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Accelerometer-Based Navigation versus Conventional Total Knee Arthroplasty for Posttraumatic Knee Osteoarthritis

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Background: Posttraumatic osteoarthritis (PTOA) frequently comprises femoral or tibial deformity, which makes it difficult to perform total knee arthroplasty (TKA). Accelerometer-based navigation (ABN) could be effective in restoring a neutral mechanical axis (MA) in TKA, but a limited number of studies have been reported in association with PTOA. Therefore, we aimed to compare the lower limb MA between ABN-assisted TKA (ABN-TKA) and conventional TKA in patients with PTOA.

Methods: We conducted a retrospective analysis of 28 PTOA patients who underwent TKA using a conventional system (cTKA group, n = 16) and the ABN system (iTKA group, n = 12). Standing long-leg radiographs were assessed for MA and prosthesis alignment as primary outcomes. A postoperative MA deviating beyond ± 3° was defined as an outlier. Perioperative outcomes, Oxford Knee Score (OKS) at 2-year follow-up, and complications were also assessed.

Results: The cTKA group and the iTKA group had a mean age of 63.07 years and 65.25 years, respectively. The iTKA group had significantly better MA accuracy when compared to the cTKA group (1.60° ± 2.09° vs. 3.59° ± 1.34°, p = 0.01). The iTKA group showed significantly less MA outlier than the cTKA group (78.6% vs. 25.0%, p = 0.02). The prosthesis alignment and OKS were comparable between the groups. There were 2 periprosthetic joint infections in the cTKA group and 1 periprosthetic fracture of the distal femur in the iTKA group.

Conclusions: For PTOA of the knee, both conventional TKA and ABN-TKA significantly improved the postoperative mechanical alignment and functional outcomes. The ABN-TKA seemed to offer higher accuracy and less MA outlier when compared to conventional TKA, and thus ABN could be a good alternative option.

Keywords: *Knee osteoarthritis, Prolonged post-traumatic unawarenesses, Total knee replacement, Accelerometer-based navigation surgical, Mechanical axis, Knee prosthesis*

Fractures around the tibia or femur can compromise the normal limb axis and alter knee kinematics, resulting in chronic asymmetrical stress on the articular surface and subsequently cartilage degeneration.[1] This early degenerative change of the articular cartilage is defined as posttraumatic osteoarthritis (PTOA).[2] Approximately 21%–44% of patients with a history of lower extremity fractures will consequently develop PTOA.[3]

Recreation of the neutral mechanical axis (MA), proper prosthesis orientation, and appropriate soft-tissue balance are together the primary goal of total knee arthroplasty (TKA) to ensure the long-term success of contemporary TKA because postoperative malalignment may lead to acceleration of polyethylene wear, early prosthesis loosening, and poor functional outcome.[4,5] However, TKA in the presence of PTOA is challenging since it usually involves bony nonunion/malunion, intra- or extra-articular

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deformity, soft-tissue problems, as well as retention of hardware that may hinder accurate restoration of the lower limb alignment and proper implant position.[1,2]

Currently, there are many surgical instrument systems that can help surgeons to overcome these complex situations and achieve their goals. Computer-assisted navigation system (CAS) has been shown effective in both primary and complicated cases. Even though several studies published the good clinical results and radiographic outcomes using CAS in patients with PTOA,[6,7] there are a limited number of studies that compared CAS directly to the conventional technique.[8] Additionally, the accuracy of postoperative MA after CAS-TKA has been demonstrated to be associated with the preoperative degree of extra-articular deformity; deformity > 15° in the coronal plane yielded more outliers.[9] Furthermore, many surgeons still refrain from using the CAS because of its disadvantages including higher cost, steep learning curve, a complicated registration process, line-of-sight problem, and pin site-related complications.[10]

Accelerometer-based navigation (ABN) is a handheld, portable navigation system that can be attached to the conventional cutting block. This novel system has intelligent position sensing via the accelerometer and the gyroscope and a built-in wireless communication function inside the sterile pods. After a few simple registration steps, this device determines the lower limb alignment and suggests the resection plane in both the coronal and sagittal views with the capability of verifying or adjusting the resected surface as necessary.[11,12] Therefore, the ABN avoids the need for costly preoperative planning, does not require a bulky computer console and an infrared camera, precludes line-of-sight issues, and eliminates risks associated with the tracking pins. In addition, evidence demonstrated that the ABN is as accurate as the CAS,[13] and the learning curve for the ABN (5–7 cases required) is shorter than that for the CAS (20–30 cases required).[14,15] However, to the best of our knowledge, there are a few case series presenting results of ABN for PTOA, and none of them compared their results to conventional TKA.[16-18] This paucity of appropriate studies involving PTOA patients was the driver for the present study with the primary objectives of determining if ABN can improve the lower limb MA and prosthesis orientation after TKA for PTOA. Thus, we hypothesized that ABN may establish a better and precise MA than conventional TKA in PTOA patients.

METHODS

The study was approved by the Institutional Review Board for retrospective analysis of patients who underwent primary TKA for PTOA performed by two surgeons (PR and AL) in our hospital. The study was registered with Thai Clinical Trials Registry (TCTR20200429001), and informed consent was obtained from every patient. In accordance with Wang's criteria,[19] all deformed knees that required an extra-articular corrective osteotomy were excluded from our study. Patients who had inadequate radiography, less than 2 years of follow-up, or a history of previous infection were also excluded. From 34 eligible PTOA patients, 4 who required correction with an osteotomy were excluded from our review and 2 who were lost during the follow-up were not included in the analysis. Hence, there were 16 consecutive patients who underwent TKA using the conventional system (cTKA group) during the period of 2011–2015, and 12 consecutive cases that had been operated on using ABN (iTKA group) during the period of 2015–2018.

All the patients received an identical perioperative protocol including regional anesthesia with 2.8–3.6 mL of bupivacaine (0.5% Marcaine; AstraZeneca, Gothenburg, Sweden), a prophylactic antibiotic, and a tourniquet control of 250 mmHg. The standard medial parapatellar approach was performed through the original incisional scar where possible in all cases. For the cTKA group, the proximal tibia was cut perpendicularly to MA in the frontal plane and targeted for 5° of posterior slope by using an extramedullary (EM) reference device. So the distal femoral resection was performed with intramedullary (IM) reference targeting perpendicular to the MA as preoperative templating. For horizontal orientation, 3° of femoral external rotation was set regarding the posterior condylar axis, while an anatomical landmark between the just medial and the medial one third of the tibial tubercle was applied for the tibial component.[20] All retained hardware that hindered a surgical procedure was removed in a single stage procedure. The IM entry point of conventional TKA was occluded with a bone plug. Likewise, the iTKA group received identical surgical steps besides using the ABN system (iASSIST; Zimmer Inc., Warsaw, IN, USA) to indicate a neutral MA of the proximal tibia and distal femoral resection in the coronal plane, with 1° of flexion in sagittal orientation for the femoral component and 5° of slope of the sagittal tibial alignment. The soft tissue was balanced to achieve rectangular flexion and extension gap. The patella was selectively resurfaced. An ordinary fixed-bearing prosthesis, either posterior-stabilized or cruciate-retaining, was then implanted with polymethylmethacrylate. A deep suction drain and a 15 mg/kg of intra-articular tranexamic acid were inserted into the knee joint for blood loss and pain reduction prior to the arthrotomy closure.[21] Of 2 patients with severe stiff knees in the conventional TKA group, 1 required quadricep V-Y plasty, and 1 had a tibial tubercle osteotomy and advancement to gain adequate exposure and optimize postoperative range of motion (ROM).

The same postoperative management and rehabilitation protocol were provided to all patients. A compressive dressing was applied, and the drain was clamped for 3 hours and then discarded at 24 hours after the surgery. Intravenous patient-controlled analgesic morphine and 30 mg of ketorolac were administered systematically during the first 48 hours. Thereafter, 250 mg of naproxen was given every 12 hours orally and 2 mg of morphine was used as rescue analgesia for controlling breakthrough pain throughout the hospitalization. Postoperative thromboembolic prophylaxis with low-molecular-weight heparin and bridging warfarin was administered in all patients. Every patient was encouraged to start early ambulation and mobilization as tolerated.

For the primary outcome, the standard standing long-leg radiograph that was controlled by pointing the patellar forward perpendicular to the X-ray beam was collected preoperatively and 1–2 years postoperatively. Only adequate radiographs without evidence of malrotation at preoperative and 2 years after the surgery were analyzed. Five radiographic measurements were assessed:[22,23] (1) MA of the lower extremity, (2) coronal femoral angle (CFA), (3) sagittal femoral angle (SFA), (4) coronal tibial angle (CTA), and (5) sagittal tibial angle (STA). The MA was determined by the line connecting the center of the femoral head and the anatomic center of the knee and ankle (Fig. 1). A postoperative MA that deviated beyond ± 3° of neutral alignment was considered as an outlier.[24] Blinded assessment of all radiographic parameters was independently performed by three well-trained orthopedic surgeons (SR, TT, and WE). The Oxford Knee Score (OKS) and ROM at 2 years of follow-up were compared to the preoperative status for clinical assessment. Perioperative parameters including operating time, drain output, preoperative and postoperative hematocrit (Hct) level, value of Hct at 24 hours postoperative compared to preoperative baseline (ΔHct), blood transfusion rate, and length of postoperative hospital stay (LPHS) were also recorded. Any complications that occurred during follow-up were also noted.

Statistical Analysis

All measurement characteristics and outcomes were summarized with descriptive statistic. Mean and standard deviation was used to measure central tendency of normal distribution data, and the Student *t*-test and chi-square test were applied to compare these outcomes between groups. For the data with skewed distribution, range was also presented. Reliability assessment revealed good intraclass correlation coefficients (ICCs) for both inter-rater (86.8%; 95% CI, 72.7%–95.8%) and intra-rater reliability (89.4%; 95% CI, 77.8%–94.7%) for MA. The inter- and intra-rater ICCs for tibial and femoral alignment angle were 80.3% (95% CI, 71.3%–86.5%) and 82.7% (95% CI, 73.5%–88.8%), respectively. For post-hoc analysis using the postoperative MA in Table 1, the sample size of the present study had 82.2% power to detect a significant difference, with an α error of 5%. The SPSS ver. 17.0 (SPSS Inc., Chicago, IL, USA) was used for all analyses with statistical significance defined as $p < 0.05$.

RESULTS

The details of participating patients are shown in Table 2, and both groups had comparable age, sex, body mass index (BMI), American Society of Anesthesiologists (ASA) status classification, and preoperative Hct. The cTKA group had a mean follow-up period of 69.14 months while that of the iTKA group was 33.08 months.

The MA of both groups was significantly improved toward neutral alignment ($p < 0.01$). The iTKA group had significantly better postoperative MA accuracy when

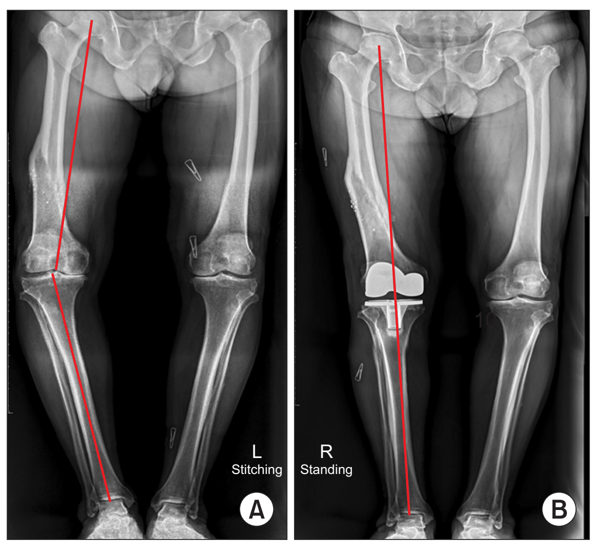

Fig. 1. Mechanical axis (MA) of a patient with posttraumatic osteoarthritis. (A) The preoperative MA deviated beyond ± 3° of neutral alignment. (B) Neutral postoperative MA was achieved after accelerometer-based navigation-assisted total knee arthroplasty.

Table 1. Demographic Data and Preoperative Characteristics Compared between Studied Groups

Parameter	cTKA	iTKA	*p*-value
No. of patients	16	12	
Age (yr)	63.07 ± 7.56	65.25 ± 7.46	0.45
Sex (male : female)	6 : 10	5 : 7	0.77
BMI (kg/m^2)	26.68 ± 3.55	26.57 ± 1.52	0.87
ASA physical status classification (1 : 2 : 3)	1 : 9 : 6	1 : 7 : 4	0.67
Location of deformity (femur : tibia : both)	9 : 6 : 1	9 : 3 : 0	0.58
Plane of deformity (coronal : sagittal : rotational)	13 : 7 : 4	12 : 5 : 3	0.93
Preoperative Hct (%)	37.01 ± 4.93	36.67 ± 3.08	0.84
Preoperative MA (°)	7.10 ± 7.05 (–5.8 to 24.8)	9.38 ± 10.79 (–14.8 to 26.2)	0.24
Preoperative CFA (°)	92.26 ± 5.32 (82.5 to 102.0)	95.92 ± 3.84 (91.9 to 101.1)	0.06
Preoperative SFA (°)	88.61 ± 6.24 (73.3 to 101.0)	90.33 ± 9.69 (79.5 to 111.9)	0.59
Preoperative CTA (°)	85.57 ± 5.06 (74.2 to 91.1)	82.88 ± 7.19 (65.7 to 91.9)	0.28
Preoperative STA (°)	83.19 ± 5.58 (72.9 to 90.4)	76.29 ± 25.80 (64.3 to 101.5)	0.34
Preoperative ROM (°)	85.64 ± 40.07 (10 to 125)	87.92 ± 18.52 (60 to 115)	0.86
Preoperative OKS	14.07 ± 5.53 (3 to 21)	13.00 ± 5.41 (5 to 22)	0.43

Values are presented as mean ± standard deviation (SD) or mean ± SD (range).
cTKA: conventional total knee arthroplasty, iTKA: accelerometer-based navigation total knee arthroplasty, BMI: body mass index, ASA: American Society of Anesthesiologists, Hct: hematocrit, MA: mechanical axis, CFA: coronal femoral angle, SFA: sagittal femoral angle, CTA: coronal tibial angle, STA: sagittal tibial angle, ROM: range of motion, OKS: Oxford Knee Score.

compared to the cTKA group (1.60° ± 2.09° vs. 3.59° ± 1.34°, $p = 0.01$). The iTKA group showed significantly less MA outliers than the cTKA group (78.6% vs. 25.0%, $p = 0.02$). The postoperative CFA, SFA, CTA, and STA were comparable between the groups. The iTKA group tended to have less operative time, drain output, ΔHct, and blood transfusion and had significantly shorter LPHS than the cTKA group. The OKS and ROM at 2 years of follow-up were significantly improved after TKA in both groups ($p < 0.01$) and were comparable between groups (Table 1).

At the latest follow-up, 3 complications were found in the cTKA group including 2 periprosthetic joint infections (PJIs) and 1 suspected PJI with culture negative, and all were treated with debridement and implant retention. There was 1 periprosthetic fracture of the distal femur in the iTKA group, which was managed with minimally invasive plate osteosynthesis.

DISCUSSION

The handheld navigation system has been introduced to reduce the risk of unacceptable mechanical and prosthesis alignment. This system provides a validation tool that helps confirm both coronal and sagittal cutting planes and allows surgeons to revise the cuts as necessary, particularly in cases with significant bony deformity. The ability to create a precise lower limb alignment and component positioning may clinically benefit complex cases (Fig. 2). In the present study, we found that the iTKA group had significantly better MA accuracy and less outlier beyond ± 3° of neutral alignment. The postoperative alignment of prostheses was comparable between groups. Recently, two prospective case series that performed ABN-TKA for PTOA revealed a high accuracy rate in achieving neutral mechanical alignment and significant improvement of both Knee Society Knee Score (KSKS) and Knee Society Functional Score (KSFS).[16,17] Nevertheless, both studies reported on short-term results and had no control group for comparisons. Although we also found that the OKS and ROM of both groups were significantly improved after TKA, those outcomes were not significantly different between cTKA and iTKA.

Posttraumatic osteoarthritic knees may involve coronal plane, sagittal plane, or multi-planar deformity at

Table 2. Perioperative and Postoperative Outcomes of Studied Groups

Parameter	cTKA	iTKA	*p*-value
Operative time (min)	130.64 ± 41.46 (67–200)	109.92 ± 30.20 (75–180)	0.16
Removal of retained implant	8	0	< 0.01*
Prosthesis type (PS : CR)	16 : 0	8 : 4	0.02*
Component assembled with extension stem (femur : tibia)	3 : 2	0 : 0	0.05
Drain output (mL)	466.07 ± 290.73 (130–1050)	353.33 ± 195.60 (140–700)	0.27
Hct at 24 hours after TKA (%)	31.80 ± 4.46 (24.1–39.0)	33.04 ± 3.52 (26.1–36.0)	0.44
ΔHct	5.21 ± 3.65 (1.9–9.6)	3.63 ± 3.56 (1.5–8.6)	0.28
Blood transfusion (%)	42.9	33.3	0.46
LPHS (day)	5.21 ± 1.58 (4–10)	3.92 ± 0.79 (3–5)	0.01*
Postoperative MA (°)	3.59 ± 1.34 (1.0–5.6)	1.60 ± 2.09 (–2.9–4.27)	0.01*
MA outlier (%)	78.6	25.0	0.02*
Postoperative CFA (°)	95.21 ± 3.29 (89.9–101.2)	94.53 ± 2.81 (90.2–99.8)	0.58
Postoperative SFA (°)	88.63 ± 2.42 (84.5–92.5)	88.52 ± 3.72 (81.9–97.2)	0.93
Postoperative CTA (°)	90.42 ± 1.68 (87.8–93.5)	89.19 ± 2.15 (85.5–91.5)	0.12
Postoperative STA (°)	86.70 ± 4.18 (77.6–93.9)	87.28 ± 5.25 (76.3–92.7)	0.76
ROM at 2 years of follow-up (°)	102.86 ± 17.84 (65–125)	102.08 ± 13.89 (85–120)	0.90
OKS at 2 years of follow-up	42.79 ± 2.12 (39–46)	43.42 ± 1.98 (40–46)	0.73

Values are presented as mean ± standard deviation (range).
cTKA: conventional total knee arthroplasty, iTKA: accelerometer-based navigation total knee arthroplasty, PS: posterior-stabilized, CR: cruciate-retaining prosthesis, Hct: hematocrit, TKA: total knee arthroplasty, *Δ*Hct: value of Hct at 24 hours after TKA that decreased from baseline, LPHS: length of postoperative hospital stay, MA: mechanical axis, MA outlier: postoperative MA exceeding ± 3° of neutral MA alignment, CFA: coronal femoral angle, SFA: sagittal femoral angle, CTA: coronal tibial angle, STA: sagittal tibial angle, ROM: range of motion, OKS: Oxford Knee Score.
*Statistical significance.

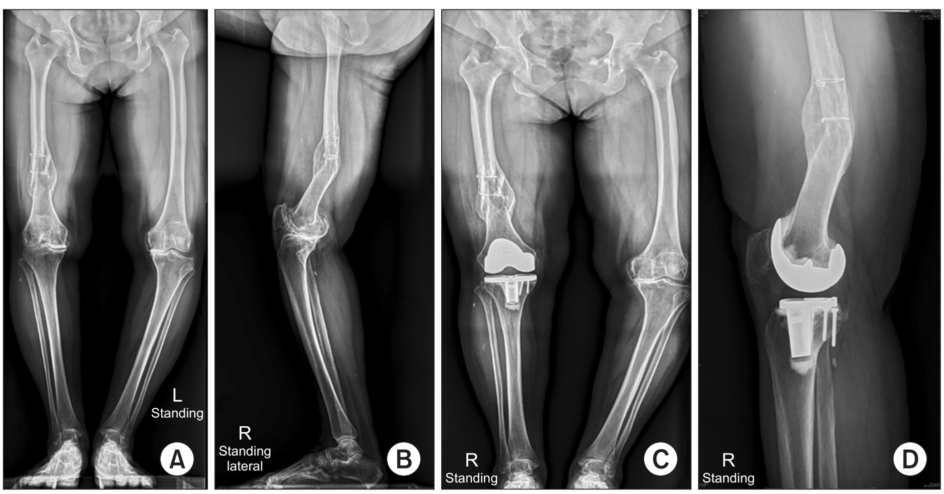

Fig. 2. An 80-year-old female presented with posttraumatic osteoarthritis and malunion of the right distal femur (35 years ago). (A, B) Preoperative standing long-leg radiographs. (C, D) Postoperative radiographs taken after accelerometer-based navigation-assisted total knee arthroplasty.

either the femoral or tibial site. No standard classification systems that categorize these deformities are currently available.[25] Some severe deformities may require extra-articular correction with either a single or staged osteotomy. However, this procedure is associated with an increased risk of osteotomized nonunion, extensile surgical exposure, technical difficulty, and a high complication rate.[1,26,27] Therefore, the current trend is toward intra-articular correction using an asymmetrical bone resection technique, which provides an excellent outcome, particularly if coronal deformity is < 20° in the femur or ≤ 30° in the tibia.[19] Generally, the deformed bony anatomy, crooked medullary canal, and retained hardware that preclude an insertion of a conventional system can be overcome by some surgical strategies.[27,28] For instance, Paredes-Carnero et al.[29] reported a significant improvement of KSKS, KSFS, and ROM after intra-articular correction for extra-articular deformity (EAD) in 9 TKAs by altering the IM entry point. Loures et al.[30] reported significant improvement of Knee Society Score in 25 knees with PTOA, and the mean MA was corrected from 9.3° of valgus to 0.6° of varus alignment with 20% outlier noted, when an EM reference guide of a conventional system was chosen. One study consisting of 15 PTOA showed that more than 85% of patients presented with a good to excellent KSKS and KSFS whether IM or EM reference instrument was utilized.[31] However, it should be noted that surgeons' experiences may have been an important factor affecting the results when conventional instruments were applied in these challenging cases. In our study, the ABN system was more reliable to restore the neutral MA for PTOA than the conventional device. Additionally, iTKA might help surgeons to avoid simultaneous removal of the osteosynthetic material and result in potentially less surgical trauma and blood loss and subsequently shorter LPHS than cTKA (Fig. 3). Nevertheless, the functional outcomes of both groups were similar at 2 years of follow-up.

CAS is considered an effective surgical option to achieve a target alignment for PTOA because it has a valuable feature that can calculate the MA of the lower extremity irrespective of local landmarks without harming the IM canal. A case series of 40 PTOAs revealed that CAS could improve the lower limb alignment from 166.7° to 179.1° and increase KSKS and KSFS.[6] Tani et al.[8] compared CAS and a conventional system and found that KSFS was significantly better (93.3 ± 5.9 vs. 73.6 ± 15.4, respectively; $p = 0.008$) with slightly better KSKS, prosthesis position, and MA. Nevertheless, Rhee et al.[7] found a difference in MA between an intraoperative assessment by CAS and a postoperative weight-bearing radiograph. They found that 13 patients with EAD had 0° of MA when assessed by CAS intraoperatively, but 4 patients (30.8%) showed MA exceeding ± 2° on postoperative weight-bearing radiographs. They suspected that an error in tracker placement and fixation and improper soft-tissue balancing were the causes of this deviation. In addition, the extra-articular deformity > 15° was related to a greater outlier of postoperative MA when performing CAS-TKA in knee models.[9] For patient-specific instrument (PSI), to our knowledge, there was a single cohort study on PSI-TKA performed in 10 cases of PTOA, where PSI-TKA showed a significantly improved OKS, flexion-extension arc, and postoperative MA.[32] Compared to CAS and PSI, ABN is at least as accurate as the others in terms of MA restoration.[13,33] However, the benefit of ABN is that it is a handheld, portable device that can be attached to the conventional cutting block, is possibly cheaper, does not require a robust console and special preoperative planning, and may demand a lesser learning curve when compared to CAS or PSI.[14,15,33]

Our study has some limitations that need to be considered when interpreting the outcomes. First, it was a retrospective study with some inherent limitations related to the study design. Second, although the number of the enrolled patients was relatively small, our cohort had an 82.2% power to detect a significant difference regarding MA. Nevertheless, the population of our study might not have enough power to detect a difference of secondary outcome measures such as blood loss, LHPS, OKS, and

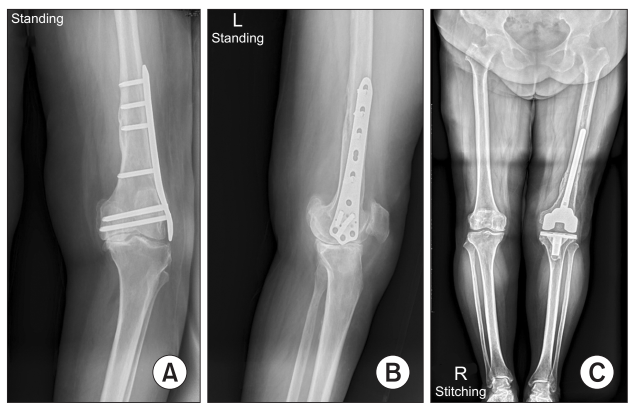

Fig. 3. A 75-year-old female presented with posttraumatic osteoarthritis and malunion of the left distal femur with plate and screw fixation (22 years ago). She was also diagnosed with osteoporosis. (A, B) Preoperative standing knee radiographs showing plate and screw fixation that precluded insertion of an intramedullary reference guide into the distal femur. (C) Postoperative standing long-leg radiograph obtained after conventional total knee arthroplasty with simultaneous plate and screw removal. A femoral component assembled with an extension stem was applied to bypass stress riser from multiple screw holes.

complications. Although a prospective, randomized study with a larger group of patients may help in verifying our findings, it may not be feasible because of the low incidence of PTOA.[8] Third, albeit a three-dimensional computed tomography scan can provide component rotatory information in the axial plane with higher measurement resolution, standing two-dimensional plain radiographs reflected the actual alignment under physiologic load, which could not be achieved with a CT scan.[34] Lastly, the follow-up duration of the present study was relatively short, and a longer follow-up period may be necessary to verify the clinical outcomes and actual cost-effectiveness of this ABN system in terms of implant survivorship.

For PTOA, both the conventional TKA and ABN-TKA significantly improved postoperative mechanical alignment and functional outcomes. ABN-TKA seemed to show higher accuracy and less MA outlier when compared to the conventional system, and thus this device could be a good alternative option.

CONFLICT OF INTEREST

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

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