Preliminary outcomes of intraoperative cartilage thickness measurement in kinematically aligned robot- assisted total knee arthroplasty

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Abstract

Purpose: This study aimed to assess the preliminary outcomes of the intraoperative cartilage thickness measurement in kinematically aligned robot-assisted total knee arthroplasty (TKA).

Methods: Patients who underwent kinematically aligned robot-assisted TKA were included in this study. Three-point cartilage thickness measurement was performed from the intact distal femoral cartilage by a digital caliper intraoperatively in order to detect the actual cartilage thickness of the patient. Hip-knee-ankle angle (HKA), mechanical lateral distal femoral angle (mLDFA), mechanical medial proximal tibial angle (mMPTA), joint-line orientation angle (JLOA), and joint-line convergence angle (JLCA) were measured through standing full-length anteroposterior radiographs. Knee Injury and Osteoarthritis Outcome Score, Oxford score, VAS pain and satisfaction score, and Forgotten Joint Score were used to assess clinical outcomes.

Results: A total of 142 knees of 109 patients (92 females and 17 males) were evaluated in this study. The mean cartilage thickness was 1.9 ± 0.5 mm, 2.2 ± 0.6 mm, and 2.0 ± 0.5 mm from anterior to posterior respectively ($p = 0.006$). There was a significant correction in HKA, JLCA, and mMPTA postoperatively (p = <0.001, <0.001, and 0.029, respectively). We observed no significant change in mLDFA and JLOA measurements. All clinical scores significantly increased at the latest follow-up.

Conclusion: Our results demonstrated that distal lateral femoral cartilage thickness varied among patients and also differed in the different regions of the condyle. Cartilage thickness measurement technique in kinematically aligned robot-assisted TKA demonstrated no significant change in mLDFA and JLOA, but significantly corrected HKA, mMPTA, and JLCA.

Introduction

Knee osteoarthritis, also defined as gonarthrosis, is the most common joint disease that can cause pain and functional limitation [1]. Conventional knee radiographs can assess the degree of knee cartilage loss according to the narrowing of joint distance and can classify the severity of the disease. Magnetic resonance imaging (MRI) is currently the most useful method to detect local and generalized articular cartilage defects in patients with knee osteoarthritis [2]. Currently, 3.0-T MRI had better detection and visualization of knee cartilage lesions and knee cartilage thickness; however, it still has limitations for the accurate measurement of cartilage thickness [3, 4].

In a kinematically aligned total knee arthroplasty (TKA), the alignment of the femoral component is based on the cartilage and bone resections according to the thickness of the femoral component of the prosthesis [5]. For example, for varus gonarthrosis, femoral distal and posterior resections are performed according to the cartilage wear of the knee. If the cartilage tissue is intact at the lateral compartment and there is total cartilage wear at the medial compartment femur, when a 2 mm cartilage wear is considered, the medial distal and posterior resection thickness should be 7.5 mm (implant thickness–cartilage wear, 9.5 mm–2 mm = 7.5 mm), and the femur lateral distal and posterior cuts should be 9.5 mm. The thickness of the saw blade should also be considered during the conventional total knee arthroplasty.

Dr. Stephen Howell described the resection of the femoral component according to a 2 mm cartilage thickness as mentioned above in his surgical technique for kinematically aligned TKA [6]. In their study evaluating the cartilage thickness of varus and valgus knees in MRI, in varus knees, Nam et al. reported the cartilage thickness of distal medial femur as 0.05 mm and distal lateral femur as 1.8 mm, whereas posterior medial as 1.5 mm and posterior-lateral as 1.9 mm [7]. The authors recommended that the cartilage wear of the knee is predictable, and they recommended using generic instruments during kinematically aligned TKA as described by Dr. Howell [7]. Despite the varus-valgus alignment of the knee that depends on the cartilage wear in a kinematically aligned TKA, posterior condyle cartilage wear and its effect on femoral component rotation is also an important issue to be evaluated. Apart from conventional mechanically aligned TKA, the rotation of the femoral component also depends on the cartilage wear of the posterior condyles. In a kinematically aligned TKA, the thickness of the resection should be set according to the thickness of the prosthesis as mentioned above [6]. In their MRI study, Nam et al. remarked on the importance of MRI for assessing the cartilage thickness of the posterior condyles while detecting the rotational axis of the femoral component [8].

In our center, we performed kinematically aligned TKA by conventional technique since 2010, and by robot-assisted technique since 2019. We used generic instruments for the conventional TKA, and we previously accepted a 2 mm cartilage thickness as described by Dr. Howell in kinematic alignment technique. Since 2020, we began to use a digital caliper to assess the cartilage thickness of the intact cartilage to define the actual cartilage thickness of the patient. Then, we changed the thickness of the resection with 0.5 mm increments according to the actual cartilage thickness of the patient. According to the main idea of the kinematically aligned TKA technique, we hypothesized that every patient has a different cartilage thickness, and considering this issue during kinematically aligned TKA may have an effect on clinical and radiographic outcomes. Therefore, we aimed to assess the preliminary outcomes of the intraoperative cartilage thickness measurement in kinematically aligned robot-assisted TKA.

Patients And Methods

Study Population

This retrospective case-series study was performed under the approval of the institutional ethical review board (ID: E-22686390-050.01.04-4761) and conducted in accordance with the Declaration of Helsinki. Informed consent was obtained for each participant. The data of patients who underwent kinematically aligned robot-assisted TKA in our center were retrospectively reviewed. Patients with either unilateral or bilateral varus gonarthrosis who underwent kinematically aligned robot-assisted TKA between January 2020 and March 2021 by patient-specific cartilage thickness measurement were included in this study. Patients with incomplete medical and operative records and those with lateral femoral condyle cartilage damage that was not suitable for cartilage thickness measurement were excluded (Fig. 1).

Surgical Technique

All surgeries were performed by the senior author of this study (KT) who is experienced in the robot-assisted knee and hip arthroplasty since 2016 over 1200 cases. Robot-assisted total knee arthroplasties were performed by *NAVIO Surgical System* (Smith & Nephew, Memphis, USA), an image-free handheld robotic system with a proven accuracy in TKA procedure [9, 10]. Under pneumatic tourniquet, a classic anterior approach with medial parapatellar arthrotomy was applied in each case. Following the resections of soft tissue, osteophytes, menisci, and anterior cruciate ligament, femur, and tibia arrays were implanted by two Schanz pins each. Bony landmarks were registered and femur and tibia surface mapping were finished then. Implant positioning and planning was performed according to kinematic alignment introduced by Stephen Howell in 2005. We used a posterior stabilizing *ANTHEM Total Knee System* (Smith & Nephew, Memphis, USA) TKA implant that has a distal and posterior 9.5 mm thickness of the femoral component. Therefore, we planned to cut the lateral side according to the implant thickness at 9.5 mm, and we cut the medial side according to our patient-specific cartilage thickness measurement. We prepared three holes from the cartilage surface to the subchondral bone by a small surgical curette to measure the cartilage thickness of the intact lateral femoral cartilage (Fig. 2). Then, we measured the three-point cartilage thickness by a digital caliper (*ABSOLUTE Digimatic Caliper*, Mitutoyo Corp., Kanagawa, JAPAN) (Fig. 3). If the three different cartilage thicknesses were between 1.5 and 2.5 mm, we routinely set the cartilage thickness as 2 mm. If we measured < 1.5 mm in all three holes, we set 1.5 mm, and if we measured > 2.5 mm in all three holes, we set 2.5 mm as the cartilage thickness. We routinely set the planned hip-knee-ankle angle at one varus for females and at two varus for males according to the study of Bellemans et al. [11]. Implant planning was completed according to kinematic alignment. Distal femoral cut was performed by the handheld burr. Femoral and tibial cuts were performed with the cutting blocks by the help of visualization tool that shows the current location of the cut according to the plan. The device can also burr all femoral and tibial surface for prosthesis implantation. After checking the implant position, flexion-extension gaps, and range of motion with the trial components, TKA components were cemented and implanted to tibia and femur, respectively. Last range of motion and flexion-extension gap control was performed after hardening of the cement.

Data Analysis

Patients' demographics (age, gender), body mass indexes (BMI), operative records (cartilage thickness measurements), and robotic records (preoperative alignment, planned alignment, coronal-sagittal-axial positions of femoral and tibial components) were noted through our records.

Radiographic measurements were performed by three senior authors of the study (MK, YU, AT). Preoperative and postoperative: hip-knee-ankle angle (HKA), mechanical lateral distal femoral angle (mLDFA), mechanical medial proximal tibial angle (mMPTA), joint-line orientation angle (JLOA), and joint-line convergence angle (JLCA) were measured through standing full-length anteroposterior radiographs. Joint-line orientation angle was assessed by measuring the angle between the tibial joint line and the line parallel to the floor [12]. Joint-line convergence angle was evaluated by measuring the angle formed between femoral and tibial joint orientation lines [13].

Preoperatively and at the postoperative 1-year control, all patients fulfilled Knee Injury and Osteoarthritis Outcome Score (KOOS), KOOS for Joint Replacement (KOOS-JR), Oxford score, and Visual Analog Scale (VAS) pain score. Patients also fulfilled University of California Los Angeles (UCLA) activity score preoperatively and Forgotten Joint Score (FJS) and VAS satisfaction score at postoperative 1-year control. All complications were recorded.

Statistical Analysis

Statistical analysis was performed by SPSS 25.0 (SPSS Inc., IBM, NY, USA). Continuous data were given as means and standard deviations, while categorical data were given as frequencies and percentages. Comparison of preoperative and postoperative measurements was performed by paired t-test. Comparison of cartilage thickness measurements was performed by one-way ANOVA test. Bonferroni test was used for post hoc analysis. P values lower than 0.05 were considered as statistically significant.

Results

A total of 142 knees of 109 patients (92 females and 17 males) were analyzed in this study. The mean age of the patients was 66.3 ± 9.3 years (ranges, 34 to 89 years old) and the mean BMI was 26.4 ± 12.7 kg/m^2 (ranges, 18.5 to 39.3 kg/m^2). The median preoperative UCLA score was 2.

The mean cartilage thickness was 1.9 ± 0.5 mm (ranges, 0.9 to 3.5 mm) in the anterior portion of the distal lateral femur, while it was 2.2 ± 0.6 mm (ranges, 1.1 to 5 mm) in the mid-portion and 2.0 ± 0.5 mm (ranges, 1.2 to 3.2 mm) at the posterior portion of the distal lateral femur. The mean of the all three-point measurements was 2.0 ± 0.4 mm (ranges, 1.2 to 3.2 mm) (Fig. 4). We observed significant differences among three measurements. Cartilage thickness measurement at the anterior portion of the distal lateral femoral condyle was significantly lower than the mid-portion of the distal lateral femoral condyle (p = 0.006). However, there was no significant difference between posterior and mid-portion and anterior and posterior portion of the distal lateral femoral condyle in terms of cartilage thickness (p = 0.091 and 0.999, respectively).

Robotic data including planned HKA and planned position of the prosthetic components were summarized in Table 1. We observed no significant change in mLDFA and JLOA when preoperative and postoperative radiographs were compared (p = 0.317 and 0.115, respectively). There was a significant decrease in HKA and JLCA, and we found a significant increase in mMPTA postoperatively (p = < 0.001, < 0.001, and 0.029, respectively) (Table 2). We detected significant improvements in all domains of the KOOS and in the Oxford and VAS pain scores (Table 3).

Table 1
Robotic measurements assessed during the operations.

Preoperative HKA	**mean ± SD**	**(min,max)**	**9.0 ± 4.3 (-2, 19)**
Planned HKA	mean ± SD	(min,max)	1.0 ± 0.9 (-1, 4)
Femoral Component			
Coronal position	mean ± SD	(min,max)	(-)1.2 ± 2.2 (-6, 3)
Sagittal position	mean ± SD	(min,max)	3.6 ± 1.9 (0, 7)
Axial position	mean ± SD	(min,max)	(-)2.1 ± 2.0 (-6, 1)
Tibial Component			
Coronal position	mean ± SD	(min,max)	2.2 ± 1.7 (0, 6)
Sagittal position	mean ± SD	(min,max)	3.2 ± 0.7 (0, 6)
Axial position	mean ± SD	(min,max)	(-)0.1 ± 2.3 (-10, 12)
(-) values indicate valgus in coronal plane, extension in sagittal plane and internal rotation in axial plane			

Table 2
Preoperative and postoperative comparison of radiographic measurements.

		Preoperative	Postoperative	p values*
HKA angle	mean ± SD	11.0 ± 6.1	2.3 ± 3	**< 0.001**
mMPTA	mean ± SD	83.1 ± 15.3	86.6 ± 1.5	**0.029**
mLDFA	mean ± SD	87.8 ± 18.2	89.3 ± 2.8	0.317
JLOA	mean ± SD	1.3 ± 8.3	0.4 ± 4.4	0.115
JLCA	mean ± SD	5.2 ± 2.7	0.7 ± 0.7	**< 0.001**
* p values according to the paired t-test. Bold p values indicate statistical significance				
HKA: hip-knee-ankle angle, mMPTA: mechanical medial proximal tibial angle, mLDFA: mechanical lateral distal femoral angle, JLOA: joint-line orientation angle, JLCA: joint-line convergence angle				

Table 3
Preoperative and postoperative comparison of clinical scores of the patients.

		Preoperative	Postoperative	p values*
VAS pain	mean ± SD	8.8 ± 1	2.5 ± 1.2	< 0.001
VAS satisfaction	mean ± SD		8.3 ± 1.5	N/A
KOOS				
Symptom	mean ± SD	33.8 ± 13.4	86.6 ± 7.7	< 0.001
Pain	mean ± SD	28.7 ± 10.6	81.2 ± 8.6	< 0.001
Daily activity	mean ± SD	25.7 ± 8.4	77.3 ± 7.3	< 0.001
Sport	mean ± SD	9.7 ± 10.1	46.7 ± 10.7	< 0.001
Quality of Life	mean ± SD	25.4 ± 17.4	72.1 ± 13.3	< 0.001
KOOS JR	mean ± SD	24 ± 9.5	72.3 ± 8.3	< 0.001
Oxford Score	mean ± SD	12.1 ± 5.6	32.4 ± 6	< 0.001
Forgotten Joint Score	mean ± SD		67.6 ± 12.5	N/A
* p values according to the paired t-test.				
VAS: visual analog scale, KOOS: Knee Injury and Osteoarthritis Outcome Score, JR: joint replacement				

Although we encountered five technical problems resulting in the cancellation of the robot-assisted TKA procedure, we did not switch to the manual technique due to the presence of another NAVIO device in our clinic. We did not observe any major or minor complications intraoperatively and during the hospitalization period. We encountered two major and three minor complications postoperatively. One patient had a periprosthetic femur fracture after falling at ground level. The patient had a notch at the anterior femur and femoral pin tracks were near to the notch level. We applied open reduction and internal fixation with a distal femoral anatomic plate, bone union was achieved at postoperative 4th months control. Three patients had a prolonged wound drainage and healing. In these patients, low-molecular-weight heparin was stopped (prophylaxis continued with acetylsalicylic acid) and an antibiotherapy started.

Discussion

The most important finding of this study was observing significantly different cartilage thickness measurements at the distal lateral femoral condyle, in patients who underwent three-point cartilage thickness measurement during kinematically aligned robot-assisted TKA. However, the mean of the three-point cartilage thickness measurements was found to be similar to the measurement of the originally described kinematically aligned TKA technique that was accepted as 2 mm. Our radiographic outcomes demonstrated that patient-specific kinematically aligned TKA by cartilage thickness measurement did not significantly change mLDFA and JLOA, but significantly corrected HKA, mMPTA, and JLCA. Preliminary clinical results showed a significant improvement in all scores as expected. Our null hypothesis can be partially accepted that every patient has a different cartilage thickness, and kinematically aligned TKA by patient-specific cartilage measurement significantly corrected the deformity without changing patients' JLOA.

Since its first description, kinematically aligned TKA has gained interest and popularity by years with the help of the development in computer-assisted patient-specific instrumentation and robot-assisted surgery. To date, many prospective randomized controlled clinical studies that compared mechanically and kinematically aligned TKA reported either similar outcomes or superior results in favor of kinematically aligned TKA [14–23]. The main advantage of kinematically aligned TKA is restoring the patient's original anatomy and resurfacing the bones by making the bone cuts according to the patients' native anatomy and setting the bone cuts according to the thickness of the implant. In addition, prevention of the excessive release of medial collateral ligament (MCL) and restoring the constitutional varus also affect the kinematic and the function of the knee joint. In their study on 250 healthy subjects, Bellemans et al. found the mean HKA as 1.87-degree varus in males and 0.79-degree varus in females [9]. In another study by Almaawi et al., 4884 lower limb computed tomography (CT) were scanned and the authors reported that only 5.5% of the patients had a HKA of 0 degree [24]. In our study, we performed kinematic alignment in all cases and the mean planned HKA was 1 ± 0.9 degree. Nevertheless, we found a mean 2.3 ± 3 degrees at postoperative standing full-length radiographs. This difference can be explained by the lying robotic and standing radiographic measurements. We also noticed this difference in the studies of Bellemans et al. and Almaawi et al. Despite Bellemans et al.'s study, Almaawi et al. reported a mean HKA of 0.1-degree varus in their CT scan study of a large population that also performed in lying position [11, 24]. This issue should be investigated by further population studies in larger cohorts to define the exact value of HKA angle in normal pre-arthritic knee.

Joint-line orientation is still in debate and in the center of the discussion between kinematically and mechanically aligned TKA. There are limited long-term studies in the literature evaluating the JLOA and its effect on functional outcomes. In a recent study by D'amato et al., the authors mentioned that restoration of the JLOA did not affect the clinical outcomes in the postoperative 1-year [25]. In another recent study, Celek et al. reported that restoring the tibial joint line (joint-line orientation angle) parallel to the floor had no effect on outcomes [26]. D'Amato et al. and Celek et al. both observed that patients with medially opened JLOA had better outcomes than their laterally opened opposites [25, 26]. A medially opened JLOA also means a residual varus position of the tibia that can be observed in patients with constitutional varus. Shin et al. also remarked on this issue and reported better functional and joint awareness scores in their TKA technique preserving the constitutional varus [27]. In our study, we found no significant difference between preoperative and postoperative JLOA measurements, and this finding demonstrated that patients' native JLOA was preserved. Interestingly, we observed a high variation in JLOA measurements that showed the diversity of the anatomy of the patients. The idea of kinematically aligned TKA is based on this concept in which every patient is different and also patient's every leg is different, so rather than adjusting the bone cut perpendicular to the 0-degree mechanical axis, the patient's native anatomy should be preserved. The reason for observing similar mLDFA measurements can be explained by making the bone cuts in concordance with the distal femoral cartilage wear. In addition, the coronal degree of tibial bone cuts that is set in relation to the femur also does not change the patients' JLOA, which is also described as a tibial joint-line orientation angle.

In this study, as expected, we observed significant increases in the mean KOOS scores and Oxford Knee scores after kinematically aligned robot-assisted TKA. The Forgotten Joint Score is an important outcome measurement especially for kinematically aligned TKA due to its philosophy of preserving the joint kinematic and the patient's native anatomy. Elbuluk et al. compared mechanical and kinematic alignment in their study and observed significantly better FJS at postoperative 1-year and 2-year [28]. However, Mc Ewen et al. did not observe a significant difference between computer-assisted mechanic and kinematic alignment in terms of functional scores and FJS [29]. In our study, we have no chance to compare the functional scores and FJS of patients with another group. We detected a mean 67.6 point of FJS in the present study. Singh et al. reported a relatively small FJS with a mean of 38.2 in postoperative 1-year [30]. In another study of Singh et al., authors observed a mean FJS of 42.6 and threshold value between 33.3 and 77.1 for detecting patient acceptable symptom state in primary TKA [31]. Zuiderbaan et al. and Peersman et al. reported a mean 59.3 and 54.8 FJS, respectively, at postoperative 1-year [32, 33]. Our joint awareness outcome by FJS is consistent with the current literature. Nevertheless, there are limited studies in the literature evaluating FJS in kinematically aligned robot-assisted TKA.

The retrospective design of the study is the major limitation of our study. However, we evaluated a prospectively followed patient population operated by a single surgeon in a single center. Lack of control group is another limitation of this study. Nevertheless, we aimed to only present the preliminary outcomes of kinematically aligned robot-assisted TKA by patient-specific cartilage thickness measurement. The main strength of our study is being the first study that assesses the cartilage thickness of the knee joint intraoperatively for the application of kinematic alignment. In addition, our study is the largest case series in the literature reporting the outcomes of robot-assisted TKA performed by NAVIO Surgical System.

Conclusion

Our results demonstrated that distal lateral femoral cartilage thickness varied among patients and also differed in the different regions of the condyle. Cartilage thickness measurement technique in kinematically aligned robot-assisted TKA demonstrated no significant change in mLDFA and JLOA, but significantly corrected HKA, mMPTA, and JLCA. In addition, we observed significant improvements in functional outcomes with a satisfactory Forgotten Joint Score.

Declarations

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Ethical approval: *This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the Ethics Committee of Istanbul Atlas University (Date: 25.06.2021 /No:* E-22686390-050.01.04-4761*)*

Consent to participate: *Informed consent was obtained from all individual participants included in the study.*

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Figures

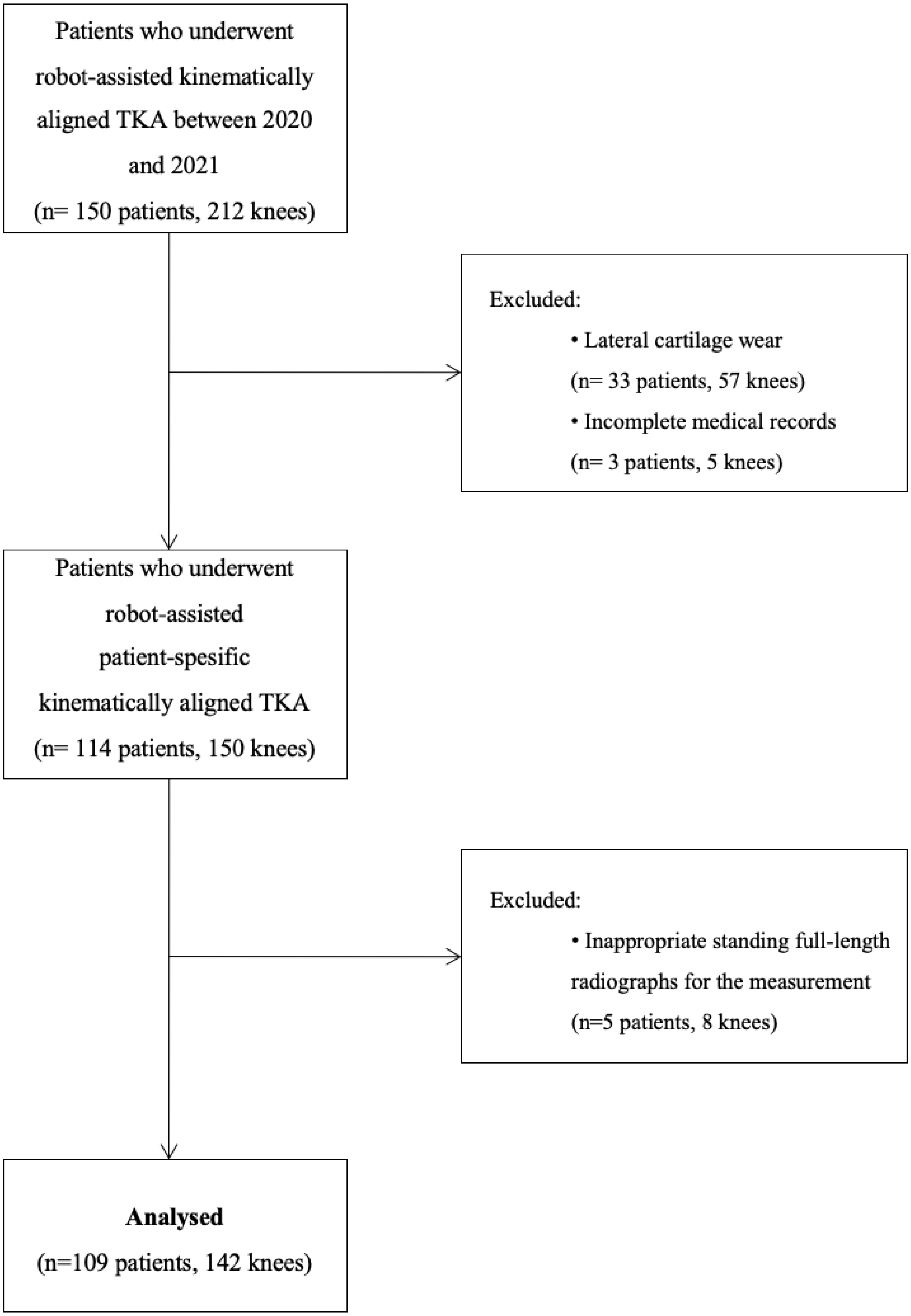

Figure 1

Flowchart diagram of the study.

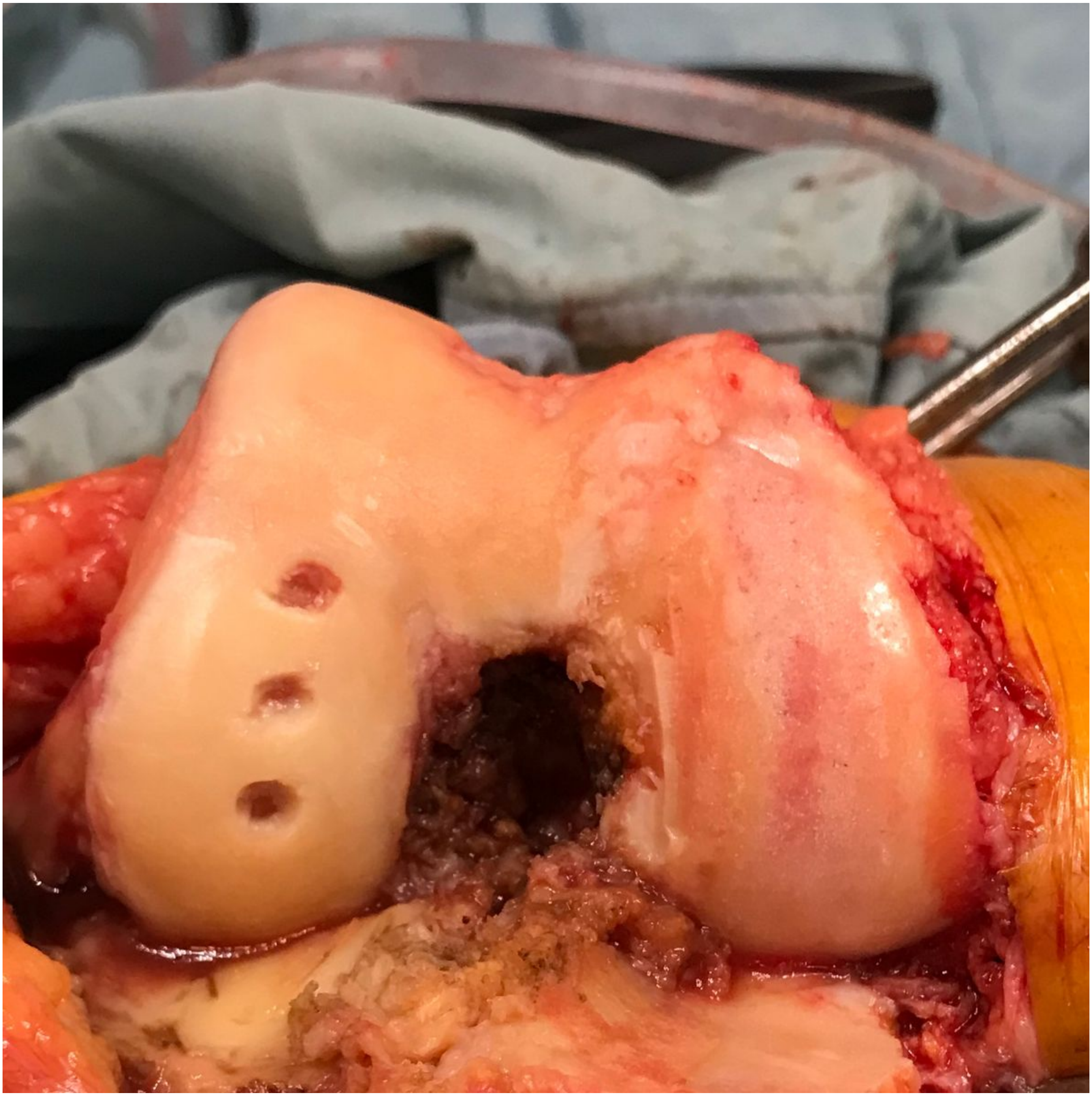

Figure 2

Preparation of three holes from the cartilage surface to the subchondral bone by a small surgical curette to measure the anterior, middle, and posterior cartilage thickness of the intact distal lateral femoral condyle cartilage.

Figure 3

Cartilage thickness measurement by the digital caliper (*ABSOLUTE Digimatic Caliper*, Mitutoyo Corp., Kanagawa, JAPAN).

Figure 4

The diagram shows the anterior, mid, posterior, and overall cartilage thickness measurements.