Original Article
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Risk of Anterior Femoral Notching in Navigated Total Knee Arthroplasty

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Background: We retrospectively investigated the prevalence of femoral anterior notching and risk factors after total knee arthroplasty (TKA) using an image-free navigation system.

Methods: We retrospectively reviewed 148 consecutive TKAs in 130 patients beginning in July 2005. Seventy knees (62 patients) underwent conventional TKA, and 78 knees (68 patients) received navigated TKA. We investigated the prevalence of femoral anterior notching and measured notching depth by conventional and navigated TKA. Additionally, the navigated TKA group was categorized into two subgroups according to whether anterior femoral notching had occurred. The degree of preoperative varus deformity, femoral bowing, and mediolateral suitability of the size of the femoral component were determined by reviewing preoperative and postoperative radiographs. The resection angle on the sagittal plane and the angle of external rotation that was set by the navigation system were checked when resecting the distal femur. Clinical outcomes were compared using range of motion (ROM) and the Hospital for Special Surgery (HSS) and Western Ontario and McMaster Universities Osteoarthritis Index (WOMAX) scores between the two groups.

Results: The prevalence of anterior femoral notching by conventional TKA was 5.7%, and that for navigated TKA was 16.7% (p = 0.037). Mean notching depth by conventional TKA was 2.92 ± 1.18 mm (range, 1.8 to 4.5 mm) and 3.32 ± 1.54 mm (range, 1.55 to 6.93 mm) by navigated TKA. Preoperative anterior femoral bowing was observed in 61.5% (p = 0.047) and both anterior and lateral femoral bowing in five cases in notching group during navigated TKA (p = 0.021). Oversized femoral components were inserted in 53.8% of cases (p = 0.035). No differences in clinical outcomes for ROM or the HSS and WOMAX scores were observed between the groups. A periprosthetic fracture, which was considered a notching-related side effect, occurred in one case each in the conventional and navigated TKA groups.

Conclusions: Surgeons should be aware of the risks associated with anterior femoral notching when using a navigation system for TKA. A modification of the femoral cut should be considered when remarkable femoral bowing is observed.

Keywords: *Navigation, Total knee arthroplasty, Anterior femur, Notching*

The success of total knee arthroplasty (TKA) relies on many factors, including patient selection, prosthesis design, soft-tissue balancing, alignment of the components, and restoration of the joint line.[1)] Among them, component and limb alignment is one of the most important factors determining the longevity of TKA. Navigation systems have been introduced recently for TKA to provide more reliable alignment of the femoral and tibial components relative to the mechanical axis. Most studies have demonstrated superior results aligning components in the coronal plane in navigated compared with conventional TKA, with fewer outliers outside a range of 3° varus or valgus.[2-4)] However, previous reports show that the sagittal femoral

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mechanical axis varies significantly for navigation systems according to the reference point on the distal femoral condyle.[5] Navigation systems used for TKA have a potential risk of anterior femoral notching.[6] However, these previous studies were not clinical studies, but simulative and experimental studies.[5,6] Anterior femoral notching should be avoided because it contributes to complications, such as a postoperative supracondylar femoral fracture.[7,8] No clinical data describe the prevalence of anterior femoral notching with the use of a navigation system during TKA or document its association with any clinical outcome.

The purpose of this study was to describe the prevalence of anterior femoral notching among patients receiving a single type of TKA with use of an image-free navigation system and to identify risk factors that predict anterior femoral notching.

METHODS

Patients

A total of 148 consecutive TKAs were performed in 130 patients using the Triathlon Knee System (Stryker, Mahwah, NJ, USA) from July 2005 to December 2007. The patients were followed for at least 50 months postoperatively. The patients included had primary or secondary osteoarthritis. Exclusion criteria were: bone graft due to severe deformity or bone defect, revision surgery, infected TKA, male patients. In addition, patients who had fixed flexion contracture > 20° were excluded because that deformity could influence the zero setting of the navigation system. The Triathlon Knee System cuts bone using a posterior referencing system; the anterior flange angle of the femoral component was changed from 3° to 7° to reduce anterior femoral notching.

Seventy knees (62 patients) underwent conventional TKA in a retrospective case control study. Seventy-eight knees (68 patients) underwent navigated (ver. 3.0 Stryker Orthopedics, Kalamazoo, MI, USA) TKA. The clinical data of sex, age, follow-up period, bone mineral density (BMD), bone mass index (BMI), and preoperative varus deformity between the conventional TKA and navigated TKA groups are compared in Table 1. These parameters were matched between the groups.

Table 1. Patient Demographic Data

Characteristic	Group A	Group B	*p*-value*
Case	70	78	-
Bilateral	8	10	-
Age (yr)	71.0 (50–86)	69.4 (56–83)	0.51
Follow-up (mo)	54.6 (52–72)	53.2 (50–62)	0.84
BMD-F (g/cm^2)	–2.8 (0.0 to –4.8)	–2.7 (0.3 to –4.4)	0.33
BMI (kg/m^2)	24.6 (17.0–32.4)	25.7 (18.9–33.4)	0.42
Varus deformity (°)	13.8 (5–26)	12.6 (4–27)	0.64

Values are presented as mean (range).
Group A: conventional total knee arthroplasty (TKA), Group B: navigated TKA, BMD-F: bone mineral density-femur, BMI: bone mass index.
*Unpaired *t*-test.

Surgical Technique

The knee was exposed through a standard medial parapatellar arthrotomy. The femoral and tibial trackers of the navigation system were attached rigidly to the bone using screws to guarantee corresponding reference frames for all measurements. A standard anatomical survey using an instrumented pointer provided calibrating landmarks and axes for the navigation system. The proximal tibia and distal femur were cut perpendicular to the mechanical axis in the coronal and sagittal planes. Posterior inclination was cut 3° in the posterior cruciate-retaining (CR) type and 0° in the posterior cruciate-substituting (PS) type with respect to the tibial mechanical axis. We referenced the posterior condylar line, the transepicondylar line, and the patellar groove to align femoral rotation (Whiteside's line). Rotation of the tibial component was aligned through cycles of passive knee flexion and extension after implanting trial femoral and tibial components. We chose 3° of external rotation (ER) as the reference. The distal femoral cut is measured using a resection technique in conventional TKA with use of intramedullary rods. The intramedullary drill hole was located approximately 1 cm anterior to femoral attachment of the posterior cruciate ligament and slightly medial to the midline of the distal femur if the anterior femoral bowing was not severe after checking the overall shape of the distal femur in the sagittal plane on a preoperative radiograph. A short intramedullary rod was placed parallel with the posterior cortex to secure neutral insertion of the femoral component if anterior femoral bowing was significant. After the femoral stylus point was placed on the lateral cortex of the distal femur, anterior resection level was checked to confirm the correct size by sliding a blade runner through the size-specific anterior slots of the sizing guide and assessing the resection. The proximal tibia was cut perpendicular to the tibial mechanical axis in the coronal and sagittal planes. However, posterior inclination was cut 3° in the CR type and 0° in the PS type.

Radiological Evaluation

All radiographic parameters were measured using a picture archiving communication system (Infinitt, Seoul, Korea) by two independent observers.

The prevalence of anterior femoral notching was compared in a review of postoperative lateral knee radiographs after conventional TKA and those of navigated TKA. The depth of anterior femoral notching was measured as the distance between the anterior cortex line and the anterior cut line of the distal femur (Fig. 1). If the two lines were not parallel because a component was inserted in the flexed or extended position to the anteroposterior (AP) resected surface of the distal femur, the distance between the point where the resection surface abutted the component and the line extending parallel with the anterior cortex was measured. The group was categorized into two subgroups when using the navigation system, depending on whether an anterior femoral notch had occurred. The degree of varus deformity from the neutral mechanical axis, lateral bowing and anterior bowing[9] of the femur, and mediolateral suitability of the size of the femoral component were determined after reviewing pre- and postoperative radiographs. The lower limb mechanical axis was defined as a line drawn on a standing long leg AP radiograph from the center of the femoral head to the center of the talar dome (Fig. 2A). Femoral bowing was measured by dividing the femoral diaphysis into four equal parts. The line that best described the midpoint of the endosteal canal was drawn in each quarter. Overall lateral and anterior bowing was defined as the angle between the proximal and distal quarters of the femoral diaphysis (Fig. 2). Bowing had occurred if the overall angle was > 3°.

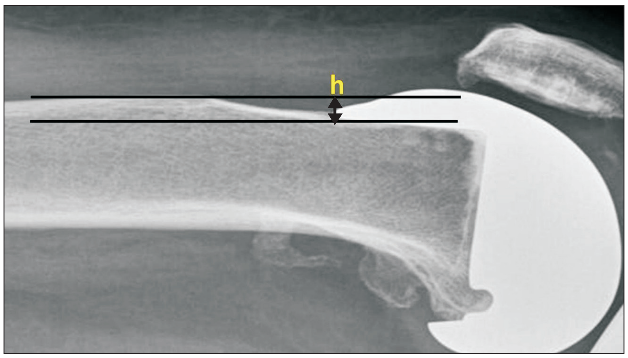

Fig. 1. The depth of anterior femoral notching (h) was measured as the distance between the anterior cortex line and anterior cut line of the distal femur.

BMD-femur (BMD-F) and BMI were analyzed between the two groups. Also, the resection angle in the sagittal plane and the ER angle were set during resection of the distal femur, and the navigation system was examined.

Clinical Evaluation

Clinical outcomes were compared using range of motion (ROM) and the Hospital for Special Surgery (HSS) and Western Ontario and McMaster Universities Osteoarthri-

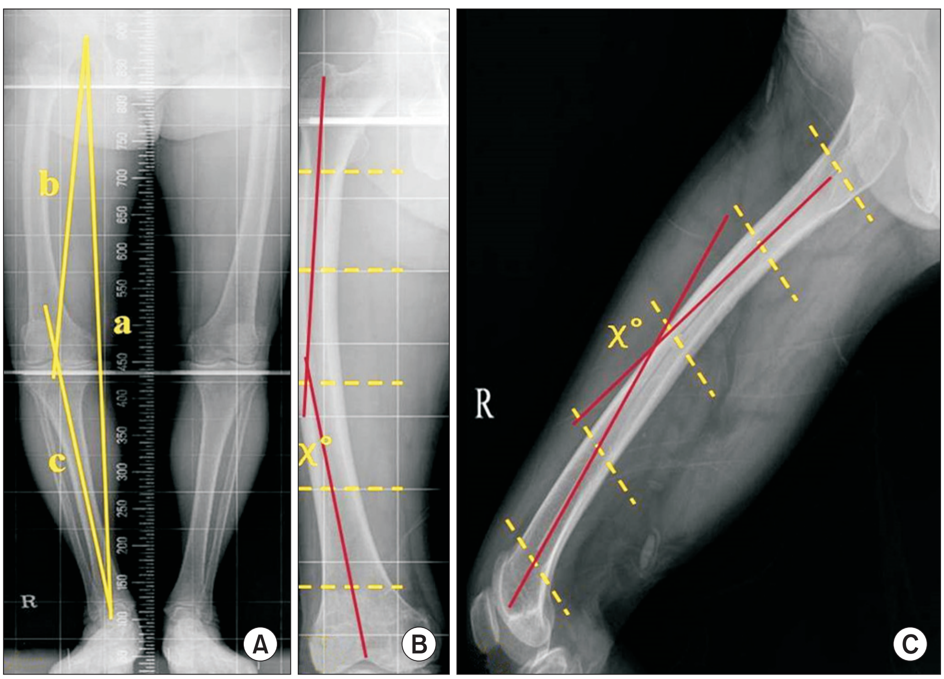

Fig. 2. (A) Standing anteroposterior radiograph of the entire lower limbs. a: mechanical axis of the lower limb, b and c: amount of varus deformity. (B) Lateral bowing of the femur. (C) Anterior bowing of the femoral shaft.

tis Index (WOMAX) scores between the groups.

Statistical Analysis

The results were analyzed statistically using PASW ver. 18.0 (SPSS Inc., Chicago, IL, USA). The difference in the number of cases between the two groups was analyzed using the chi-square test. The differences in the mean preoperative or postoperative results between the two groups were analyzed using the unpaired *t*-test. A p-value < 0.05 was considered significant.

RESULTS

Interobserver and Intraobserver Variability

The intraobserver analysis indicated mean differences of 0.24 to 0.62 for each parameter. The interobserver analysis indicated mean differences of 0.28 to 0.74 for each parameter. No differences were observed between the two measurements of observer A (A1 and A2) or between the measurements of observer A and B for each parameter (Table 2).

Anterior Femoral Notching

Four cases (5.7%) of anterior femoral notching occurred during conventional TKA, and 13 cases (16.7%) occurred during navigated TKA (p = 0.037). Mean notching depth was 2.92 ± 1.18 mm (range, 1.8 to 4.5 mm) fort conventional TKA and 3.32 ± 1.54 mm (range, 1.55 to 6.93 mm) for navigated TKA (p = 0.642). Notching depths > 3 mm occurred in two cases (50%) in the conventional TKA and

Table 2. Interobserver and Intraobserver Difference in Each Parameter

Parameter	Interobserver difference (°)				Intraobserver difference (°)			
	Mean	*p*-value*	95% Confidence interval		Mean	*p*-value*	95% Confidence interval	
			Lower	Upper			Lower	Upper
Notching depth	0.28	NS	–0.23	1.12	0.24	NS	–1.57	0.84
Varus deformity	0.74	NS	–0.25	1.02	0.62	NS	–0.10	0.64
Lateral bowing	0.42	NS	–0.26	0.46	0.56	NS	–0.58	2.1
Anterior bowing	0.58	NS	–0.18	0.89	0.60	NS	–0.28	1.4
Mediolateral size	0.60	NS	–0.16	0.74	0.54	NS	–0.84	1.8

NS: not significant.
**p*-value by Student *t*-test.

Table 3. Comparison of Risk Factors between the Notching and Non-Notching Groups during Navigated Total Knee Arthroplasty (TKA)

Variable	Notching	Non-notching	*p*-value
Varus deformity (°)	13.77 ± 5.37 (5–27)	15.77 ± 5.63 (5–26)	0.217*
Lateral femoral bowing	8/13 (61.5)	22/65 (33.8)	0.061†
Anterior femoral bowing	8/13 (61.5)	21/65 (32.3)	0.047†
ML suitability of femoral component size	7/13 (53.8)	16/5 (24.6)	0.004†
Resection angle on the sagittal plane (°)	0.58 ± 0.81 (extension –0.5 to flexion 2.0)	0.52 ± 0.61 (extension –1.5 to flexion 5.5)	0.754*
Angle of ER (°)	–0.39 ± 1.83 (ER –2.5 to IR 2.5)	0.51 ± 1.69 (ER –3.0 to IR 5.5)	0.298*
BMD-F (g/cm^2)	–2.74 ± 0.95 (0.9 to –4.4)	–2.66 ± 0.97 (0.3 to –4.1)	0.778*
BMI (kg/m^2)	25.1 ± 2.91 (20.3 to 30.4)	25.9 ± 2.96 (18.9 to 33.4)	0.383*

Values are presented as mean ± standard deviation (range) or number (%).
ML: mediolateral, ER: external rotation, IR: internal rotation, BMD-F: bone mineral density-femur, BMI: bone mass index.
*Chi-square test. †Unpaired *t*-test.

in seven cases (53.8%) in the navigated TKA group.

Varus Deformity and Femoral Bowing in the Navigated TKA Group

The mean preoperative varus deformity was 13.77° ± 5.37° (range, 5° to 27°) in the notching group and 15.77° ± 5.63° (range, 5° to 26°) in the non-notching group. Eight cases of preoperative lateral femoral bowing occurred among 13 notching cases (61.5%), and 22 occurred among 66 non-notching cases (33.8%, $p = 0.061$). Eight cases of preoperative anterior femoral bowing occurred in the notching group (61.5%), and 21 cases occurred in the non-notching group (32.3%, $p = 0.047$). Five cases each of lateral and anterior femoral bowing occurred in the notching group and eight occurred in the non-notching group ($p = 0.021$) (Table 3).

Mediolateral Suitability of Femoral Component Size in Navigated TKA

Mediolateral overhang of the femoral component was found in seven cases (53.8%) in the notching group, whereas it was found in 16 cases (24.6%) in the non-notching group ($p = 0.035$) (Table 3).

BMD-F and BMI in Patients Who Underwent Navigated TKA

Mean BMD-F was –2.74 ± 0.95 g/cm^2 (range, 0.9 to –4.4 g/cm^2) in the notching group and a mean of –2.66 ± 0.97 g/cm^2 (range, 0.3 to –4.1 g/cm^2) in the non-notching group ($p = 0.778$). Mean BMI was 25.1 ± 2.91 kg/m^2 (range, 20.3 to 30.4 kg/m^2) in the notching group and 25.9 ± 2.96 kg/m^2 (range, 18.9 to 33.4 kg/m^2) in the non-notching group ($p = 0.383$) (Table 3).

Resection Angle on the Sagittal Plane and ER Angle in Patients Who Underwent Navigated TKA

The resection angle on the distal femur sagittal plane was set to a mean of 0.58° ± 0.81° (range: extension, –0.5°; flexion, 2.0°) in the notching group and a mean of 0.52° ± 0.61° (range: extension, –1.5°; flexion, 5.5°) in the no-notching group ($p = 0.754$) using the navigation system. Mean ER angle was –0.39° ± 1.83° (range: ER, –2.5°; internal rotation [IR], 2.5°) in the notching group and a mean of 0.51° ± 1.69° (range: ER, –3.0°; IR, 5.5°) in the no-notching group ($p = 0.298$) (Table 3).

Clinical Outcomes

ROM improved from 102.5° ± 12.9° (range, 80° to 125°) preoperatively to 125.2° ± 10.1° (range, 110° to 140°) at the final follow-up in the notching group, and from 106.2° ± 12.86° (range, 80° to 135°) to 126.6° ± 9.1° (range, 105° to 140°) in the non-notching group ($p = 0.623$). The HSS score improved from 59.2 ± 8.8 (range, 36 to 69) to 91.7 ± 3.1 (range, 87 to 98) in the notching group and from 54.6 ± 9.3 (range, 34 to 69) to 90.8 ± 6.7 (range, 65 to 98) in the non-notching group ($p = 0.622$). The WOMAX score improved from 62.5 ± 10.0 (range, 45 to 74) to 2.9 ± 1.26 (range, 0 to 5) in the notching group and from 59.0 ± 10.5 (range, 48 to 82) to 2.57 ± 1.3 (range, 0 to 5) in the non-notching group ($p = 0.37$) (Table 4).

Complications Associated with Anterior Femoral Notching

Two supracondylar femoral fractures occurred in 148 consecutive TKAs. One patient who received conventional TKA sustained a supracondylar fracture of the femur 8 days after surgery following a fall at the hospital. The fracture was treated operatively by retrograde intramedullary nailing. One patient who underwent navigated TKA had developed a distal femoral fracture gradually on follow-up radiographs, which was treated with plating.

Table 4. Comparison of Outcome Scores Measured Preoperatively and at the Last Follow-up between the Notching and Non-notching Groups during Navigated Total Knee Arthroplasty

Score	Notching		Non-notching		*p*-value*
	Preoperative	Last follow-up	Preoperative	Last follow-up	
ROM (°)	102.5 ± 12.9 (80–125)	125.2 ± 10.1 (110–140)	106.2 ± 12.86 (80–135)	126.6 ± 9.1 (105–140)	0.623
HSS	59.2 ± 8.8 (36–69)	91.7 ± 3.1 (87–98)	54.6 ± 9.3 (34–69)	90.8 ± 6.7 (65–98)	0.622
WOMAX	62.5 ± 10.0 (45–74)	2.9 ± 1.26 (0–5)	59.0 ± 10.5 (48–82)	2.57 ± 1.3 (0–5)	0.370

Values are presented as mean ± standard deviation (range).
ROM: range of motion, HSS: Hospital for Special Surgery, WOMAX: Western Ontario and McMaster Universities Osteoarthritis Index.
**p*-value: notching vs. non-notching, unpaired *t*-test.

DISCUSSION

Anterior femoral notching occurs when the anterior femoral cortex is violated while preparing the bone for TKA. The prevalence of anterior femoral notching during conventional TKA is 3.5%–26.9%,[10-12] Anterior femoral notching occurs due to excess IR or ER of the femoral component in a posterior referencing system. The stress created by anterior femoral notching is considerable because of a possible association with supracondylar femoral fractures.[12]

A computer-assisted navigation system has been developed to improve alignment accuracy during the osteotomy and implantation, and the usefulness of this system has been reported in several studies.[1-4,13-15] Navigation systems are becoming popular because the exact bone resection plane relative to the mechanical axis is known. The computer is programmed to show the distal femoral cut perpendicular to the mechanical axis. However, the mechanical axis is set based on the center of the femoral head relative to the intercondylar notch, and the configuration of the femoral shaft is not considered. Therefore, if the femur has some variation, a distal femoral cut perpendicular to the mechanical axis may induce an unexpected result. In this study, the prevalence of anterior femoral notching was 5.7% during conventional TKA and 16.7% during navigated TKA ($p = 0.037$).

Elderly women scheduled to have TKA have shorter and more anteriorly bowed femurs.[4,16] Anterior bowing of the femur extends the anterior cortex line of the femoral component when aligned with the sagittal mechanical axis of the femur. Theoretically, the anatomical axis of the distal femur (orientation of the intramedullary rod) deviates anteriorly to the mechanical axis of the femur in the presence of anterior femoral bowing. Therefore, sagittal alignment of the femoral component during conventional TKA is perpendicular to the anatomical axis of the distal femur, although it is in slight flexion compared to the mechanical axis of the entire femur. However, the computer in a computer-assisted navigation system is programmed to show the distal femoral cut as perpendicular to the mechanical axis. Therefore, a distal femoral cut perpendicular to the mechanical axis may induce anterior femoral notching.

In this study, marginally significant notching occurred where lateral femoral bowing was detected on preoperative radiographs, statistically. Significant notching occurred in cases where anterior femoral bowing was observed ($p = 0.047$). In particular, cases with both anterior and lateral femoral bowing had a significantly higher prevalence of notching ($p = 0.021$). Lateral femoral bowing tends to increase the difference between the mechanical and anatomical axis of the femur,[17] which results in a large number of outliers during navigated TKA. The distal femoral cut can be in a more valgus position if it is made perpendicular to the mechanical axis in a knee with lateral femoral bowing. Therefore, the distal femoral cut during navigated TKA must be modified in cases of severe lateral femoral bowing on a preoperative radiograph.[17] Stulberg[18] also showed a tendency for a hyperextended orientation of the femoral component in the presence of anterior femoral bowing during navigated TKA. The level of the anterior femoral cut was determined to avoid notching into the anterior cortex with the femoral component oriented in extension. Thus, the resulting size selected by the TKA navigation system larger than that corresponding to the preoperative sagittal dimensions. An oversize component can lead to narrow flexion spaces and overstuffing of the patellofemoral joint. It also causes a decline in knee function.[19] We chose up-sized components for the mid-size femoral component. Accordingly, mediolateral overhang occurred frequently. The occurrence of mediolateral overhang was significant in notching group during navigated TKA ($p = 0.035$).

Perlick et al.[20] inserted the femoral component in slight flexion of 2° to the anterior femoral cortex to avoid notching during navigated TKA. A preoperative radiological evaluation is essential. The femoral cut should be modified during navigated TKA if remarkable anterior femoral bowing is detected.[20]

Hirsh et al.[21] suggested that femoral fractures during the early postoperative period could be prevented by avoiding notching, which weakens the anterior and posterior femoral cortices. Merkel and Johnson[22] hypothesized that this weakening may be the result of concentrated stress when the cortex is breached. Culp et al.[23] measured notching depth on lateral postoperative radiographs. They concluded that violating the anterior femoral cortex in the supracondylar region by up to 3 mm reduces its torsional strength by 29%. In addition, Shawen et al.[24] concluded that anterior femoral notching ≥ 3 mm decreases the torsion and bending load to failure of the distal femur by 31%. The major determinants of distal femoral load to failure are bone mass present, as determined from local BMD, and distal femoral cortical bone geometry. In this study, mean notching depth was 2.92 ± 1.18 mm (range, 1.8 to 4.5 mm) in conventional TKA and 3.32 ± 1.54 mm (range, 1.55 to 6.93 mm) during navigated TKA ($p = 0.642$). However, notching depths ≥ 3 mm occurred in two cases (50%) in the conventional TKA and in seven (53.8%) in the navigated TKA group. A high prevalence of ≥ 3 mm anterior femoral notching may induce a supracondylar femoral fracture during navigated TKA than that during conventional TKA, in which continuous follow-up radiographs are needed to prevent a periprosthetic fracture. In this study, one periprosthetic fracture occurred in each of the groups. One patient who underwent conventional TKA sustained a supracondylar femoral fracture 8 days postoperatively after falling at the hospital. Notching depth was 5.5 mm and BMD-F was –2.5. The fracture was treated operatively with retrograde intramedullary nailing. One patient who underwent navigated TKA had an impending distal femoral fracture on follow-up radiographs. Notching depth was 1.8 mm, BMD-F was –3.2, and BMI was 31 kg/m^2. This was considered an impending supracondylar fracture of the femur. This fracture was treated operatively with plating. We found no correlation between notching and BMD. However, the combination of femoral notching and poor bone quality decreased the torsion and bending load to failure of the distal part of the femur, which required continuous follow-up radiographs to prevent a periprosthetic fracture.

This study had some limitations. First, this was a retrospective and non-randomized study. Therefore, it surgeon selection bias may have occurred for the operative method. Second, the Triathlon Knee System cuts done bone using a posterior referencing system; therefore, after cutting the posterior line it proceeds to cut the anterior line based on the prior cut. Thus, the same flexion gap is achieved but the size is selected by the AP plane rather than the mediolateral plane, so there may have been increased risks for notching or oversizing. Third, the navigation system we used was a computed tomography-free navigation system; therefore, we could not preoperatively plan for notching. However, different from previous simulative and experimental, our clinical study is the first to evaluate the prevalence of notching and risk factors of notching using a navigation system. A prospective randomized study as well as a comparative study of the posterior and anterior referencing systems for notching during navigated TKA are needed.

Surgeons should be aware of the risk associated with anterior femoral notching when using a navigation system for TKA and modifying the femoral cut should be considered when remarkable femoral bowing is detected.

CONFLICT OF INTEREST

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

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