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Original Article

Computer-assisted navigation for cruciate-retaining total knee arthroplasty in patients with advanced valgus arthritic knees

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A B S T R A C T

Background: The valgus arthritic knee is a complex deformity involving both soft tissue and bony problems that significantly affect the positioning of the components for, and decrease the accuracy of, reconstructed alignment in total knee arthroplasty (TKA). The unique bony deformity and soft tissue problem makes the use of conventional mechanical instrumentation difficult and leads to unsatisfactory results.

Purpose: The purpose of this study was to investigate the effect of computer-assisted navigation for TKA on the postoperative mechanical axis, component alignment, and functional outcomes in the arthritic knee with genu valgus deformity.

Methods: From January 2003 to August 2009, 24 patients (24 knees) with advanced valgus knee arthritis who underwent computer-assisted navigation for cruciate-retaining TKA were retrospectively reviewed. The accuracy of the postoperative mechanical axis and component alignment, and functional outcomes were assessed.

Results: The mean postoperative mechanical axis was 180.2° (range, 178.1–182.5°). All patients achieved the targeted goal of a leg axis within 3° of the neutral axis. The joint line was not substantially elevated. No patient required conversion to a constrained component to achieve stability. At a mean follow-up of 45.5 months, the Hospital for Special Surgery (HSS) knee score improved from a mean preoperative score of 55.6 to 92.8 postoperatively. The International Knee Society (IKS) clinical score improved from 42.2 to 95.9. The IKS for pain improved from 15.4 to 47.1, and the IKS knee function score improved from 35.8 to 95.4.

Conclusion: Computer-assisted navigation for TKA is a useful alternative technique for advanced valgus knee arthritis where accurate restoration of the joint line, proper alignment of the limb and prosthetic components, and meticulous soft tissue balancing may be challenging because of bony deformities and soft tissue contractures.

1. Introduction

Total knee arthroplasty (TKA) is a reliable, successful, and reproducible procedure for treating the advanced arthritic knee. The effectiveness of computer-assisted navigation for TKA for the arthritic knee has been well-documented in the literature, and provides excellent results for accuracy of component alignment, correction of the limb axis, and soft tissue balancing.[1–9] Approximately 10% of patients requiring TKA present with a valgus deformity (Fig. 1). When using the mechanical alignment guiding systems, correction of the valgus deformity has posed technical challenges and has produced variable clinical results. The bony abnormalities encountered with the valgus knee include distal femoral hypoplasia, posterior femoral condylar erosion, unusual proximal femoral neck-shaft angles, external rotation deformity of the distal part of the femur, patellar maltracking, and metaphyseal remodeling of both the femur and the tibia (which can lead to malalignment or malrotation of the femoral component).[10,11] Even experienced surgeons often rely on a constrained implant and mechanical alignment guiding systems to correct a valgus deformity.[12] Application of computer-assisted navigation for TKA in the valgus knee would allow precise cutting of the femur and tibia in conjunction with meticulous soft tissue releases and likely offer improved outcomes.

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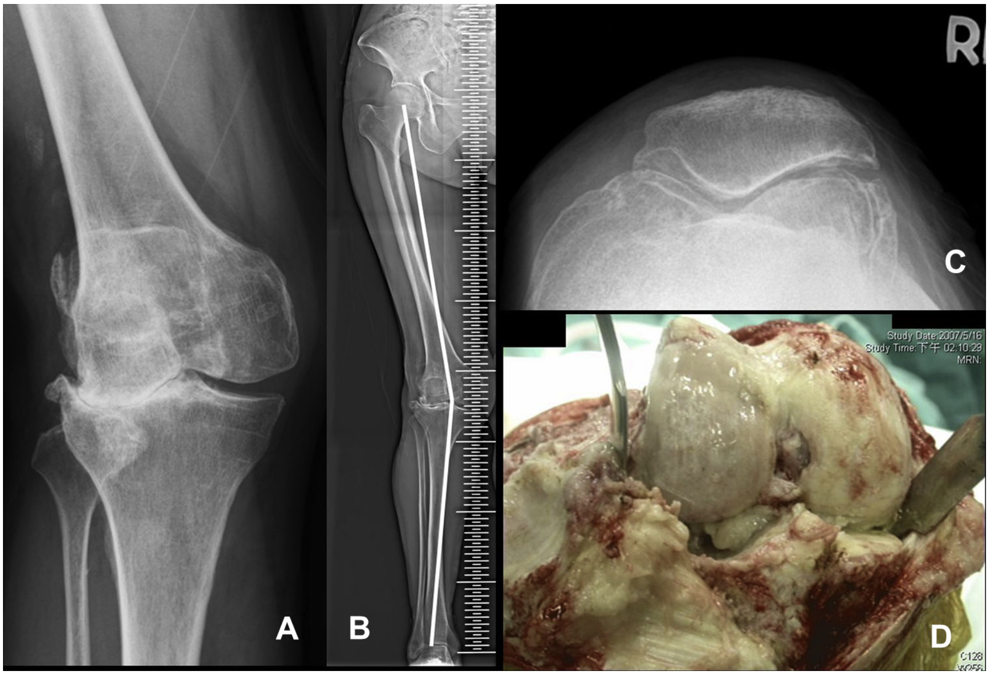

Fig. 1. A 78-year-old male with an advanced valgus deformity of the right knee. (A) Radiograph of the right knee before surgery. (B) Preoperative standing full-length weight-bearing radiograph shows significant genu valgus deformity with a 13.3° preoperative mechanical axis. (C) Preoperative skyline view shows advanced osteoarthritis of the right patellofemoral joint. (D) Intraoperative picture shows destruction of the tibiofemoral and patellofemoral joints and hypoplasia of the lateral femoral condyle.

2. Purpose

There have been few attempts to clarify the role of computer-assisted navigation for TKA patients with genu valgus deformities. The purpose of this study was to investigate the effect of computer-assisted navigation for TKA on the postoperative mechanical axis, component alignment, and functional outcome in the arthritic knee with genu valgus deformity (Fig. 2).

3. Materials and methods

This study was approved by the Institutional Review Board of Chang Gung Memorial Hospital (99-2386B).

A retrospective review was performed on the medical records, radiographic data, and functional outcomes of all patients who had arthritis of the knee joint with genu valgus deformity and underwent computer-assisted navigation TKA at the Chiayi Chang Gung Memorial Hospital between January 2002 and August 2009. Clinical data collected included age, sex, diagnosis, type of valgus deformity (explained below), perioperative findings, tourniquet time, total amount of blood loss, and radiographic assessments before and after surgery. Preoperative and postoperative functional scores were obtained for all patients with the use of the Hospital for Special Surgery (HSS)[13] and International Knee Society (IKS) scoring systems.[14] Patients who had an extra-articular deformity of the femur or tibia related to trauma or previous surgery, or incomplete medical records with respect to radiographic analyses and functional evaluations were excluded from the study.

All patients enrolled in this current study were evaluated using radiographic analyses with long-leg weight-bearing split scanograms and anteroposterior (AP) and lateral radiographs of the knees taken preoperatively and postoperatively, as previously described.[15] The skyline view of the patellofemoral joint was also obtained, and the lateral patellar tilt and displacement were estimated according to the criteria of Laurin et al.[16,17] Radiographic parameters including mechanical axes, valgus correction angle of the distal femur (explained below), and the components of alignment (i.e., femoral valgus angle [FV], tibial valgus angle [TV], femoral flexion angle [FF], and tibial flexion angle [TF]) were measured.[18] The position of the prosthetic joint line was measured on radiographs taken at the last follow-up. Adequate restoration of the joint line was defined as 10 ± 3 mm proximal to the fibular styloid and 25 ± 3 mm distal to the medial epicondyle of the femur.[19] All measurements were made with a precision of 0.1°, on digital radiographs using a computer.

Ranawat et al described three types of valgus knees.[11] Type I deformity has minimal valgus and medial soft tissue stretching. Type II fixed valgus deformity has a more substantial deformity (>10°) with medial soft tissue stretching, and type III deformity is a severe bony deformity after a prior osteotomy with an incompetent medial soft tissue sleeve. The valgus correction angle of the distal femur was measured according to the method described by Yau et al,[20] and represents the angle between the line joining the center of the femoral head and the intercondylar notch of the distal femur and the line joining the femoral intercondylar notch and the femoral isthmus.

The planned position of the tibial component was at a TV of 90° in the coronal plane; the planned position for the femoral component was at a FF of 0°; and the planned position for the tibial component was at a TF of 87° in the sagittal plane. The desired FV angle was based on the valgus correction angle of the distal femur, which was measured by long-leg weight-bearing split scanograms. The goals of TKA were to reconstruct the mechanical axis and component alignments (FV, TV, FF, and TF) to within 3° varus/valgus after surgery.

3.1. Surgical technique

All patients received the same cruciate-retaining type of total knee prosthesis (DePuy PFC knee systems, DePuy Orthopaedics,

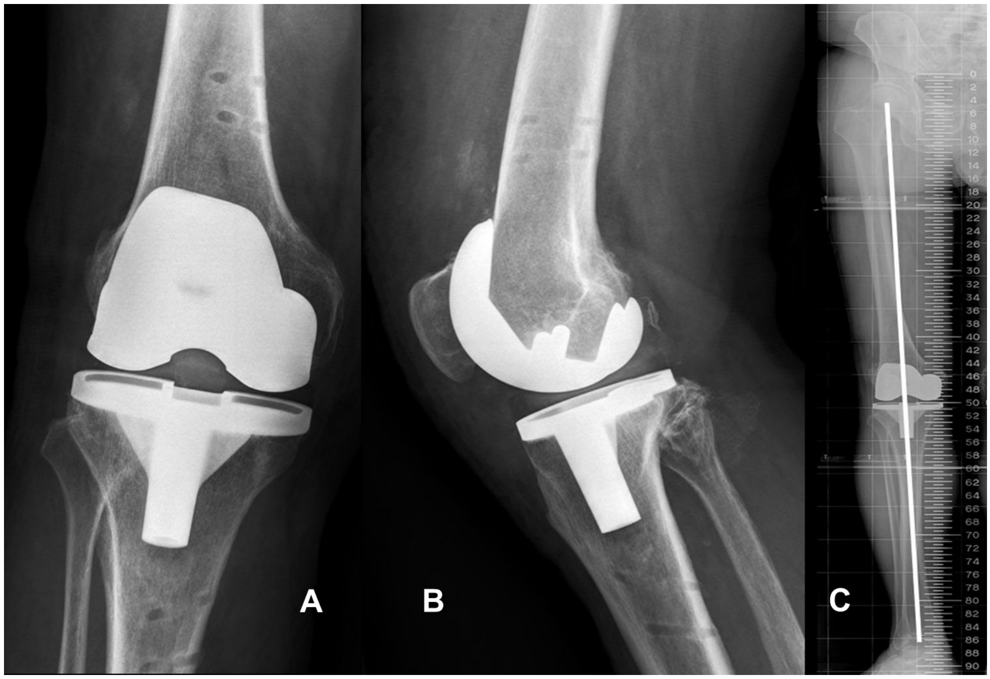

Fig. 2. A 78-year-old male with an advanced valgus deformity. Radiographs of the knee joint after surgery. (A,B) Radiographs after total knee replacement with cruciate-retaining type prosthesis. (C) Postoperative radiograph shows complete restoration of limb alignment after undergoing computer navigation TKA.

Inc.; Warsaw, IN; USA) and underwent implantation with the use of a computed tomography (CT) free navigation system (BrainLAB, Inc., Munich, Germany). All patients received an anterior longitudinal skin incision and a medial parapatellar arthrotomy. After removal of osteophytes from the femur, the soft tissues of the lateral compartment were released from the proximal tibia. The reference arrays were then implanted on the distal femur and the proximal tibia, respectively. After determining the center of the femoral head, point registration of the articular surfaces and the centers of the knee and ankle joints were performed in order to construct the mechanical axis. The implant size and orientation were identified by dragging the pointer along the bone surface to reconstruct the 3-D bone model. The femoral preparation was performed first, followed by the tibial preparation under the guidance of the CT free navigation system. The femoral component was referenced parallel to the anterior cortex of the distal femur. The rotation of the femoral component was guided by the epicondylar line and Whiteside's line that were previously registered in the navigation system. The rotation of the tibial component was adjusted to match the femoral component and was made parallel to the axis between the medial-third of the tibial tuberosity and the center of the tibial plateau. The soft tissue balance was assessed at the trial reduction and achieved by sequential release of the tight structures (i.e., iliotibial [IT] band, popliteus, lateral collateral ligament [LCL], and the lateral head of the gastrocnemius) in both flexion and extension as described by Whiteside.[21] The posterior cruciate ligament (PCL) was assessed using the pull-out lift-off test described by Scott and Chmell,[22] and released as needed from its insertion site in the tibia to obtain the desired tension. The femoral and tibial reference arrays were retained until the cement had fully set and were removed after verifying the alignment under navigation. The tourniquet was then deflated, and assessment of hemostasis and patellar tracking were performed. All TKA procedures were performed by the senior surgeon (R.W.-W. Hsu) who has extensive experience in the use of computer-assisted navigation.

All patients enrolled in this investigation were treated according to identical protocols. Prophylactic intravenous administration of 1.0 g of a first-generation cephalosporin (i.e., cefazolin) occurred 1 hour before the operation and continued every 8–24 hours postoperatively for 48 hours depending on each patient's renal function. Wound suction drains were used for 48 hours. All patients were allowed to walk with full weight-bearing after the surgery. A continuous passive-motion machine was used from the day of surgery throughout the hospital stay.

Data including tourniquet time, blood loss, length of hospital stay, complications associated with operative technique, and radiographic parameters were collected and analyzed by two independent surgeons. The statistical analyses were performed using SPSS 13.0 for Windows (SPSS Inc., Chicago, IL; USA). The Chi-square test or Fisher's exact test was used to compare categorical data. The paired sample t test was applied for comparisons of functional results. Statistical analysis was conducted by an independent statistician blinded to the surgical outcomes. A value of $p < 0.05$ was considered statistically significant.

4. Results

A total of 24 patients (24 knees) with arthritic knees and genu valgus deformity who underwent computer-assisted navigation TKA were enrolled in the current study. There were nine males and 15 females with a mean age of 70.5 years (range, 48–84 years). Twenty-one patients had primary osteoarthritis, and three patients had rheumatoid arthritis. The mean hospital stay was 6.3 days (range, 4–10 days), and the mean follow-up time was 45.5 months (range, 24–95 months) (Table 1).

The mean tourniquet time was 81.8 minutes (range, 58–117 minutes), and the mean total blood loss was 523 mL (range, 285–790 mL). Seven patients received local autograft for the lateral tibial plateau. Ten patients did not receive additional soft tissue release after removing osteophytes and releasing the soft tissues of the lateral compartment from the proximal tibia. The IT band was

Table 1
Patients' demographic data.

Parameters	$N = 24$
Age (y)	70.5 ± 8.6 (48–84)
Sex	
Male	9 (37.5%)
Female	15 (62.5%)
Body height (cm)	155.9 ± 9.8 (133–174)
Body weight (kg)	67.0 ± 12.7 (35–95)
Body mass index (kg/m^2)	27.4 ± 4.0 (19.8–38.1)
Type of arthritis	
Primary osteoarthritis	21 (87.5%)
Rheumatoid arthritis	3 (12.5%)
Hospital stay (d)	6.3 ± 1.2 (4–10)
Mean follow-up time (mo)	45.5 ± 25.8 (24–95)

Values are presented as mean ± SD with the range in parentheses or *n* (%) where appropriate.

released by the pie-crusting technique in 14 patients. No patient had need for further surgical intervention to restore medial collateral ligament (MCL) tension. A total of 3 patients required release of the lateral retinaculum to obtain adequate patellar tracking. No joint line elevation occurred in this study. The thickness of the polyethylene spacer was 8 mm in three patients, 10 mm in 16 patients, and 12.5 mm in five patients. No patient was converted to a posterior-stabilized type or constrained components during the surgery (Table 2).

In the radiographic evaluation, the mean preoperative mechanical axis was 196.7° (range, 190.5–207.7°), and the mean valgus correction angle of the distal femur was 4.6° (range, 2.9–6.3°). The mean postoperative mechanical axis was 180.2° (range, 178.1–182.5°). The mean FV angle was 96.6° (range, 93.5–100.6°); the mean FF was 2.6° (range, 0.2–3.9°); the mean TV was 90.1° (range, 88.7–91.1°); and the TF angle was 87.0° (range, 85.1–90.4°) (Table 2).

Clinically, the active range of motion (ROM) improved from 96° to 118°. The HHS score improved from a mean preoperative score of 55.6 to 92.8 postoperatively ($p < 0.001$). According to the IKS rating scores, the pain score improved from 15.4 to 47.1 ($p < 0.001$), the clinical knee score improved from 42.2 to 95.9 ($p < 0.001$), and the functional knee score improved from 35.8 to 95.4 ($p < 0.001$) (Table 3).

Table 2
Perioperative and radiographic data.

Parameters	$N = 24$
Preoperative data	
Total blood loss (mL)	523 ± 111 (230–790)
Tourniquet time (min)	81.8 ± 22.7 (58–117)
Bone grafting	7 (29.2%)
Soft tissue release	
No release	10 (41.7%)
Iliotibial band	14 (58.3%)
Lateral retinaculum for patellar tracking	3 (12.5%)
Joint line elevation	0
Thickness of polyethylene spacer	
8 mm	3 (12.5%)
10 mm	16 (66.7%)
12.5 mm	5 (20.8%)
Radiographic data for leg axis	
Valgus correction angle of the distal femur (°)	4.6 ± 0.8 (2.9–6.3°)
Preoperative MA (°)	196.7 ± 4.9 (190.5–207.7°)
Postoperative MA (°)	180.2 ± 1.2 (178.1–182.5°)
Component alignment	
Femoral valgus angle (°)	96.6 ± 1.8 (93.5–100.6°)
Femoral flexion angle (°)	2.6 ± 2.1 (0.2–3.9°)
Tibial valgus angle (°)	90.1 ± 0.4 (88.7–91.1°)
Tibial flexion angle (°)	87.0 ± 2.6 (85.1–90.4°)

Values are presented as mean ± SD with the range in parentheses or *n* (%) where appropriate.
MA = mechanical axis.

No complications (e.g., peroneal nerve neuropraxia, pulmonary emboli, deep vein thrombosis, perioperative or postoperative fracture related to pin placement for the femoral and tibial reference arrays, postoperative periprosthetic fracture, postoperative wound infection, wound healing problems, joint instability, or patellar problems) were encountered. No patients showed loosening or osteolysis on radiographs at the time of the last follow-up. No patients received revision surgery for any reason by the last follow-up.

5. Discussion

The most important finding in the present study was that the computer-assisted navigation cruciate-retaining total knee replacement provided satisfactory results with excellent functional outcomes. This surgical approach represents a reliable alternative for valgus arthritic knees where accurate restoration of the joint line and alignment of the limb and the components may be challenging because of associated bony deformities and soft tissue contractures.

The CT-free navigation system was introduced to the Chiayi Chang Gung Memorial Hospital in January 2002, and our early reports demonstrated that the computer-assisted navigation TKA improved the accuracy of the orientation of components and mechanical axis of the lower limb compared to the conventional technique.[7–9] Furthermore, our results were compatible with the literature.[1–6] However, little research has focused on treatment of the valgus deformity with computer-assisted navigation TKA. Hadjicostas et al[4] analyzed 15 consecutive patients with severe valgus deformities and reported excellent mid-term results with osteotomy of the lateral femoral condyle and computer-assisted navigation TKA. In the current study, the computer-assisted navigation TKA provided good results without additional osteotomy in all patients. The mechanical axis was corrected from 196.7° (range, 190.5–207.7°) preoperatively to within 3° of the neutral axis. Similar results were presented for component alignment; all components were within 3° of the planned alignment. Excellent functional improvement was also achieved after a mean follow-up of 45.5 months.

Approximately 10% of patients with primary osteoarthritis requiring TKA have a genu valgus deformity.[23] Correction of the valgus knee deformity is technically challenging and may be associated with greater risks for component malposition, malalignment of the mechanical axis, and joint line elevation because of

Table 3
Knee Society Scores, Hospital for Special Surgery Score, and active range of motion preoperatively and at the last follow-up visit.

	Preoperatively	Last follow-up	(p)
HSS score (points)	55.6 ± 6.6 (41–65)	92.8 ± 3.4 (84–96)	<0.001*
IKS score for pain (points)	15.4 ± 5.0 (10–30)	47.1 ± 3.5 (40–50)	<0.001*
IKS score for clinical knee score (points)	42.2 ± 10.8 (16–60)	95.9 ± 4.4 (84–100)	<0.001*
IKS score for functional knee score (points)	35.8 ± 9.8 (20–50)	95.4 ± 5.8 (80–100)	<0.001*
Active range of motion (°)	96 ± 13.5 (80–120)	118 ± 11.9 (100–125)	<0.001*

Values are presented as mean ± SD with the range in parentheses.
*$p < 0.05$.
HSS = Hospital for Special Surgery; IKS = International Knee Society.

the bony abnormalities and coexisting soft-tissue contractures.[3,11,12,23] Successful treatment requires precise bone resection, and the bony abnormalities make it difficult to achieve correct external rotation of the femoral component and may lead to over-resection of the medial femoral condyle when using a conventional guide jig. When utilizing conventional intramedullary femoral jigs, the deficiencies of the lateral femoral condyle often render the posterior condylar axis inadequate as a reference for determining the rotation of the femoral component. Therefore, using a constant 3° of rotation may result in a greater risk of malrotation of the femoral component. Malrotation of the femoral component may increase the contact pressure within the patellofemoral joint and accelerate wear of the patellar button.[24]

The valgus correction angle of the distal femur determined the choice of the distal femoral cutting block needed to achieve a perpendicular distal femoral bone cut to the mechanical axis of the femur. Unusual proximal femoral neck-shaft angles change the angular relationship between the anatomic axis and the mechanical axis of the femur; therefore, a 3° valgus distal femoral cut is suggested in the literature instead of the usual 5–7° for varus knees.[11] In the current study, the mean valgus correction angle of the distal femur was 4.6° (range, 2.9–6.3°), and routinely using a 3° valgus distal femoral cut may not be advisable.

The computer-assisted navigation TKA provided excellent results for accuracy in component alignment, limb axis correction, intra-articular bone resection, and soft tissue balancing.[4,7,19,25] This technique focused on the centers of the hip, knee, and ankle joint and overlooked deformities of the femur and tibia.

Balancing the soft tissues is critical for optimal long-term outcome, prevention of accelerated wear, and reduction of the revision rate. Inappropriate management may result in residual imbalance of the soft tissue and lead to poor seating of the components despite precise bone cutting.[26] In addition, imbalance of the soft tissues may result in instability, poor joint ROM, and abnormal patellofemoral tracking.[27–29] Coexisting soft tissue contractures frequently encountered in the genu valgus deformity include contracted lateral capsule, IT band, LCL, popliteus tendon, and hamstring muscles.[10,11] Among the many soft tissue balancing techniques in the valgus knee that have been proposed,[11,12,21,30–33] Ranawat et al suggested a reasonable approach that might prevent an oversized polyethylene spacer and constrained implant.[10,11] In the current study, the soft tissue was managed by sequential release of the tight structures as recommended by Whiteside[27] under computer-assisted navigation. An equal flexion and extension gap throughout the knee joint ROM was achieved under the quantitative feedback by navigation system for surgeons.

There is no consensus on the choice of implant in these cases. Many authors suggest the use of PCL-substituting implant designs in order to avoid concerns with PCL balancing and dealing with a potentially abnormal native ligament.[12,23,31,34,35] Furthermore, some authors have advocated the use of primary constrained components.[12,31] With proper soft tissue balance techniques, a PCL-retaining prosthesis achieved satisfactory outcomes in many published studies.[33,34,36,37] Meanwhile, Koskinen et al[38] reported that poor soft tissue balance with residual instability was the main reason for revision in PCL-retaining prostheses. Under the assistance of the navigation system, precise correction of bony deformities and soft tissue balancing were easily achieved, and the cruciate-retaining prosthesis provided satisfactory results with excellent functional outcomes.

Joint line elevation could increase the patellofemoral contact forces and contribute to postoperative complications, such as pain, polyethylene wear, and inferior clinical results.[24,26,39] Preventing joint line elevation of more than 8 mm during TKA was suggested by Figgie et al.[40] With more precise bony resection and soft tissue balancing, computer-assisted navigation TKA could prevent the use of a thick polyethylene spacer and decrease the risks of peroneal nerve neuropraxia and joint line elevation.[41,42] The joint line was not substantially elevated in our study, and no oversized polyethylene spacers were used. No patient in the current study was converted to a constrained component to achieve stability because of inadequate or extensive soft tissue releases.

The major limitations in this study must be acknowledged. First, the small number of patients with short-term follow-up occurred because of the relative rarity of type II genu valgus deformities in patients with arthritic knees. Second, the current study was a retrospective design; however, patients underwent computer-assisted navigation TKA by a single surgeon with the same protocol, which might diminish the bias. Additionally, only type II valgus deformities were enrolled in the current study, and patients with the severe type III deformities were not analyzed. Finally, no control group that underwent the conventional technique for TKA was included for comparison to demonstrate the advantages of computer-assisted navigation TKA in the treatment of the genu valgus deformity.

6. Conclusion

Computer-assisted navigation TKA provides a very effective alternative for the treatment of the arthritic knee with advanced genu valgus deformity where accurate restoration of the joint line, proper alignment of the limb and prosthetic components, and adequate soft tissue balancing may be challenging because of associated bony deformities and soft tissue contractures.

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