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Case Report

# Total Knee Arthroplasty with Concomitant Corrective Tibial Osteotomy Using Patient-Specific Instrumentation and Computed Tomography–Based Navigation in Severe Post–High Tibial Osteotomy Valgus Collapse

Koji Shibano, MD, PhD [a], Yasuo Kunugiza, MD, PhD [b, *], Kunihiko Kawashima, MD, PhD [c], Tetsuya Tomita, MD, PhD [d]

[a] Department of Orthopedics, Minoh City Hospital, Osaka, Japan
[b] Department of Orthopedics, JCHO Hoshigaoka Medical Center, Osaka, Japan
[c] Department of Orthopedics, Japanese Red Cross Society Himeji Hospital, Hyogo, Japan
[d] Department of Orthopedic Biomaterial Science, Osaka University Graduate School of Medicine, Osaka, Japan

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A B S T R A C T

We report the case of a 78-year-old woman with lateral knee osteoarthritis and severe valgus knee deformity after high tibial osteotomy. The patient's severe valgus tibial deformity with a valgus angle of 45° was evaluated using a 3-dimensional bone model, and a closing-wedge osteotomy was planned. Combined total knee arthroplasty and closing-wedge tibial osteotomy were performed using patient-specific instrumentation and a computed tomography–based navigation system. A semiconstrained total knee system with a long stem was implanted for fixation of the osteotomy site in the tibia. The patient was able to walk without pain 2 years postoperatively. The Knee Society Score improved from 13 to 73 points, and the functional score improved from 30 to 65 points. This preoperative planning method and the treatment procedure would be beneficial for clinical decision-making and treatment of severe valgus knee deformities.



## Introduction

A valgus knee deformity that occurs after high tibial osteotomy (HTO) has been reported to be difficult to treat because of shortening and contracture of the patellar ligament, malalignment, tibial deformity, and soft-tissue balance of the joint [1-4]. Tibial osteotomy has several complications such as vascular injury, compartment syndrome, and peroneal nerve palsy [5]. To treat this condition, it is imperative to obtain detailed preoperative information relating to the knee and tibial deformities; however, routine preoperative planning involving 2-dimensional plain radiographs is insufficient to understand the complex three-dimensional (3D) geometry of the deformity [6]. Recently, 3D evaluation using computed tomography (CT) has become popular [7,8] and has been applied for preoperative planning for the treatment of complex deformities [6,9-11].

There have been several reports published on the use of tibial osteotomy, total knee arthroplasty (TKA), or combined procedures for the treatment of valgus knee deformity [12-18]. In most cases, the valgus knee deformity angle has been reported to be less than 30°, with few reporting the treatment of deformity angles of greater than 30°. In this case, the valgus angle of the knee deformity was 45°, the intra-articular valgus deformity was 23°, and the extra-articular one was 22°. From several simulations of the operative procedure, we concluded that correction of the deformity by TKA or tibial osteotomy alone would be challenging because of the presence of severe intra- and extra-articular valgus deformities. The present article reports a case of severe progressive valgus knee deformity after HTO, with a mechanical femorotibial angle (FTA) of 135°, which was treated with combined TKA and tibial osteotomy using a patient-specific instrumentation (PSI) and CT-based navigation after thorough 3D preoperative planning.

* Corresponding author. Department of Orthopedics, JCHO Hoshigaoka Medical Center, Hoshigaoka 4-8-1, Hirakata City, 573-8511 Osaka, Japan. Tel.: +81 72 840 2641.

*E-mail address:* kunugiza-y@umin.ac.jp

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## Case history

A 78-year-old Japanese woman underwent primary bilateral HTO 15 years prior at an outside facility for medial osteoarthritis of both knees. After the procedure, the valgus deformity of the left knee developed and progressed gradually for more than 10 years with concomitant severe and progressive left knee pain. At the initial consultation, she was unable to walk without a cane. Her Knee Society Score [6] was 13 points, and the functional score [6] was 30 points. The range of motion in the left knee joint indicated a flexion arc of 60°-90°. Radiographic examination revealed osteoarthritis of the left lateral knee with severe valgus deformity. Measurements from the coronal radiograph revealed an intra-articular valgus deformity angle of 23°, an extra-articular valgus deformity angle of 22°, and an FTA of 135°; the mechanical axis passed 114 mm laterally from the intercondylar center (Fig. 1).

We initially planned TKA using the tibial component with an offset stem; however, the valgus deformity angle of the tibia was so severe that there was a risk of perforating the cortex of the tibia at the end of the tibial stem. Therefore, we decided to perform TKA with a concomitant tibial osteotomy.

The tibial valgus deformity was evaluated using 3D CT imaging with the original digital viewer (Orthopedic Viewer, Osaka University). We constructed 3D bone surface models of the entire femur and tibia, and the plan for 3D correction of the deformity was made using planning software (Bone Simulator; Orthree, Osaka, Japan). Because the contralateral tibia exhibited valgus deformity after HTO, we used tibial data from another patient whose body height and weight were similar to the patient. We matched the images of the proximal and distal parts of the tibia of the 2 patients. We also identified the midpoint of the medial and lateral eminences of the proximal tibia and the midpoint of the proximal tibia at the folding level. A line passing the 2 midpoints was set as the mechanical axis of the proximal part of the tibia. We also identified the midpoint of the tibia at the folding level and the center of the tibial articular surface of the ankle joint. A line passing these 2 points was set as the mechanical axis of the distal part of the tibia. We identified the point of intersection of the mechanical axis of the proximal and distal parts of the tibia and measured the angle between the axes. The planned amount of correction of the proximal tibia was 20°. The proximal plane of tibial osteotomy was perpendicular to the axis of the proximal tibia, and the distal plane of tibial osteotomy was perpendicular to the axis of the distal tibia. We simulated the closing-wedge osteotomy by setting the mechanical axis of the proximal and distal tibias to the same angle (Fig. 2).

It would be difficult to perform an accurate tibial osteotomy using the conventional procedure because of the extra-articular 3D deformity. To perform the osteotomy in precisely the same position as was preoperatively planned, a PSI and CT-based navigation system (OrthoMap 3D Navigation System; Stryker Navigation, Kalamazoo) were used. The PSI comprised a plastic model created by the rapid-prototyping technology, involving automatic construction of physical objects using computer data, which was generated using Eden250 (Objet Geometries, Rehovot, Israel) with medical-grade resin (Fig. 3a). We created the bone model and performed mock surgery using this PSI.

Open surgery was performed using the lateral parapatellar approach. We exposed the knee joint, dissected the soft tissue from the proximal part of the tibialis anterior muscle attachment, and placed the PSI on the surface of the proximal tibia (Fig. 3b). The CT-based navigation system was used to confirm the position and angle for the pinhole of the PSI (Fig. 3c). The planned oblique tibial osteotomy was performed using both the PSI and CT-based navigation system (Fig. 2a, white arrow), followed by distal tibial

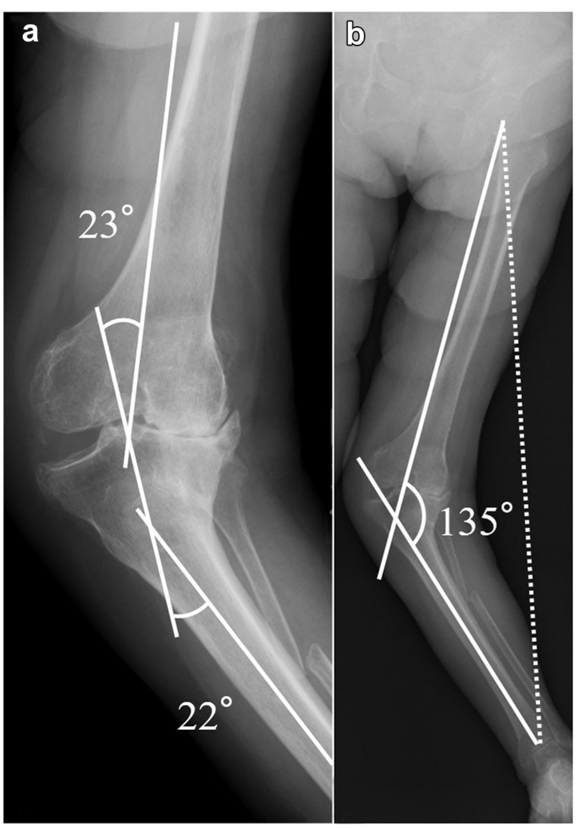


**Figure 1.** Preoperative radiographs of (a) the anteroposterior knee joint and (b) the lower extremity taken in the standing position. Radiographs show that the femorotibial angle is 135°, the intra-articular valgus deformity angle is 23°, and the extra-articular valgus deformity angle is 22° and that the dotted line is the mechanical axis.

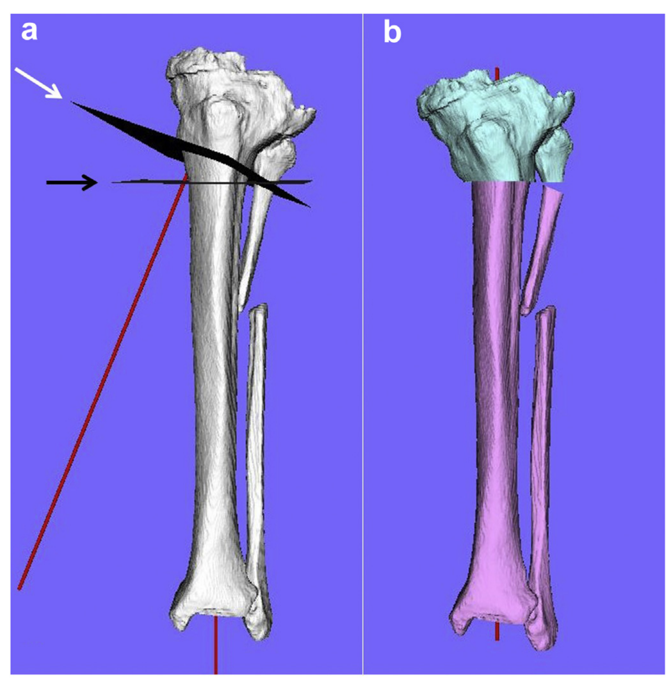


**Figure 2.** Diagrammatic representation of preoperative 3-dimensional planning for corrective tibial osteotomy. (a) The proximal part (white arrow) of the tibial osteotomy is parallel to the articular surface of the proximal tibia, and the distal part (black arrow) of the tibial osteotomy is perpendicular to the axis of the tibia. (b) We coordinated the axis of the proximal tibia with the axis of the distal tibia.

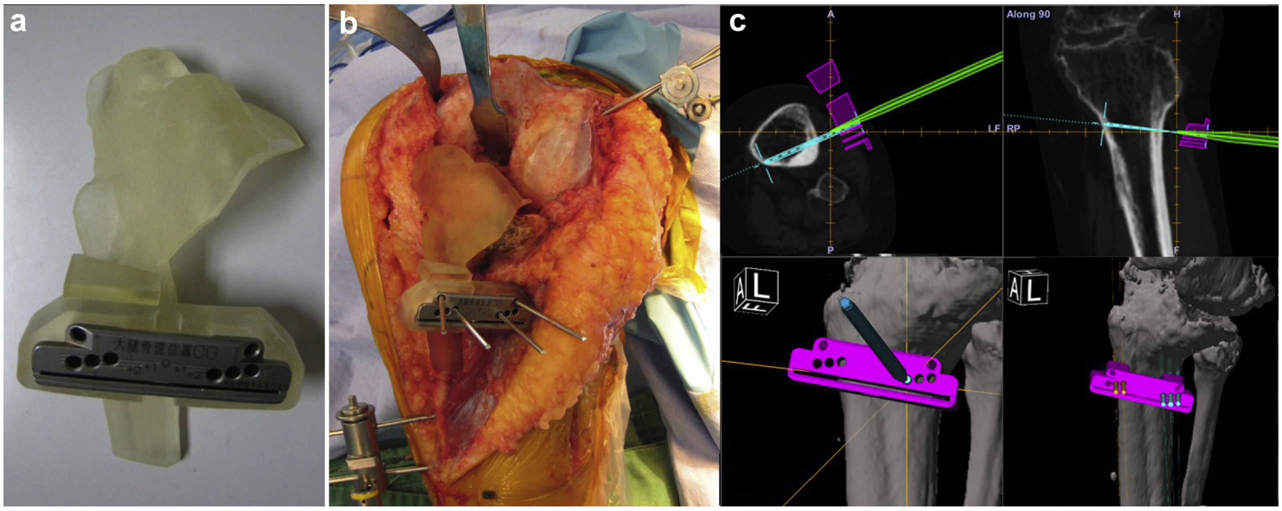


**Figure 3.** (a) A photograph of the patient-specific instrumentation (PSI). The instrumentation was manufactured as a plastic model with medical-grade resin. (b) Intraoperative photograph of the knee. We exposed the knee joint from the lateral approach and set the PSI. (c) Intraoperative images on the navigation system. The images show the entry point and direction of pinning to fix the PSI.

osteotomy using an intramedullary guide with the lowest point of the cutting surface as a reference (Fig. 2a, black arrow). After removal of a wedge-shaped bone fragment, we connected the proximal and distal tibias and performed the proximal tibial osteotomy for the total knee using the intramedullary guide. Subsequently, distal surface osteotomy of the femur was performed using the intramedullary guide, and 4-surface osteotomy was performed with the epicondylar axis as a reference. Finally, the tibial component with a press-fit stem was implanted by cementing just the surface of the tibial tray, and femoral component was implanted by cementing both the femoral component and stem (Scorpio total stabilizer system; Stryker, Kalamazoo). Postoperatively, the patient began partial weight-bearing with a knee brace 1 week after surgery; range-of-motion exercises and full weight-bearing commenced 2 weeks postoperatively. At 2 months postoperatively, the patient could walk with a T-cane, and the knee flexion arc improved from 60°-90° to 0°-90°. At 4 months postoperatively, callus formation of the tibial osteotomy site was observed; at 1 year postoperatively, bone union at the tibial osteotomy site was confirmed. At 2 years after the procedure, the flexion arc was maintained at 0°-90°, and the patient was able to walk without pain. At that point, the Knee Society Score had improved from 13 to 73 points and the functional score had improved from 30 to 65 points. The patient experienced no serious complications such as instability, compartment syndrome, or peroneal nerve palsy during the postoperative period. The FTA improved from 135° to 178°, and the mechanical axis passed through the intercondylar center (Fig. 4).

The Osaka University Hospital Ethics Committee audited and approved the study protocol. Informed consent for the procedure and publication of data was obtained and documented.

## Discussion

Various treatments have been reported for valgus knee deformity caused by intra-articular deformity including loss of cartilage and subchondral bone in the lateral knee joint. These include proximal tibial osteotomy, reported by Coventry [12] and Marti et al. [13], and TKA, reported by Fiddian et al. [14] and Elkus et al. [15]. In cases where both intra- and extra-articular deformities are present, Wang and Wang [16] and Windsor et al. [2] have reported the benefits of TKA, whereas Apostolopoulos et al [17] and Meehan et al. [18] reported the use of TKA combined with tibial osteotomy. Although most of these studies report good clinical results, the valgus deformity angle was less than 30° in the aforementioned studies. Few articles have reported treatment of severe valgus knee deformities with angles greater than 30°. The present study reports a case in which the valgus deformity angle of the knee deformity was 45° and occurred secondary to progression of knee osteoarthritis in the lateral compartment and overcorrection of the tibia after HTO.

To correct these deformities, we planned TKA combined with tibial osteotomy, that is, tibial osteotomy to treat the extra-articular deformity and TKA for the intra-articular deformity. Owing to difficulties in evaluating the deformity in detail and planning the surgery with 2-dimensional information, we simulated a 3D correction of the deformity using a computer model of the bones. A mirror image of the contralateral bone is typically used for simulation of the osteotomy [6,9]; however, in the present case, HTO of the contralateral tibia had been performed previously, meaning a mirror image was not suitable. Therefore, after obtaining informed consent, we used the data of a tibia from another patient of similar body height and weight.

Corrective osteotomy of the upper extremity using PSI has been reported to result in accurate correction based on 3D data [6,9,10]. The use of PSI in TKA has also been reported to produce favorable results in terms of restoration of mechanical alignment [19]. However, other studies have reported unfavorable results [20]. In one report, alignment of the femoral and tibial components after surgery using PSI assessed by computer navigation did not match the preoperative plan in a proportion of cases [21]. One study on femoral component positioning in total hip arthroplasty found that a CT-based navigation system with PSI was more accurate and consistent than the conventional technique for assessing anteversion of the femoral stem [22]. A CT-based navigation system can provide real-time feedback about intraoperative stem position during surgery [22]. In our case, we suppose that one factor contributing to the successful tibial osteotomy consistent with preoperative planning was a PSI and CT-based navigation system.

Compartment syndrome and peroneal nerve palsy are among the reported severe complications that develop in patients with valgus deformity who undergo tibial osteotomy or TKA [23,24]. There were no complications from the surgery in our case.

The preoperative planning of the present case led us to create a 3D bone model and plan closing-wedge tibial osteotomy to

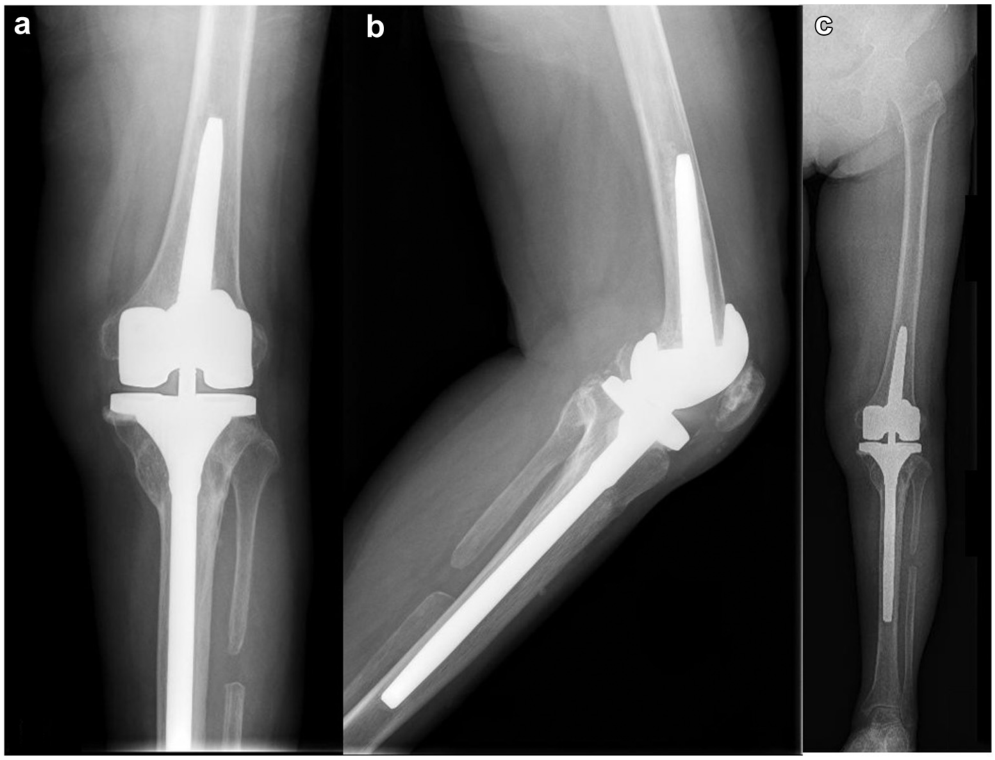


**Figure 4.** The radiographs of (a) the anteroposterior and (b) lateral knee joint and (c) lower extremity in the standing position taken 2 y after the operation. These radiographs show improvement in the femorotibial angle from 135° preoperatively to 178°.

evaluate the severe valgus tibial deformity. Based on this 3D planning, we performed TKA and tibial osteotomy using a PSI and a CT-based navigation system intraoperatively and achieved good patient outcomes. To the best of our knowledge, this is the first case involving TKA and tibial osteotomy performed using a PSI and CT-based navigation system. These 3D methods and surgical techniques would be beneficial for clinical decision-making and treatment of a severe valgus knee deformity.

## Summary

We describe the use of combined TKA and tibial osteotomy for the treatment of severe valgus tibial deformity. We achieved accurate osteotomy through preoperative planning and perioperative use of a PSI and CT-based navigation system; hence, the symptom and function of the knee were well improved. These 3D methods and surgical techniques would be beneficial for clinical decision-making and treatment of severe valgus knee deformities.

## Conflict of interests

The authors declare there are no conflicts of interest.

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