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ORIGINAL PAPER

Comparison of the outcomes of navigation-assisted revision of unicompartmental knee arthroplasty to total knee arthroplasty versus navigation-assisted primary TKA

Han-Jun Lee[1] · Yong-Beom Park[1] · Min-Ku Song[1] · Yoon-Ho Kwak[1] · Seong Hwan Kim[2]

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Abstract

Purpose Revision of unicompartmental knee arthroplasty (UKA) to total knee arthroplasty (TKA) is technically demanding but can be performed with computer navigation system guidance. The purpose of this study was (1) to compare the outcomes of revision of UKA to TKA to those of primary TKA and (2) to describe a surgical technique for the revision of UKA to TKA using a navigation system.

Methods From May 2011 to April 2014, a total of 298 knees underwent primary navigation-assisted TKA (group 1), and navigation-assisted UKA revision to TKA was performed in 15 patients (group 2). One to three propensity score matching was performed to compare the two groups after a minimum of three years of follow-up. Radiographic and clinical outcomes in addition to radiolucent lines were evaluated during follow-up.

Results In group 1, there was one case that required metal block augmentation with the long stem under the tibial plate due to severe bone loss, while in other cases, short stems were used, and cement and autogenous bone grafts were used to fill bone defects due to minimal bone loss. Pre- and post-operative outcomes were significantly improved in both groups ($p < 0.001$). There were no statistical differences between groups in pre- and post-operative outcomes except post-operative Knee Society Function Score (KSFS) ($p = 0.008$). There were no radiolucent lines in the tibia or femur in either group during follow-up.

Conclusions With the use of an appropriate surgical technique, navigation-assisted revision of UKA to TKA can yield clinical and radiologic outcomes comparable to those of primary navigation-assisted TKA.

Level of Evidence: Level IV

Keywords Unicompartmental knee arthroplasty · Unicompartmental knee arthroplasty revision · Navigation system · Total knee arthroplasty

Introduction

Unicompartmental knee arthroplasty (UKA) was introduced to allow prosthetic replacement of only the affected joint compartment with preservation of bone stock. UKA is considered an alternative method to total knee arthroplasty (TKA) or high tibial osteotomy for treatment of isolated unicompartmental knee arthritis. Though UKA has several advantages over TKA, the revision rate is higher for UKA than for TKA [1]. When UKA failure occurs, a revision to TKA is often necessary. The main reason for early and late failure after medial UKA is advancing arthritis in other compartments, followed by aseptic loosening. Polyethylene wear as a contributing factor in early failure is extremely rare [2, 3]. Therefore, interests have been raised about the outcomes of revised UKAs.

Some researchers found that conversion of failed UKA to TKA was associated with poorer outcome as compared to primary TKA [4–8]. Others reported that the outcomes of revision UKA were very satisfying and comparable to primary TKA [9–11]. Though there was controversy on the outcomes, many authors reported about using bone augmentations, metal blocks, stems, or constrained implants which might cause surgical difficulties [10–13].

Han-Jun Lee and Yong-Beom Park contribute equally this article as a first author.

✉ Seong Hwan Kim
ksh170177@nate.com

[1] Department of Orthopedic Surgery, Chung-Ang University Hospital, Chung-Ang University, Seoul, South Korea

[2] Department of Orthopedic Surgery, Hanmaeum Changwon Hospital, Han-Yang University, Changwon-Si, Kyungsangnam-Do, South Korea

The main reason that makes revision of UKA to TKA difficult is the filling of bone defects, which occurs during implant removal [4, 13]. These bone defects have negative effects to locate the TKA components, restore the mechanical axis, and evaluate ligament balance, which are the most important contributors to successful TKA [14]. These factors can be controlled by using a computer navigation system verified for primary TKA [14] but have rarely been used for revision TKA or UKA [15, 16].

We assessed the clinical and radiologic outcomes of revision of mobile-bearing UKA to TKA performed using the navigation system and compared these outcomes to those of primary navigation-assisted TKA. It is hypothesized that the clinical and radiologic outcomes of navigation-assisted UKA revision would not be worse than that of navigation-assisted primary TKA.

Materials and methods

This was a retrospective, matched-pairs, case-control study of patients who underwent TKA between 2011 and 2014 with a minimum of three years of follow-up. A total of 328 knees of 278 patients who had undergone primary navigation-assisted TKA (Columbus®, Aesculap, Tuttlingen, Germany), using the OrthoPilot navigation system for measured resection were enrolled in this study. All the patients had a history of degenerative osteoarthritis (OA) with varus deformity. All of the included cases of UKA revision were Oxford mobile bearing design UKA (Biomet, Bridgend, UK) in the same institution. Exclusion criteria were as follows: cases with bone graft due to severe deformity or bone defect, revision surgery, severe flexion contracture over 20°, varus/valgus deformity greater than 20°, BMI over 30 kg/m^2, and less than three years of follow-up. After applying exclusion criteria, there were 298 knees (248 patients) in the primary navigation-assisted TKA group. Navigation-assisted UKA revision was performed in 15 patients (15 knees) using the same prosthesis and navigation system. All patients that underwent UKA revision had a minimum of three years of follow-up, and the mean time from UKA to revision surgery was 92.3 ± 7.5 months. Then, 1:3 propensity score matching was performed. Finally, 45 knees in the primary navigation-assisted TKA group (group 1) and 15 knees in the UKA revision group (group2) were enrolled in this study. Patient demographics were similar between these two groups (Table 1).

All patients were assessed clinically and radiologically before surgery, at six weeks after surgery, at six and 12 months after surgery, and then yearly thereafter. Post-operative scores were obtained for all patients using the Knee Society Score (KSS), Hospital for Special Surgery (HSS) score, WOMAC (Western Ontario and McMaster Universities) score, patellofemoral (PF) scoring system of Feller et al. [17], and post-operative range of motion (ROM).

The mechanical femorotibial angle (MAD) in the coronal plane was evaluated on standardized full-length weight-bearing radiographs. The following angles of component alignment were evaluated: coronal femoral (α), coronal tibial (β), sagittal femoral (γ), and sagittal tibial (δ) [18]. Moreover, the change in joint line level was measured on pre-operative and post-operative radiographs [19]. The computed tomographic scanning (CT) was performed to measure the femoral and tibial component rotation angle pre-operatively and post-operatively. The femoral component rotation angle on CT was defined as the angle between a line connecting the most prominent points of the medial and lateral epicondyles of the femur and a line connecting the surface of the posterior condyle of the femoral prosthesis. The value of pre-operative femoral component rotation angle on CT was compared with the value of femoral component rotation angle on navigation intra-operatively to obtain proper rotation angle. The post-operative tibial component rotation angle on CT was defined as the angle between a line which projected perpendicular to the transepicondylar axis (the clinical epicondylar axis) connecting the most prominent points of the lateral epicondyle to the medial anatomical epicondyle of femur and the line perpendicular to the line tangential to the posterior condyles of the tibial component [20]. The post-operative values of revision UKA and primary TKA were also compared to assess proper rotation. In post-operative TKA radiologic evaluations, the width of each radiolucent line was measured based on all seven zones of the femur on lateral view and seven and three zones of the tibia on anteroposterior and lateral views, respectively [21]. All measurements were performed by two orthopaedic surgeons under the same conditions on a picture archiving and communications system (PACS; General Electric, Chicago, IL, USA).

Surgical technique

All surgeries were performed by single surgeon using a standard medial parapatellar approach. Medial soft tissue release was performed to establish a transmitter for navigation. After fixation of the two transmitters in femur and tibia, dynamic registration of the knee, hip, and ankle centre was followed by registration of the UKA component in situ. To register the tibial and femoral anatomical reference points, the probe was used to palpate the tibial and femoral component surfaces with the UKA components in situ (Fig. 1a). Determination of the femoral alignment and rotation angle was also performed with the UKA components in situ (Fig. 1b) and compared with the pre-operative rotational angle in CT. After all registrations were performed, UKA components were meticulously removed. After removal of the UKA components, the thickness of resection was determined by navigation with the UKA

Table 1 Patients' demographic data before and after propensity matching (mean ± standard deviation)

	Unmatched group		*p* value	Standardized difference	Propensity-matched groups		*p* value	Standardized difference
	Primary TKA	UKA revision			Group 1	Group 2		
Number of cases	248	15	–	–	45	15	–	–
Age (years)	67.5 ± 14.3	69.3 ± 8.9	0.631	0.128	69.5 ± 8.3	69.3 ± 8.9	0.937	− 0.023
Body mass index (BMI)	24.9 ± 6.1	26.1 ± 3.4	0.452	0.2	26.4 ± 3.7	26.1 ± 3.4	0.782	− 0.083
Gender (male/female)	92:156	4: 11	0.59	− 0.217	12: 33	4: 11	0.736	0.00
Flexion contracture	10.6° ± 5.3	7.6° ± 3.6	0.03	− 0.574	7.4° ± 3.2	7.6° ± 3.6	0.799	0.061
Further flexion	119.5° ± 12.5	125.5° ± 8.8	0.07	0.487	125.3° ± 9.7	125.5° ± 8.8	0.944	0.021
KSS scores								
KS Knee Score	44.8 ± 19.2	47.6 ± 15.3	0.581	0.147	46.6 ± 17.6	47.6 ± 15.3	0.845	0.059
KS Function Score	48.1 ± 14.2	43.9 ± 8.4	0.259	− 0.301	44.1 ± 10.1	43.9 ± 8.4	0.945	− 0.021
HSS score	48.8 ± 13.2	53.5 ± 9.7	0.176	0.361	51.9 ± 11.0	53.5 ± 9.7	0.716	0.056
WOMAC scores								
Total	54.3 ± 19.6	49.8 ± 16.2	0.385	− 0.232	50.2 ± 17.8	49.8 ± 16.2	0.956	− 0.023
Pain	9.2 ± 5.2	9.5 ± 3.9	0.826	0.058	9.6 ± 4.1	9.5 ± 3.9	0.952	− 0.024
Stiffness	4.9 ± 2.1	4.8 ± 1.4	0.856	− 0.048	4.8 ± 1.3	4.8 ± 1.4	1.000	0.00
Function	39.5 ± 17.9	36.8 ± 16.8	0.569	− 0.151	37.1 ± 15.3	36.8 ± 16.8	0.962	− 0.019
Mechanical tibiofemoral angle	Varus 11.3° ± 5.3	Varus 8.5° ± 3.7	0.045	− 0.536	Varus 8.4° ± 4.1	Varus 8.5° ± 3.7	0.952	0.025
Pre-operative femoral rotation angle in CT	4.6° ± 3.6	4.1° ± 2.7	0.598	− 0.141	4.2° ± 3.2	4.1° ± 2.7	0.938	− 0.032
Follow-up (month)	41.6 ± 8.4	44.2 ± 2.4	0.237	–	43.2 ± 3.6	44.2 ± 2.4	0.321	–

components in situ again. During bone resection plan, femoral and tibial resection guides with the corresponding transmitter were used to evaluate the alignment and thickness of the bone resection (Fig. 1c, d). The entire thicknesses of the distal femoral and proximal tibial resection were assessed with the UKA components in situ (Fig. 1e). If there was a persistent femur or tibial bone defect after cutting, it was filled with cement and bone grafts from resected femoral bone. Soft tissue release was performed to achieve gaps for flexion/extension and medial/lateral tissue balance; all gap differences were ≤ 3 mm after step-by-step release. After confirming flexion and extension gap balance and patellar tracking, tibial and femoral components were fixed with cement. A short or long stem for the tibia prosthesis was used in all UKA revision to TKA cases in order to enhance stability. A long stem implantation with metal augmentation was performed when a large bone defect over 5 mm was found, whereas a short stem implantation with bone graft and cementing was performed with small bone defect less than 5 mm.

All patients were prescribed the same postoperative protocol and were encouraged to begin weight bearing with a walker and range of motion exercises at two days after the operation. Two weeks from the operation, patients were discharged home or to a rehabilitation center with their weight supported by crutches or a walker.

Statistical analysis

Statistical analyses were performed using SPSS software (Chicago, IL, USA) and "matchit" and "optmatch" R-packages (ver.3.4.1 "Single Candle"). Primary TKA and UKA revision patients were propensity score matched to adjust for differences in baseline variables associated with outcome. The propensity score was calculated by binary logistic regression using R-packages with the covariates specified in Table 1. A greedy matching algorithm with a 3:1 ratio was used. The standardized difference was used as a balance diagnostic, and a less than 10% difference in mean or prevalence of covariates between groups was considered acceptable [22].

The primary outcome measurement was mean Knee Society Function Score (KSFS) at final follow-up. The post hoc power analysis was calculated as 0.8058438 with a two-sided α error of 5% and 0.8558093 of effect size. Patient demographics in these two groups were analyzed using the chi-square test for categorical variables and independent *t* test for continuous variables using the matched pair criteria. Moreover, a paired *t* test was performed to compare pre-operative and post-operative data. Statistical significance was set at $p < 0.05$. A test-retest for inter- and intra-observer reliability was performed with each orthopedic surgeon after two weeks from the first measurement and was determined using the intraclass correlation coefficient (ICC) with consistency.

Results

Clinical results

The pre-operative evaluation results for the UKA revision group are summarized in Table 2. Radiolucent lines less than 2 mm in width were found in 66.7% of the UKA cases, while

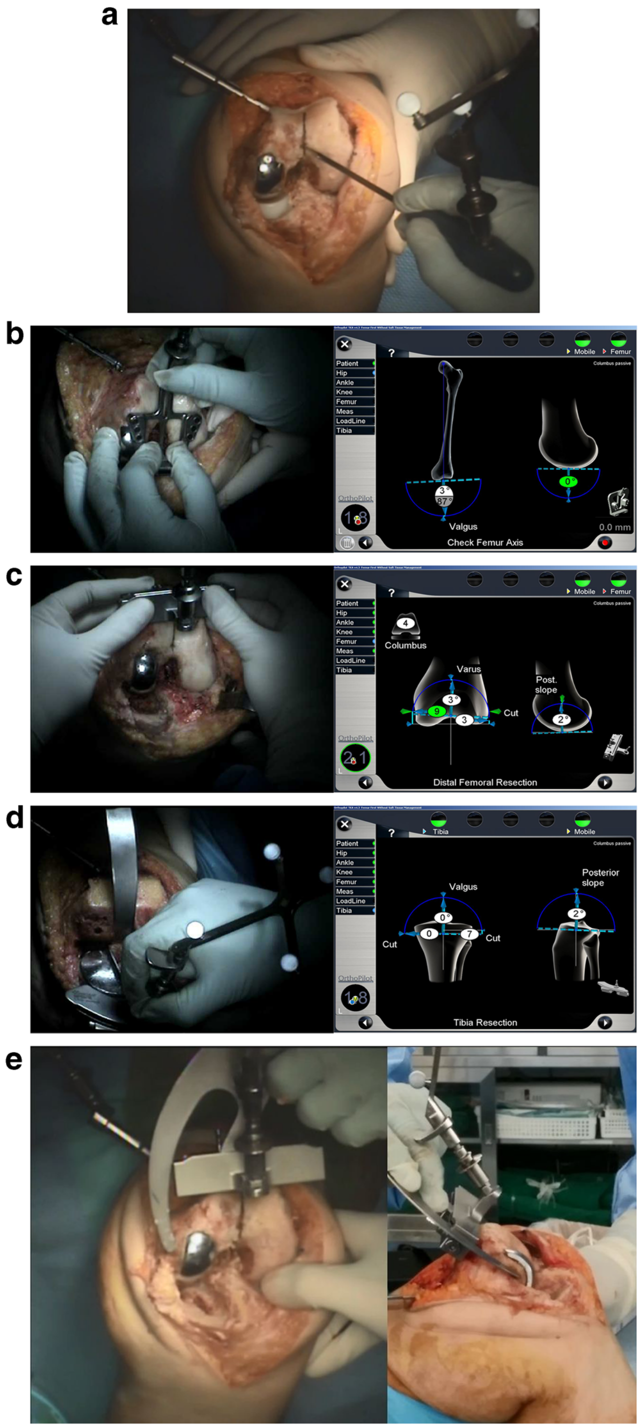

Fig. 1 **a** Registration of the tibial and femoral anatomical reference points. **b** Measurement of femoral alignment. **c** Measurement of femoral cutting level. **d** Measurement of tibial cutting level. **e** The entire thickness of the distal femoral cut was reassessed with the UKA components in situ

lines more than 2 mm were found in 40.0% of UKA cases, which was diagnosed as aseptic loosening. Reasons for UKA revision are also listed in Table 2. Component loosening/failure with radiolucent lines was the prime reason for revision of UKA. No revisions were performed because of infection or instability due to cruciate ligament injury. All revised UKAs were Oxford design (Biomet, Bridgend, UK) (Figs. 2 and 3). At the time of revision surgery, stemmed implants were used on the tibial side in all 15 knees (100%). One case was performed revision UKA with long stem and metal block, and others were performed with short stem and bone graft, cementing. No constrained knee implant was required. There were no allogenous bone augmentations for UKA revision, but cement and an autogenous bone graft were used to repair minimal bone loss (Fig. 2a, b), and metal block augmentation was performed in one case due to severe bone loss (Fig. 3a, b).

Clinical results after propensity matching are summarized in Table 3. Pre- and post-operative clinical outcomes in the two groups were significantly different in all matched evaluations ($p < 0.05$). When results were compared between the two groups at final follow-up, KSFS was significantly different. There was a significant difference in pain going up or down stairs, but not in functional scores (difficulty scores with motion), between the two groups in terms of KSFS items. Similar tendencies were found in WOMAC scores, but not the other scores. Although scores for specific functional questions in the KSFS and WOMAC systems were not significantly different between the two groups, the absolute values of scores in group 2 were seemed lower than those in group 1. The patellofemoral scores of Feller were not significantly different between the two groups. Flexion contracture was also not significantly different between the two groups, even though the flexion contracture angle appeared to be worse in group 2 than group 1.

There were no post-operative complications such as infection or loosening until final follow-up in either group.

Radiographic results

The radiologic results are summarized in Table 4 (also see Figs. 2 and 3). There were no differences in radiographic evaluations between groups at final follow-up. The thickness of polyethylene seemed to be larger in group 1 than that of group 2 although there were no statistical differences. There were no visible radiolucent lines in either group at final follow-up. The intra- and inter-observer reliability based on ICC ranged from 0.898 to 0.932.

Discussion

The most important finding from this study is that the short-term outcomes of revision UKA to TKA under a computer navigation system are satisfactory and comparable with the clinical and radiologic outcomes of primary navigation-assisted TKA, although the function scores were slightly lower in the revision UKA group than the primary TKA group. Moreover, anatomic registration using navigation with the

Table 2 The reasons for revision of UKA and locations of radiolucent lines pre-operatively

	Location of radiolucency			Total (A + B + C)	Percentage (%)
	Femur (A)	Tibia (B)	Femur and Tibia (C)		
Less than 2 mm	0	7	3	10	66.7 (10/15)
More than 2 mm	0	5	1	6	40.0 (6/15)
Reasons for revision of UKA		Number of cases		Percentage (%)	
Component loosening/failure		6		40.0 (6/15)	
Progressive arthritis		3		20.0 (3/15)	
Polyethylene wear		5		33.3 (5/15)	
Bearing dislocation		1		6.7 (1/15)	

UKA components in situ is comparable to primary TKA. The navigation system could be used to assist surgical procedures to reduce bone loss, find the ideal joint line and limb alignment, decrease the invasiveness of the surgery, and perform soft tissue balancing, all of which can be challenging when performing revision of UKA. The detailed surgical technique used in this study describes how to perform navigation-assisted revision of UKA to TKA for reliable anatomic alignment.

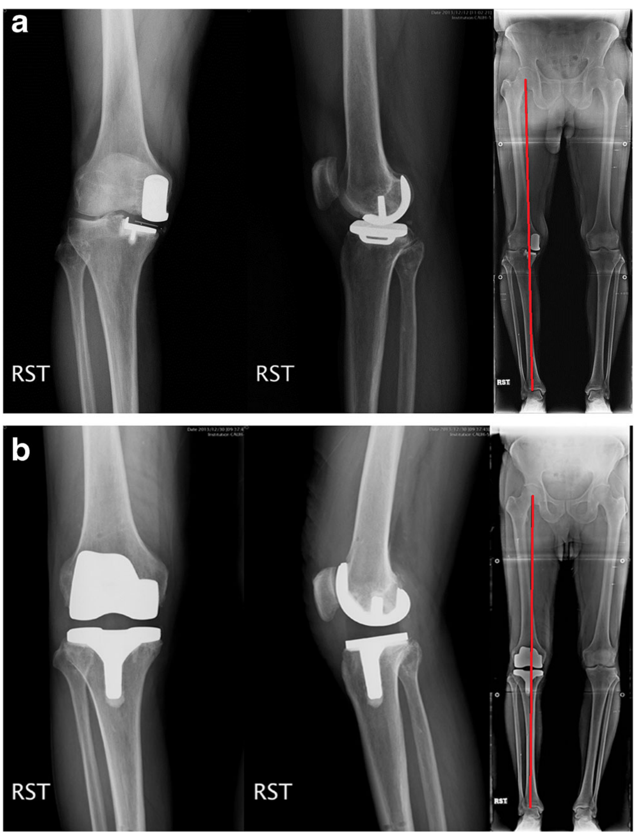

Fig. 2 **a** Pre-operative radiograph of a 62-year-old patient at 98 months after unicompartmental knee arthroplasty. Joint subluxation and narrowing due to polyethylene wear were found. **b** Post-operative radiograph after revision to TKA at final follow-up

Revision of UKA to TKA is considered either a challenging procedure or a routine primary replacement, according to experience. Several studies have reported a poorer outcome for UKA converted to TKA than that of primary TKA [5–8]. Revision of UKA to TKA is considered a technically demanding procedure in terms of management of bone loss,

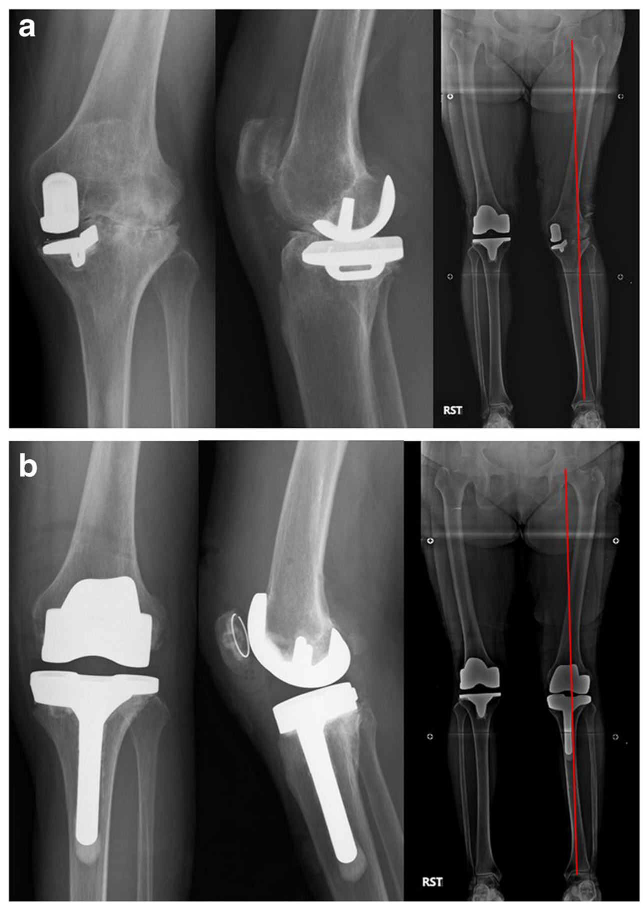

Fig. 3 **a** Pre-operative radiograph of a 67-year-old patient at 87 months after unicompartmental knee arthroplasty. Progression of arthritis in the lateral and patellofemoral compartments was found with valgus deformity. **b** Post-operative radiograph after revision to TKA at final follow-up. Metal augmentation was performed, and a long stem was added to the tibia

Table 3 Comparison of post-operative clinical outcomes between groups at final follow-up (mean ± standard deviation)

	Group 1	Group 2	*p* value
Flexion contracture	2.6° ± 3.2	4.2° ± 4.5	0.137
ROM	129.4° ± 9.1	128.9° ± 9.5	0.856
HSS score	92.3 ± 7.1	89.5 ± 9.5	0.23
KSS scores			
KS Knee Score	98.3 ± 8.8	93.5 ± 7.6	0.064
KS Function Score	91.5 ± 8.1	85.1 ± 6.8	0.008
Pain at going up or down stairs	14.1 ± 3.9	11.8 ± 3.1	0.043
Difficulty with ascending stairs	12.5 ± 5.8	11.1 ± 3.2	0.379
Difficulty with descending stairs	12.4 ± 3.2	12.0 ± 4.4	0.705
Difficulty with rising from sitting	13.7 ± 4.5	12.5 ± 3.9	0.36
WOMAC scores			
Total	11.4 ± 5.5	11.7 ± 7.6	0.869
Pain	2.5 ± 3.1	3.0 ± 2.4	0.571
Stiffness	1.4 ± 1.1	2.0 ± 1.2	0.078
Function	9.2 ± 8.1	9.6 ± 10.3	0.878
Pain at going up or down stairs	0.22 ± 0.4	0.5 ± 0.4	0.022
Difficulty with ascending stairs	0.74 ± 2.5	1.1 ± 2.6	0.634
Difficulty with descending stairs	0.75 ± 1.3	0.69 ± 1.5	0.882
Difficulty with rising from sitting	0.66 ± 1.1	0.65 ± 0.9	0.974
Patellofemoral score of Feller			
Anterior knee pain	14.1 ± 2.7	13.8 ± 2.1	0.696
Ability to rise from chair	4.8 ± 0.6	4.5 ± 0.5	0.087
Ability to climb stairs	4.5 ± 0.7	4.3 ± 0.8	0.358

restoration of the joint line and alignments; thus, careful pre-operative planning is required. Particularly, one of the main difficulties during UKA revision surgery is bone loss which occurs in component and cement removal. Padgett et al. [23] reported technical difficulties in revision procedures and failures following the use of cement to treat large bony defects, suggesting the need for bone augmentation, metal wedges, stems, and even constrained implants. Using a navigation system can help in these circumstances because the navigation system can provide information about alignment and thickness of the bone resection so that the surgeon can design an optimal plan before resection is actually performed. In other words, using a navigation system allows the surgeon to decide the cutting level and alignment required to minimize bone loss and achieve optimal alignment. Sarraf KM et al. [24] compared primary TKA to revision of UKA to TKA without navigation system and found that the most frequently used thickness of polyethylene (PE) in primary TKA was 10 mm, compared to 12.79 mm in the revision UKA group. In our study, the change in joint line and thickness of polyethylene were not different from those observed in the primary TKA cases, indicating that using a navigation system for UKA revision can help achieve satisfactory outcomes. Moreover, we did not use allogenous strut bone grafts for severe bone defects when performing navigation-assisted UKA revision, and there were no radiolucent lines after three years of follow-up.

In our study, there were no significant differences in radiological or clinical parameters except KSFS between the UKA revision and primary TKA groups. In many previous studies [5, 7, 25], the clinical outcomes of UKA revision were found worse than that of primary TKA, even similar with that of revision TKA [25]. However, these previous studies were not used navigation system for UKA revisions. When using a navigation system for revision UKA, the outcomes were found comparable with that of primary TKA due to easily obtain pre-operative goal, although only few studies reported [15, 16]. The results of this study are also in line with the previous studies using navigation for UKA revision [15, 16]. The clinical outcomes of this study appeared to be satisfactory and not statistically different between groups, although the primary TKA group tended to have somewhat better scores. The KSFS and WOMAC scores, especially the item of pain at going up or down stairs, were significantly lower in the UKA revision group than the primary TKA group, although the functional scores in other evaluations were not different. This greater pain in the UKA revision group than the TKA group might be because the flexion contracture degree was poorer in the UKA revision group than the primary TKA group, although this difference was not statistically significant. In patients with flexion contracture, a large amount of energy needs to be provided by the quadriceps to help the knee bear load and remain stable. This causes standing, walking, and stair climbing to be abnormally tiring, reducing overall knee function [26]. Flexion contracture can be found in any revision surgery setting, and care should be taken when performing UKA revision surgery.

Using a navigation system during revision of UKA to TKA in this study showed several advantages alike previous studies [15, 16]. First, accurate planning before bone resection was possible with the navigation system. Intraoperative flexion/extension gap and varus/valgus laxity were evaluated when the UKA components were in place and were compared with the alignments of preoperative radiographs. Second, with the UKA components in place, we were able to compare the registered joint center and anatomic reference points in UKA revision cases with those in primary TKA cases. This enabled us to control bone resection precisely, and individual augmentation of bone defects was possible with measuring resection level before resection performed [15, 16]. Third, accurate bone resection reduced the use of constrained TKA implants, wedges, and allogenic bone grafts compared to previous studies [4, 9, 13, 27, 28]. In our study, only cement and minimal autogenic bone grafts were used to fill bone defects, with the exception of one case, where a tibial stem was intentionally used to achieve more stability. In addition, the mean polyethylene liner size used in revision of UKA to TKA was 12.2 ± 2.1 mm, which was not different from that used in primary

Table 4 Comparison of post-operative radiological outcomes between groups at final follow-up (mean ± standard deviation)

	Group 1	Group 2	*p* value
MAD (°)	1.3° ± 2.7	1.9° ± 1.6	0.42
α (°)	88.9° ± 2.0	88.3° ± 2.3	0.337
β (°)	89.5° ± 2.9	90.1° ± 1.4	0.445
γ (°)	3.2° ± 3.0	2.4° ± 2.7	0.363
δ (°)	86.3° ± 2.9	85.7° ± 2.4	0.473
Change in joint line position (mm)	2.7 ± 3.8	2.3 ± 4.2	0.732
Femoral component rotation angle on CT (°)	1.2° ± 1.7	1.0° ± 1.4	0.683
Tibial component rotation angle on CT (°)	2.3° ± 2.5	1.5° ± 4.2	0.375
Patellar tilt angle	1.1° ± 4.8	1.5° ± 4.1	0.774
Thickness of polyethylene	11.3 mm ± 1.5	12.2 mm ± 2.1	0.075

Negative value means valgus limb alignment

MAD mechanical femorotibial angle

navigation-assisted TKA. The thickness of polyethylene in primary navigation-assisted TKA before propensity score matching was 11.5 ± 2.8 mm during the same period for all TKA cases (298 cases, $p = 0.378$). Fourth, to accurately measure femoral rotation pre-operatively, computed tomography (CT) scanning was performed [29], but it was difficult to evaluate the femoral rotation precisely due to the UKA implants. However, evaluation of femoral rotation in navigation-assisted UKA revision was much easier than in the conventional UKA revision technique alike previous studies [15, 16]; moreover, clinical and radiologic outcomes after navigation-assisted UKA revision were comparable to those of primary navigation-assisted TKA which were well-known satisfactory. Therefore, using a navigation system in UKA revision has many advantages and can produce satisfactory results comparable with primary TKA [9, 12, 15, 16].

This study also had a number of limitations. First, this study was performed in a retrospective manner, even though power analysis was performed. Moreover, relatively few cases of UKA revision were included in this study, though we controlled for this using a matched paired study. Prospective randomized controlled trials are needed to compare conventional and navigation-assisted UKA revision or to compare primary TKA and UKA revision using navigation. Second, we also addressed short-term rather than long-term outcomes in this study; thus, longevity-related issues, such as wear and loosening, were not evaluated. Longer follow-up is needed to evaluate UKA revision cases. However, we provided a detailed description of the surgical techniques of use for navigation-assisted revision of UKA to TKA. We anticipate that this information will be valuable for surgeons with UKA patients who require revision surgery.

In summary, the clinical and radiographic outcomes of revision of UKA to TKA using a navigation system were satisfactory compared with those of primary navigation-assisted TKA. On the basis of our findings, using a navigation-assisted revision of UKA to TKA can provide reliable intraoperative information, minimal bone resection, ideal joint line, and limb alignment if an appropriate surgical technique is used.

Compliance with ethical standards

This study was approved by the appropriate ethics committee of our hospital.

Conflict of interest The authors declare that they have no conflict of interest (IRB No:1612-009-16023).

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

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