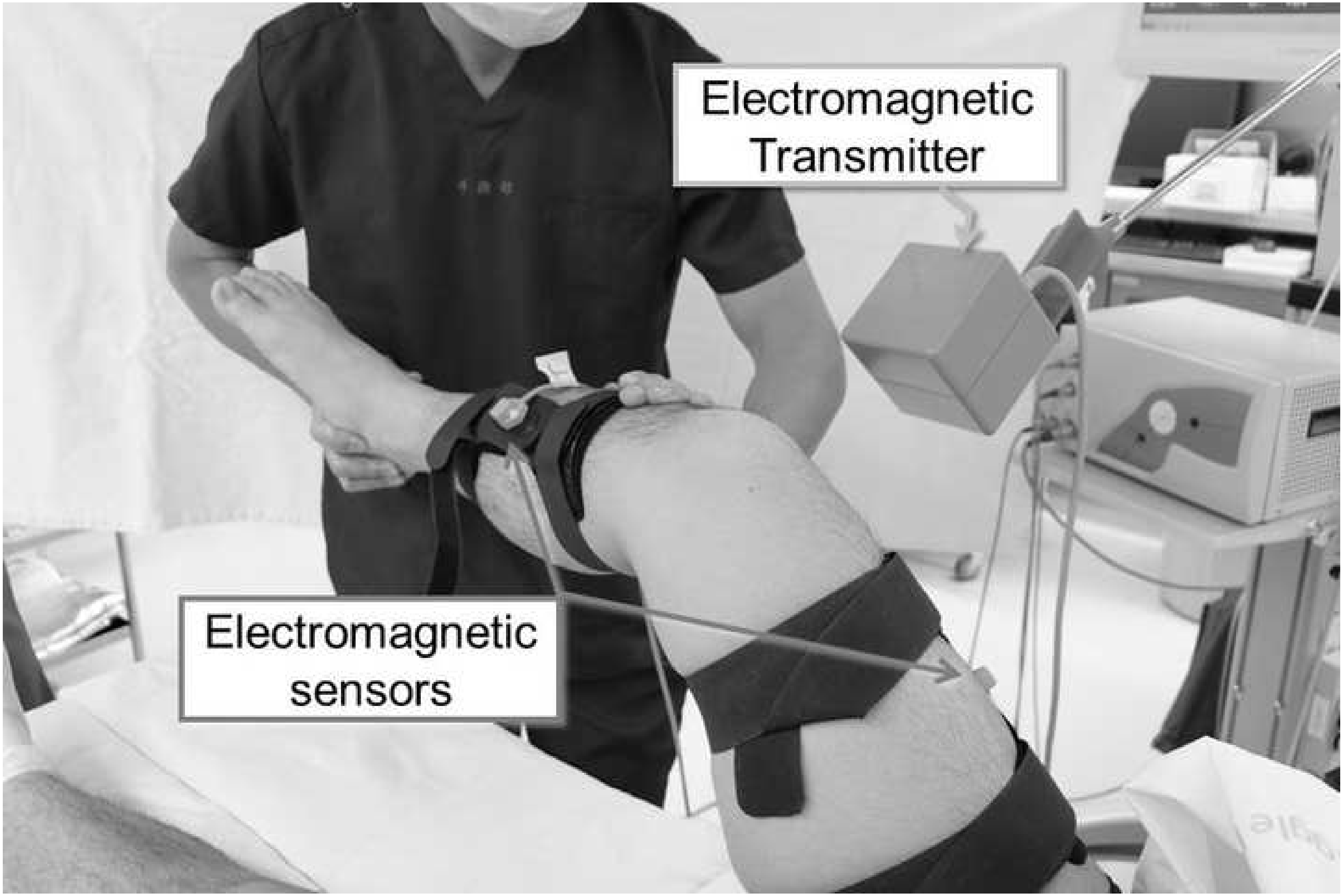
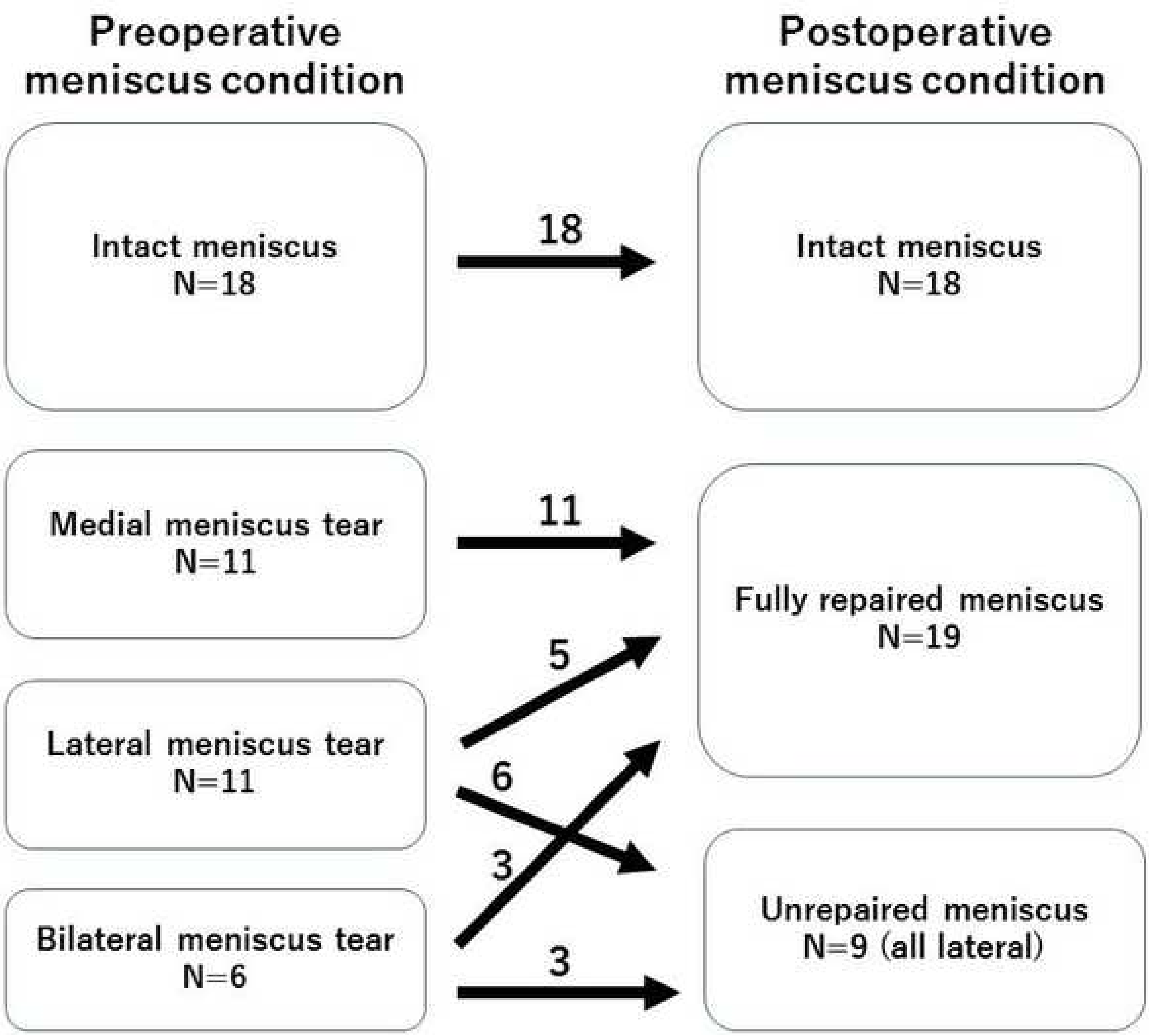


Fig2



Preoperative meniscus condition
Postoperative meniscus condition
Intact meniscus
N=18
18
Intact meniscus
N=18
Medial meniscus tear
N=11
11
Fully repaired meniscus
N=19
5
Lateral meniscus tear
N=11
6
3
Bilateral meniscus tear
N=6
3
Unrepaired meniscus
N=9 (all lateral)

Fig3

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