

# Effects of Femoral Lateral Bowing on Coronal Alignment and Component Position after Total Knee Arthroplasty: A Comparison of Conventional and Navigation-Assisted Surgery

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**Purpose:** To evaluate the effects of femoral lateral bowing on coronal alignment after total knee arthroplasty (TKA) and examine whether the use of navigation helps obtain better postoperative coronal alignment and component position.

**Materials and Methods:** Radiological results and outlier rates were compared between the conventional TKA group and the navigation-assisted TKA group, and factors associated with postoperative alignment were evaluated. For clinical assessment, patient-reported outcomes were used.

**Results:** A total of 297 knees were retrospectively reviewed. Among the patients with femoral lateral bowing, a significant difference was observed between the conventional TKA group (n=72) and the navigation-assisted TKA group (n=96) in postoperative mechanical femorotibial angle (mFTA, 1.6° vs. 0.8°; p=0.005) and femoral component alignment angle (89.0° vs 90.0°; p=0.017). Preoperative mFTA (p<0.001), femoral bowing angle (p<0.001), and mechanical lateral distal femoral angle (p=0.032) had effects on postoperative mFTA in the conventional TKA group. In the navigation-assisted TKA group, only preoperative mFTA (p<0.001) had effects on postoperative mFTA.

**Conclusions:** Despite the individualized determination of the valgus correction angle through preoperative planning, in the cases with severe lateral bowing, the outlier rate was higher in the conventional TKA group than in the navigation-assisted TKA group. However, there was no significant difference in the clinical results between the two groups in the short-term follow-up.

**Keywords:** Knee, Arthroplasty, Varus deformity, Bowing, Navigation

## Introduction

Recently, several reports have argued that coronal alignment after total knee arthroplasty (TKA) does not have a significant impact on function and longevity<sup>1-3)</sup>. Nevertheless, restoration of neutral alignment is still regarded as the most important goal of TKA<sup>4-6)</sup>. Accurate bone resection of the femur and tibia is critical

for restoring the neutral alignment. Therefore, in conventional TKA, the femur and tibia are resected using an intramedullary or extramedullary alignment guide such that they can be vertical to each mechanical axis. In case of resection of the proximal tibia, an intramedullary or extramedullary alignment guide is used depending on the preference of the surgeon. However, the intramedullary alignment guide is used in most cases of distal femur resection. According to the analysis of the alignment of lower extremity, the angle between the anatomical and mechanical axes of the femur ranges from 5° to 6°<sup>7,8)</sup>. Therefore, a lot of surgeons perform the resection of the distal femur based on the valgus correction angle of about 5° to 6°<sup>9)</sup>.

However, recent studies on the alignment of lower extremity report that bowing of the femoral shaft in the coronal plane is prevalent in Asians and that such femoral bowing affects the postoperative coronal alignment<sup>10-14)</sup>. Several authors have argued that a navigation system is useful for achieving better postopera-

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tive alignment after TKA in patients with femoral bowing<sup>11,12</sup>. In navigation-assisted TKA, bone resection of the femur and tibia is implemented based on the anatomical landmarks that are registered in the navigation system without using an intramedullary or extramedullary alignment guide. Whether the use of navigation actually improves postoperative alignment and component position is still controversial<sup>15-18</sup>. However, considering the recent studies on the effect of anatomical variances on the postoperative alignment in TKA, we believe that an anatomical feature such as femoral bowing should be accounted for when evaluating the accuracy of a navigation system in TKA. Huang et al.<sup>11</sup> reported that the use of a navigation system can be effective for component positioning and neutral alignment restoration in patients with severe femoral lateral bowing although the component position was not evaluated on weight bearing whole leg anteroposterior (AP) radiographs in their study. Lasam et al.<sup>12</sup> reported that navigation-assisted TKA can reduce outlier rates more than conventional TKA in patients with femoral lateral bowing. However, there is insufficient research that evaluates the accuracy of navigation systems in patients with femoral bowing and the factors associated with postoperative alignment.

The purpose of this study was to evaluate the effects of femoral lateral bowing on coronal alignment after TKA and examine whether the use of navigation helps obtain better postoperative coronal alignment and component position. We assumed that the navigation-assisted TKA group would have better postoperative coronal alignment and component positioning than the conventional TKA group among patients with femoral lateral bowing.

## Materials and Methods

### 1. Patients

This study was approved by the Institutional Review Board of our institution. A total of 335 knees (292 patients) that received TKA from March 2012 to September 2013 were retrospectively reviewed. All TKAs were done by one experienced knee surgeon who had performed over 100 cases of navigation-assisted TKA. There was no specific indication for navigation-assisted TKA. Among the subjects, 38 knees (11.2%) were excluded due to the following reasons: 1) valgus alignment (10 knees), 2) inflammatory arthritis (7 knees), 3) medical history of fracture in the affected extremity (2 knees), 4) medical history of prior total hip arthroplasty (2 knees), 5) follow-up period shorter than six months (5 cases) and 6) follow-up radiographs that are inappropriate for evaluating the radiological results (12 knees). A total of 297 knees (277 patients) were enrolled in this study and conventional TKA

Table 1. Demographic Data

Variable	Conventional TKA (n=128)	Navigation-assisted TKA (n=169)	p-value
Age (yr)	67.7±6.4 (53–84)	67.6±7.2 (54–83)	0.853
Sex (M:F)	12:118	14:156	0.742
BMI (kg/m <sup>2</sup> )	25.2±3.3 (15.8–36.1)	24.9±3.0 (16.0–32.4)	0.911
Implant (case)			
Vega system	90	169	
Nexgen LPS	22		
Triathlon	16		

Values are presented as mean±standard deviation (range).

TKA: total knee arthroplasty, BMI: body mass index.

was implemented on 128 knees and navigation-assisted TKA was implemented on 169 knees (Table 1).

### 2. Surgical Technique

In all knees, the surgery was performed using an anterior midline longitudinal skin incision and a medial parapatellar arthrotomy regardless of the technique. In conventional TKA, bone resection progressed from distal femur and proximal tibia to anterior and posterior femur. Resection of the distal femur was implemented by using an intramedullary alignment guide. Distal femoral cutting block was placed in valgus condition of an angle formed by anatomical and mechanical femoral axes that were measured on the preoperative weight bearing whole leg AP radiograph. The intramedullary alignment guide was inserted into the intramedullary canal through the center of the intercondylar notch of the femur from 1 cm above the femoral attachment of the posterior cruciate ligament. However, there were some cases that had severe femoral lateral bowing where the required valgus correction angle exceeded the permissible angle in the intramedullary alignment guide. In these cases, the intramedullary alignment guide was inserted into the canal by placing it slightly lateral to the center of the intercondylar notch of the femur to resect the distal femur at 90° to the mechanical axis of the femur on the coronal plane<sup>19</sup> (Fig. 1). In proximal tibial resection, a posterior tibial slope of 3°–5° was targeted by using an extramedullary alignment guide. The femoral component was placed in a condition of 3°–5° external rotation to the posterior condylar axis.

The OrthoPilot (Aesculap AG, Tuttlingen, Germany) image-free navigation was used for navigation-assisted TKA. This navigation system has a minimum measurable angle change of 1°. Anatomical landmarks were registered after the navigation tracker was fixed on the distal femur and proximal tibia. After palpating medial and lateral epicondyles with fingers, the most



Fig. 1. Insertion of an intramedullary alignment guide in a case with severe femoral lateral bowing.

prominent part was registered as medial and lateral epicondyles in the navigation system. Bone resection was implemented from proximal tibia and distal femur to anterior and posterior femur. The proximal tibia was resected to be  $90^\circ$  to the mechanical axis of tibia on the coronal plane and it was resected such that the tibia had a  $3^\circ$  posterior slope on the sagittal plane. In distal femoral resection, the distal transverse plane cut was targeted to be  $90^\circ$  to the mechanical axis of the femur. The rotation of the femoral component was determined by a measured resection technique in conventional TKA and by a gap technique in navigation-assisted TKA. In the measured resection technique, the AP axis (whiteside line) and transepicondylar line were used as a reference for determining the rotation of the femoral component, and the femoral component was  $3^\circ$  to  $5^\circ$  externally rotated relative to the posterior condylar line. VEGA system (Aesculap AG), Triathlon (Stryker, Mahwah, NJ, USA), Nexgen LPS (Zimmer, Warsaw, IN, USA) were used in conventional TKA. VEGA system was used in navigation-assisted TKA.

### 3. Evaluation

Preoperative mechanical femorotibial angle (mFTA), femoral bowing angle, tibial bowing angle, mechanical lateral distal femoral angle (mLDFA), and mechanical medial proximal tibial angle (mMPTA) were measured on preoperative weight bearing whole leg AP radiographs. The mFTA was defined as an angle formed by the mechanical axes of the femur and tibia (Fig. 2A). The mechanical axis of the femur was defined as a line that connects the center of the femoral head to the center of the intercondylar notch. The mechanical axis of the tibia was defined as a line that



Fig. 2. Measurement of preoperative radiological parameters. A: mechanical femorotibial angle, B: femoral bowing angle, C: tibial bowing angle.

connects the center of the tibial spine to the center of the tibial plafond. A valgus alignment was given a negative value and a varus alignment was given a positive value. The femoral bowing angle and tibial bowing angle were measured using a method suggested by Yau et al.<sup>14)</sup> Femoral bowing was evaluated by dividing the diaphysis of the femur into four sections (from the lowest level of the lesser trochanter to 5 cm above the lowest level of the lateral femoral condyle). The femoral bowing angle was defined as an angle formed by the proximal and distal quarter axes extending from the proximal quarter and the distal quarter, respectively, and crossing at the midpoint of the endosteal canal (Fig. 2B). Each case was categorized into straight or medial bowing ( $\leq 0^\circ$ ), mild ( $0^\circ$ – $5^\circ$ ), and severe ( $>5^\circ$ ) according to the value of the femoral bowing angle. As the number of cases with medial bowing was small in the pilot study and most had mild bowing smaller than  $3^\circ$ , a medial bowing group was not categorized separately. The tibial bowing angle was defined as an angle formed by the proximal and distal one-third axes by dividing the diaphysis of the tibia in three sections (from 5 cm below the articular surface of the proximal tibia to 5 cm above the tibial plafond) (Fig. 2C). The proximal and distal one-third axes were defined as lines that extend from the proximal and distal end, respectively, and cross at the midpoint of the endosteal canal. For femoral and tibial bowing angles, lateral bowing was given a positive value and medial bowing was given a negative value. The mLDFA was defined as an angle formed by the mechanical axis of the femur and the line connecting the distal ends of the medial and lateral femoral condyles of the femur. The mMPTA was defined as an

angle formed by the mechanical axis of the tibia and the articular surface of the proximal tibia (Fig. 3)<sup>20</sup>.

On weight bearing whole leg AP radiographs that were taken six months to one year after the surgery, postoperative mFTA, femoral component alignment angle, and tibial component alignment angle were measured. Postoperative mFTA was measured by a method identical to preoperative mFTA. Femoral component alignment angle was defined as a medial angle formed by a line that connects the distal ends of the femoral component and the mechanical axis of the femur. Tibial component alignment angle was defined as a medial angle formed by a line that is parallel to the tibial component baseplate and the mechanical axis of the tibia (Fig. 4)<sup>21,22</sup>.

At the last follow-up, weight bearing whole leg AP radiographs were taken and compared to previous radiographs to examine the change of component position and occurrence of a radiolucent line using the Knee Society roentgenographic evaluation system<sup>23</sup>. In the clinical evaluation, Knee Society knee and function scores<sup>24</sup>, Western Ontario and McMaster Universities Osteoarthritis index<sup>25</sup>, and complications were assessed. This study aimed to evaluate the effect of femoral lateral bowing on the coronal alignment after TKA. Hence, postoperative mFTA and femoral component alignment angle were used as main parameters. However, we used additional parameters including mL DFA, mMP TA, and tibial component alignment angle to evaluate diverse factors that can affect the postoperative alignment.

All radiological parameters were measured using a picture archiving and communication system (PACS, Infinitt, Seoul, Korea) on a high-resolution LCD monitor. Minimum measurable

angle of this software is 0.1°.

Age and body mass index were measured before surgery and used as demographic data.

#### 4. Statistical Analysis

We used IBM SPSS ver. 22.0 (IBM Corp., Armonk, NY, USA) to conduct statistical analysis with a significance level set at  $p < 0.05$ .

Priori power analysis was conducted by setting the alpha level at 0.5 and power at 0.8 to identify the sample size required for detecting difference in postoperative mFTA. A pilot study was implemented on 34 cases that had femoral bowing. The mean postoperative mFTA was 2.1 (standard deviation [SD], 2.2) in the conventional TKA group ( $n=17$ ) and 1.1 (SD, 2.0) in the navigation-assisted TKA group ( $n=17$ ). The sample size required for detecting the difference in postoperative mFTA between the two groups was 71 cases in each group. In this study, the number of cases with femoral bowing was 72 in the conventional TKA group and 96 in the navigation-assisted TKA group.

Independent *t*-test and chi-square test were used to compare the demographic factors and radiological parameters between the conventional TKA group and the navigation-assisted TKA group. Comparison analysis was conducted by using all the patients in each group and then subgroup analysis was conducted by categorizing the patients according to the degree of femoral bowing (mild or severe femoral bowing).

Pearson correlation analysis was conducted between femoral bowing angle, mL DFA and postoperative mFTA, femoral component alignment angle as well as between tibial bowing angle, mMP TA and postoperative mFTA, tibial component alignment



Fig. 3. Measurement of mechanical lateral distal femoral angle (mLDFA) (A) and mechanical medial proximal tibial angle (mMP TA) (B).



Fig. 4. Measurement of postoperative radiological parameters. A: femoral component alignment angle, B: tibial component alignment angle.

angle.

Multiple linear regression analysis (stepwise method) was conducted to evaluate the factors that can affect postoperative mFTA. Postoperative mFTA was used as a dependent variable and femoral bowing angle, preoperative mFTA, tibial bowing angle, mL DFA, and mMPTA were used as independent variables.

Fisher exact test was used to evaluate the incidence of outliers in cases that had femoral lateral bowing. An outlier was defined as  $>3^\circ$  or  $<-3^\circ$  for postoperative mFTA and  $>93^\circ$  or  $<87^\circ$  for femoral and tibial component alignment angles.

Radiological parameters were measured by two orthopedic surgeons twice with a two-week interval. Reliability of the measurements was assessed by using intraclass correlation coefficient (ICC). An ICC  $>0.75$  was regarded as good agreement. In this study, the interobserver reliability was between 0.77 and 0.85 and intraobserver reliability was between 0.80 and 0.91.

## Results

Femoral lateral bowing was observed in 168 knees (56.6%) and severe lateral bowing was observed in 67 knees (22.6%). Among all the patients, no significant difference in preoperative and postoperative radiographic parameters was observed between the conventional TKA group and the navigation-assisted TKA group ( $p>0.05$ , all parameters). However, in the analysis involving only the patients with femoral lateral bowing, a significant difference

was observed between the two groups in postoperative mFTA ( $1.6^\circ$  in the conventional TKA group vs.  $0.8^\circ$  in the navigation-assisted TKA group;  $p=0.005$ ) and femoral component alignment angle ( $89.0^\circ$  in the conventional TKA group vs  $90.0^\circ$  in the navigation-assisted TKA group;  $p=0.018$ ) (Table 2). On the subgroup analysis that was conducted according to the degree of femoral lateral bowing, no parameter showed a significant difference between the two groups in cases of mild femoral lateral bowing (femoral bowing angle  $\leq 5^\circ$ ); however, in cases of severe femoral lateral bowing (femoral bowing angle  $>5^\circ$ ), there was a significant difference in postoperative mFTA ( $2.0^\circ$  in the conventional TKA group vs.  $0.9^\circ$  in the navigation-assisted TKA group;  $p=0.012$ ) and femoral component alignment angle ( $88.3^\circ$  in the conventional TKA group vs.  $89.8^\circ$  in the navigation-assisted TKA group;  $p=0.038$ ) (Table 3).

Table 4 describes the results of the correlation analysis. In the conventional TKA group, femoral bowing angle showed a correlation with femoral component alignment angle and postoperative mFTA (Pearson correlation coefficient [PCC]= $-0.199$  and  $0.410$ , respectively) and mL DFA showed a correlation with femoral component alignment angle (PCC= $-0.360$ ). Tibial bowing angle did not show a correlation with either postoperative mFTA or tibial component alignment, and mMPTA showed a negative correlation with postoperative mFTA (PCC= $-0.193$ ). In the navigation-assisted TKA group, mL DFA showed a negative correlation with femoral component alignment angle and mMPTA

**Table 2.** Comparison of Radiological Results between Conventional TKA Group and Navigation-Assisted TKA Group in Total Cases and Cases with Femoral Lateral Bowing

Variable	Total			Femoral lateral bowing		
	Conventional TKA (n=128)	Navigation-assisted TKA (n=169)	p-value	Conventional TKA (n=72)	Navigation-assisted TKA (n=96)	p-value
Preoperative ( $^\circ$ )						
mFTA	11.4 $\pm$ 6.1 (0 to 37.4)	11.5 $\pm$ 5.7 (0.6 to 39.5)	0.874	12.6 $\pm$ 5.4 (3.1 to 24.6)	11.9 $\pm$ 5.2 (1.1 to 24.2)	0.341
Femoral bowing angle	3.1 $\pm$ 3.7 (-1.5 to 17.8)	2.8 $\pm$ 3.5 (-1.8 to 17.2)	0.502	5.5 $\pm$ 3.4 (1.1 to 17.8)	5.0 $\pm$ 3.3 (0.7 to 17.2)	0.289
Tibial bowing angle	1.1 $\pm$ 2.3 (-4.5 to 7.6)	1.4 $\pm$ 2.4 (-6.5 to 7.3)	0.300	1.1 $\pm$ 2.3 (-4.5 to 6.3)	1.6 $\pm$ 2.4 (-4.8 to 6.8)	0.170
mL DFA	89.2 $\pm$ 3.8 (78.7 to 101.6)	89.0 $\pm$ 3.6 (79.8 to 99.5)	0.722	88.1 $\pm$ 3.6 (78.7 to 101.6)	88.9 $\pm$ 3.8 (79.8 to 99.5)	0.151
mMPTA	85.1 $\pm$ 2.8 (79.5 to 91.3)	85.0 $\pm$ 3.0 (79.0 to 93.4)	0.823	84.8 $\pm$ 2.8 (79.5 to 89.9)	85.0 $\pm$ 3.0 (79.0 to 93.4)	0.581
Postoperative ( $^\circ$ )						
mFTA	1.1 $\pm$ 1.8 (-1.1 to 7.0)	0.6 $\pm$ 1.9 (-1.6 to 6.8)	0.056	1.6 $\pm$ 1.8 (-1.1 to 6.1)	0.8 $\pm$ 1.8 (-1.6 to 6.8)	0.005 <sup>a)</sup>
Femoral component angle	89.4 $\pm$ 2.9 (83.5 to 97.9)	90.0 $\pm$ 2.5 (83.6 to 95.7)	0.055	89.0 $\pm$ 2.7 (83.5 to 94.0)	90.0 $\pm$ 2.5 (83.6 to 95.2)	0.018 <sup>a)</sup>
Tibial component angle	89.7 $\pm$ 2.0 (85.3 to 94.4)	89.7 $\pm$ 2.1 (84.9 to 95.0)	0.856	89.4 $\pm$ 2.0 (85.5 to 93.5)	89.9 $\pm$ 2.3 (85.3 to 95.0)	0.211

Values are presented as mean $\pm$ standard deviation (range).

TKA: total knee arthroplasty, mFTA: mechanical femorotibial angle, mL DFA: mechanical lateral distal femoral angle, mMPTA: mechanical medial proximal tibial angle.

<sup>a)</sup>Statistically significant.

**Table 3.** Comparison of Radiological Results between Conventional TKA Group and Navigation-Assisted TKA Group according to the Degree of Femoral Lateral Bowing

Variable	Mild bowing			Severe bowing		
	Conventional TKA (n=38)	Navigation-assisted TKA (n=63)	p-value	Conventional TKA (n=34)	Navigation-assisted TKA (n=33)	p-value
Preoperative (°)						
mFTA	11.6±5.3 (3.1 to 19.2)	11.2±5.4 (1.1 to 23.7)	0.730	13.8±5.4 (4.4 to 24.6)	13.0±4.7 (5.3 to 24.2)	0.539
Femoral bowing angle	2.9±0.9 (1.1 to 4.6)	3.0±1.1 (0.7 to 4.8)	0.606	8.5±2.5 (5.1 to 17.8)	8.7±2.8 (5.1 to 17.2)	0.666
Tibial bowing angle	0.9±2.2 (-1.7 to 5.0)	1.4±2.3 (-4.8 to 5.8)	0.275	1.3±2.5 (-4.5 to 6.3)	1.9±2.4 (-4.7 to 6.8)	0.293
mLDFA	88.3±2.9 (81.8 to 93.2)	88.9±3.5 (80.8 to 99.5)	0.342	87.9±4.3 (78.7 to 101.6)	89.0±4.4 (79.8 to 96.2)	0.318
mMPTA	85.6±2.3 (81.6 to 89.9)	84.9±2.9 (79.0 to 91.8)	0.239	83.8±3.0 (79.5 to 89.8)	85.1±3.3 (79.6 to 93.4)	0.092
Postoperative (°)						
mFTA	1.3±1.8 (-1.1 to 5.5)	0.8±1.9 (-1.6 to 6.8)	0.163	2.0±1.8 (-0.6 to 6.1)	0.9±1.5 (-1.3 to 5.1)	0.012 <sup>a)</sup>
Femoral component angle	89.7±2.2 (85.6 to 94.0)	90.1±2.1 (87.0 to 95.0)	0.415	88.3±2.9 (83.5 to 92.9)	89.8±3.0 (83.6 to 95.2)	0.038 <sup>a)</sup>
Tibial component angle	89.8±2.1 (86.3 to 92.9)	89.9±2.1 (87.0 to 93.0)	0.884	89.0±1.8 (85.5 to 93.5)	89.8±2.6 (85.3 to 95.0)	0.141

Values are presented as mean±standard deviation (range).

TKA: total knee arthroplasty, mFTA: mechanical femorotibial angle, mLDFA: mechanical lateral distal femoral angle, mMPTA: mechanical medial proximal tibial angle.

<sup>a)</sup>Statistically significant.

**Table 4.** Correlation Analysis on the Anatomical Features and Postoperative Radiological Results

Variable	Postoperative mFTA	Femoral component alignment angle	Tibial component alignment angle
Conventional TKA			
Femoral bowing angle	0.410 (<0.001) <sup>a)</sup>	-0.199 (0.025) <sup>a)</sup>	N/A
mLDFA	0.001 (0.993)	-0.360 (<0.001) <sup>a)</sup>	N/A
Tibial bowing angle	0.098 (0.273)	N/A	-0.045 (0.557) <sup>a)</sup>
mMPTA	-0.193 (0.029) <sup>a)</sup>	N/A	0.144 (0.104)
Navigation-assisted TKA			
Femoral bowing angle	0.100 (0.197)	-0.027 (0.730)	N/A
mLDFA	0.149 (0.053)	-0.189 (0.014) <sup>a)</sup>	N/A
Tibial bowing angle	-0.017 (0.830)	N/A	-0.036 (0.640)
mMPTA	-0.021 (0.782)	N/A	0.237 (0.002)

Values are presented as Pearson correlation coefficient (p-value).

mFTA: mechanical femorotibial angle, TKA: total knee arthroplasty, N/A: not applicable, mLDFA: mechanical lateral distal femoral angle, mMPTA: mechanical medial proximal tibial angle.

<sup>a)</sup>Statistically significant.

showed a positive correlation with tibial component alignment angle (PCC=-0.189 and 0.237, respectively). However, neither variable showed a correlation with postoperative mFTA. Neither the femoral bowing angle nor the tibial bowing angle showed a correlation with postoperative mFTA and femoral component alignment angle.

According to the results of the multiple linear regression analysis that was conducted in each group, it was proven that preoperative mFTA (p<0.001), femoral bowing angle (p<0.001), and

mLDFA (p=0.032) had effects on postoperative mFTA in the conventional TKA group (R<sup>2</sup>=0.311). However, only preoperative mFTA (p<0.001) showed an impact on postoperative mFTA in the navigation-assisted TKA group (R<sup>2</sup>=0.129). Multicollinearity in each regression analysis was evaluated by the variance inflation factor and none of them exceeded 10 (Table 5).

In the outlier analysis, the navigation-assisted TKA group showed a lower rate of outliers in mFTA and femoral component alignment angle than the conventional TKA group (p=0.006 and

**Table 5.** Evaluation of Factors that Affect Postoperative mFTA in Conventional TKA and Navigation-Assisted TKA<sup>a)</sup>

	Dependent variable	Independent variable	R <sup>2</sup>	Unstandardized coefficients		Standardized coefficients $\beta$	p-value		
				B	SE (B)				
Conventional TKA	Postoperative mFTA	Preoperative mFTA	0.311	0.113	0.023	0.382	<0.001		
		Femoral bowing angle		0.173	0.038			0.356	<0.001
		mLDFA		0.080	0.037			0.169	0.032
Navigation-assisted TKA	Postoperative mFTA	Preoperative mFTA	0.129	0.117	0.024	0.359	<0.001		

mFTA: mechanical femorotibial angle, TKA: total knee arthroplasty, mLDFA: mechanical lateral distal femoral angle.

<sup>a)</sup>Multiple linear regression analysis using stepwise method.

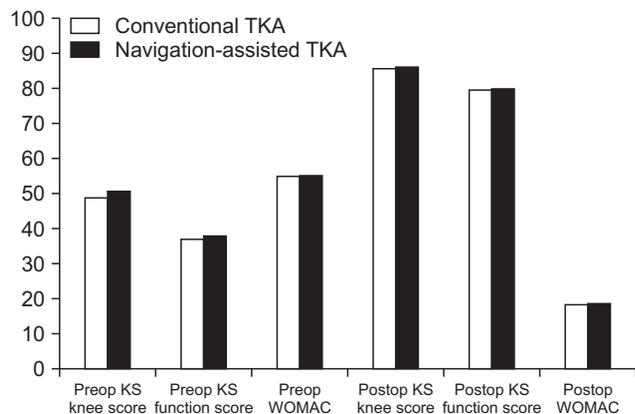
**Table 6.** Comparison of Outlier Rate between Conventional TKA Group and Navigation-Assisted TKA Group

Variable	Conventional TKA (%)			Navigation-assisted TKA (%)			p-value <sup>a)</sup>
	Mild (n=38)	Severe (n=34)	Total (n=72)	Mild (n=63)	Severe (n=33)	Total (n=96)	
Postoperative mFTA (°)	6 (15.8)	8 (23.5)	14 (19.4)	3 (4.8)	2 (6.1)	5 (5.2)	0.006 <sup>b)</sup>
Femoral component alignment angle (°)	4 (10.5)	11 (32.4)	15 (20.8)	1 (1.6)	6 (18.2)	7 (7.3)	0.012 <sup>b)</sup>
Tibial component alignment angle (°)	2 (0.8)	7 (20.6)	9 (12.5)	0 (0.0)	4 (12.1)	4 (4.2)	0.077

TKA: total knee arthroplasty, mFTA: mechanical femorotibial angle.

<sup>a)</sup>Comparison between conventional TKA group and navigation-assisted TKA group in total patients with femoral lateral bowing.

<sup>b)</sup>Statistically significant.



**Fig. 5.** Comparison of clinical results between the conventional and navigation-assisted total knee arthroplasty (TKA) groups. Preop: preoperative, KS: Knee Society, WOMAC: Western Ontario and McMaster Universities Osteoarthritis index, Postop: postoperative.

p=0.012, respectively) (Table 6).

Fig. 5 presents the patient-reported outcomes. No significant difference between the conventional TKA group and navigation-assisted TKA group was observed ( $p>0.05$ , all parameters). As for the complications, there was one case of infection in the navigation-assisted TKA group. However, other complications, including osteolysis and loosening, were not observed in either group.

## Discussion

The principle finding of this study is that navigation-assisted TKA resulted in a better postoperative coronal alignment than conventional TKA in patients with femoral lateral bowing although no significant difference was observed when patients without femoral lateral bowing was included in the analysis. Regression analysis results indicated that preoperative mFTA, femoral bowing angle and mLDFA affected postoperative mFTA in the conventional TKA group, whereas only preoperative mFTA had an impact on postoperative mFTA in the navigation-assisted TKA group.

A number of authors reported that the use of a navigation system improved postoperative alignment and component position and reduced the incidence of outliers<sup>26-29)</sup>. However, other authors have reported that there is no significant difference in postoperative alignment or outlier incidence between navigation-assisted TKA and conventional TKA<sup>15-17)</sup>. Although whether TKA using navigation improves postoperative alignment and component position is still controversial, we believe that anatomical features such as femoral bowing should be accounted for when evaluating the accuracy of using a navigation system in TKA. Yau et al.<sup>14)</sup> reported that 41/93 knees (44%) had femoral lateral bowing of  $>2^\circ$  in research conducted in China. Since then, several more authors have reported that anatomical variations such as femoral lateral

bowing are prevalent in Asians and that such features affect postoperative alignment and component position after TKA. Lasam et al.<sup>12)</sup> reported that femoral lateral bowing and varus condylar orientation of the femur are related to postoperative alignment in conventional TKA, but navigation-assisted TKA did not show such correlation. Moreover, they reported that the outlier rate was higher in cases of conventional TKA compared to navigation-assisted TKA.

In this study, radiological results showed no significant difference between the conventional TKA group and the navigation-assisted TKA group when all the patients were included in the analysis as subjects. Of note, the navigation-assisted TKA group showed a better postoperative alignment and femoral component alignment angle when we limited the subjects to only patients with femoral lateral bowing. In this study, the resection of the distal femur was implemented to match the angle formed by the anatomical axis and the mechanical axis of the femur on preoperative weight bearing whole leg AP radiographs in conventional TKA. The relatively lower accuracy compared to navigation-assisted TKA is conjectured to be caused by the inaccuracy of the intramedullary alignment guide. Despite the efforts to insert an intramedullary alignment guide into the femoral canal following the preoperative plan, it is difficult to insert the guide in the desired direction from the designated point in cases of femoral bowing referring to the two-dimensional simple radiographs, which we believe eventually lowers the accuracy. The problem of accuracy becomes more prominent in cases that have severe femoral lateral bowing than in cases that have mild femoral lateral bowing. Additionally, if a valgus correction angle for the resection of the femur is excessive ( $>9^\circ$ ), the surgeon can feel pressure when performing resection of the distal femur as planned due to the possibility that the preoperative simple radiograph was not accurately taken.

In this study, preoperative mFTA and mL DFA were proven to have an influence on postoperative alignment in the conventional TKA group, in addition to femoral lateral bowing. However, only preoperative mFTA showed a relevance to postoperative alignment in the navigation-assisted TKA group. There was no correlation between anatomical features such as femoral bowing, mL DFA, and postoperative alignment. This can be attributed to the fact that bone resection was executed vertical to the mechanical axis when using navigation, regardless of femur anatomy.

Tibial bowing and mMP TA did not affect postoperative mFTA in either the navigation-assisted TKA group or the conventional TKA group. This can be attributed to the use of an extramedullary alignment guide in cases of proximal tibia resection. Ko et

al.<sup>30)</sup> reported that cutting error is more likely to occur in bone resection when using an intramedullary guide system in cases with tibial bowing. In this study, different results were likely if an intramedullary alignment guide system was used in proximal tibia resection when conventional TKA was performed.

In the outlier analysis, the navigation-assisted TKA group showed a lower outlier rate in mFTA and femoral component alignment angle than the conventional TKA group. However, the outlier rate of postoperative mFTA was as high as 5.2% and the outlier rate of femoral component alignment angle was 7.3% in the navigation-assisted TKA group. This can be attributed to an error during the bone resection or implantation process. It can also be attributed to the patient's posture during weight bearing whole leg AP radiography or an error in the measurement of radiological parameters. Hence, we could learn that outlier occurs regardless of the surgical technique. Postoperative malalignment can occur in diverse phases, including preoperative planning, bone resection, and implantation. It might be difficult to avoid the occurrence of malalignment in all TKAs. However, we believe that careful preoperative physical examination and planning as well as accurate surgical procedure can reduce the outlier rate.

Recently, there was some controversy over whether limb alignment after TKA is correlated with mid-term or long-term results<sup>1-3)</sup>. However, an absence of difference in clinical results such as function and longevity between outlier and neutral alignment does not mean that the restoration of neutral alignment is not important in TKA. We believe that every surgery requires a certain standard. Efforts to reduce outliers will ultimately give benefits to patients. Hence, more studies that investigate the correlation between postoperative alignment and clinical results will be required.

In terms of the clinical results, there was no significant difference between the two groups. Although the navigation-assisted TKA group had higher accuracy, the difference with the conventional TKA group was only about  $1^\circ$ . Hence, we believe that it is difficult to obtain meaningful clinical results in a short-term follow-up. To address this point, a long-term follow-up in survival analysis will be required in the future.

This study had several limitations. First, we included only a small number of cases. Second, this study used only one navigation system whose minimal measurable angular change was  $1^\circ$ . Hence, the results of this study cannot represent all navigation systems, and different results will likely be obtained according to the performance of each navigation system. Third, despite the high test-retest reliability, errors in the measurement of radiological parameters were possible due to the position and flexion con-

tracture of patients when simple radiographs were taken. Finally, rotation of the femoral component was not assessed identically between the two groups in this study, which could affect the postoperative alignment. However, the rotation of the femoral component was not assessed in this study.

## Conclusions

Despite the individualized determination of the valgus correction angle through preoperative planning, conventional TKA resulted in a higher outlier rate than navigation-assisted TKA in patients with severe lateral bowing. However, there was no significant difference in the clinical results in the short-term follow-up.

## Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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