Computer-assisted High Tibial Osteotomy: Preliminary Results

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Open-wedge high tibial osteotomy (HTO) is an established technique for the treatment of symptomatic varus malaligned knees. In this study, we prospectively followed up 13 patients (14 knees) who underwent navigation system–supported HTO for varus knee deformity. Preoperatively all patients underwent a physical examination, and anteroposterior and laterolateral lower limb weight-bearing digital radiographs were obtained. The following parameters were examined: (1) Insall-Salvati index; (2) posterior tibial slope angle; (3) mechanical femorotibial angle; (4) inferior limb length. At a mean follow-up of 12.6 months, clinical examination showed satisfactory results in all patients. The mean Modified Cincinnati Rating System Questionnaire rating increased significantly from 46.5±7.2 to 84.6±8, while the mean Knee Society Score increased significantly from 51.4±9.9 to 85.1±7.3. The mean Insall-Salvati index changed from 1.11 preoperatively to 1.10 postoperatively (P=.742). According to the navigation system data, the femorotibial mechanical axis was corrected from a varus of 6.3°±1.9° to a valgus of 2.1°±1.6°. These data matched postoperative radiographic lower limb weight-bearing data. In the group of patients in whom we evaluated the posterior tibial slope with the navigation system, we detected an increase of 0.3°±0.4° compared with the preoperative radiographic examination evaluations; the comparison between the postoperative and the preoperative radiographic examination results showed an increase of 0.5°±0.7° (P=.87). The results of our study seem to show greater accuracy of mechanical axis correction and smaller increase in tibial slope when a navigation system is used in open-wedge HTO.

Traditional intraoperative measurement techniques have shown both intraobserver variability and low reproducibility, even when considering only the coronal plane. Consequently, conventional HTO techniques have demonstrated high variability with regard to postoperative alignment. This may be due to imprecise preoperative planning, inaccurate wedge cuts, or poor control of intraoperative realignment. In addition, multiplanar deformity may be present and can be either undercorrected or overcorrected during the procedure. Therefore, inaccurate coronal plane and inadvertent sagittal plane realignment is a common problem after HTOs.

Recently, HTO computer-assisted techniques were shown to be capable of accurately measuring leg alignment intraoperatively with especially high precision in the coronal plane.
In addition to potential coronal alignment corrections, HTO corrections can also be used to alter the tibial slope. This can influence the tension of both cruciate ligaments depending on whether the slope is increased or decreased.

The aim of this study was to evaluate the accuracy of the navigation system and the short-term clinical and radiologic follow-up results in patients undergoing open-wedge HTO.

**Materials and Methods**

We prospectively followed up 13 patients (14 knees) affected by varus knee deformity and medial unicompartmental osteoarthritis who underwent surgical treatment with open-wedge HTO aided by use of a navigation system (OrthoPi- lot; B. Braun Aesculap, Tuttlingen, Germany). Diagnosis was made in all cases by clinical examination and radiographic examination.

The study participants were 7 men and 6 women with a mean age of 56.5±6.2 years (range, 40-62 years). The right knee was involved in 10 cases and the left knee in 4 cases.

The inclusion criteria to enter this study were (1) age younger than 65 years, (2) grade 3 or lower score on Kellgren radiographic scale (symptomatic isolated medial knee compartment osteoarthritis), (3) failed conservative treatment, and (4) absence of additional procedures to the cartilage (autologous chondrocyte transplantation, microfractures) on the affected limb.

All patients underwent a preoperative physical examination in which inferior limb alignment (side-to-side; S/S), range of motion (ROM) S/S, and knee stability were evaluated and recorded. Moreover, patients underwent the Modified Cincinnati Rating System Questionnaire, the Knee Society Score (KSS), and the Visual Analog Scale score (VAS; 0-10 scale, 0-100 no pain).

In all cases, preoperative radiologic evaluation of the knee consisted of a standard digital anteroposterior (AP) view, a standard laterolateral (LL) view, and a Rosenberg view.

In addition, preoperative comparative lower limb weight-bearing digital radiographs (AP with extended knee and LL views) were obtained. The following parameters were examined: (1) Insall-Salvati index (to determine patellar height); (2) posterior tibial slope angle (angle between the line perpendicular to the line passing tangentially to the posterior tibial cortex and the slope of the tibial plateau); (3) preoperative mechanical femorotibial angle (mFTA); (4) inferior limb length.

All radiographic evaluations were performed by a single independent blinded expert radiologist.

**Surgical Technique**

All patients underwent medial open-wedge HTO by the same surgeon.

The kinematics-based, image-free navigation system with HTO software version 1.4 (3D Open-wedge; B. Braun Aesculap, Tuttlingen, Germany) was used for all patients. The transmitters were fixed on the distal femur and on the proximal tibia (tibial shaft) with a bi- cortical screw (Figure 1). To determine the mechanical leg axis, kinematic data for hip, ankle, and knee joints were included. Anatomic landmarks, such as the medial epicondyle, lateral epicondyle, medial malleolus, lateral malleolus, central point of the ankle, and medial point of the tibial plateau were registered with a pointer. For 3D HTO navigation, in 6 patients, an additional transmitter was fixed on the proximal third of the tibia with a 2.5-mm K-wire to monitor the tibial slope (Figure 2). The initial position of the proximal tibia was also registered. Once the registration was done, the mechanical leg axis was visualized continuously. A standard longitudinal incision was made medial to the patellar tendon to expose the proximal and medial tibia subperiosteally. The osteotomy began approximately 3 cm distal to the medi- al joint line at the medial cortex of the proximal tibia and was just proximal to the tibial tubercle, leaving 5 to 10 mm of the lateral tibial cortex intact. By monitoring the mechanical leg axis and change of the tibial slope through navigation, the osteotomy was stabilized using a plate (Position HTO Plate; B. Braun Aesculap, Tuttlingen, Germany) with a rectangular spacer block varying in size according to the degree of correction.

The plate was placed at the center of the medial cortex of the proximal tibia. Dehydrated bovine wedge was used in all patients (Figure 3). In 6 patients, we also used nano-hydroxyapatite.

During the procedure, intraoperative mFTA and tibial slope computer data were recorded and compared with the radiologic preoperative evaluation.
Postoperative Rehabilitation

Patients wore a brace for the first 2 postoperative weeks with the knee locked in full extension. Isometric quadriceps strengthening exercises were allowed from the second postoperative day. After the first 2 weeks, the brace was unlocked and passive and active exercises to recover a complete ROM were encouraged. Patients were prohibited to fully bear weight until the 6th to 8th postoperative week. Partial progressive weight-bearing was allowed only after the 5th postoperative week.

Statistical Analysis

The Student t test and analysis of variance (ANOVA) were used to analyze the data for the patients in this series. For power analysis, the alpha error was fixed at 5% (confidence interval, 95%) and the level of significance was P<.05. Statistical evaluation was done using SPSS for Microsoft Windows 7.0 (SPSS, Inc., Chicago, Illinois).

Follow-up Evaluation

We followed up with all 13 patients (14 knees) at a mean of 12.6 months (range, 5-35 months). Patients underwent a physical examination in which inferior limb alignment, knee ROM, and knee stability (S/S) were evaluated once again. Moreover, new ratings were established using the Modified Cincinnati Rating System Questionnaire and the KSS.

New lower limb weight-bearing digital AP and LL radiographs were obtained for comparison, and data regarding the postoperative patellar height, mFTA, and the tibial slope were recorded and compared with both the preoperative radiographic images and the data collected by the navigator intraoperatively.

RESULTS

Clinical examination showed satisfactory results in all 13 patients. All patients reported a significant improvement of the painful symptoms, with a mean VAS score raised from 4 (range, 3-6) to 8 (range, 8-10). Postoperative ROM was complete in all cases, both in flexion and extension. The Modified Cincinnati Rating System Questionnaire rating increased significantly from 46.5±7.2 (range, 35-58) to 84.6±8 (range, 69-96) (P=.008), while the KSS increased significantly from 51.4±9.9 (range, 40-67) to 85.1±7.3 (range, 71-95) (P=.002).

According to Kellgren scores, 7 knees were grade 2 (50%) and 7 were grade 3 (50%).

The mean Insall-Salvati index changed from 1.11 preoperatively (range, 1.02-1.31) to 1.10 postoperatively (range, 0.70-1.40); statistical analysis showed no significant differences regarding the effect of the HTO on the patellar height (P=.742).

After open-wedge HTO, according to the navigation system data, the femorotibial mechanical axis was corrected from a varus of 6.3°±1.9° (range, 4°-9°) to a valgus of 2.1°±1.6° (range, 0°-5°); therefore, femorotibial mechanical axis was corrected to valgus of 8.5°±0.3° (range, 7°-11°). According to the data obtained by the lower limb weight-bearing radiographs in the coronal plane, mFTA was corrected from a varus of 6.8°±3.3° (range, 3°-13°) to a valgus of 3.3°±1.7° (range, 1.5°-6.2°). No statistically significant difference was found in the coronal plane between the angle results detected in the navigation data and the radiographs (P=.99).

In patients in whom the posterior tibial slope was evaluated with the navigation system, we detected an increase of 0.3°±0.4° (range, 0°-1°) compared with preoperative radiographic examination evaluations. The comparison between the postoperative and the preoperative radiographic examination results showed an increase of 0.5°±0.7° (range, 0°-1.8°). No statistically significant differences were found in the posterior tibial slope angle between the navigation data and the radiologic results (P=.87).

On the contrary, in patients in whom the tibial slope was not evaluated with the navigation system, we found a mean increase of the slope of 2.8°±3.3° (range, 0°-7°); these data were obtained by comparing preoperative and postoperative radiographic examinations. In this group of patients, a statistically significant increase in the posterior tibial slope was detected at follow-up (P=.03).

No significant lower limb lengthening was found at the final follow-up.

The mean operating time was 78.9±15.9 minutes, including 20 minutes used for acquisition of the anatomic landmarks and digital parameters.

No intraoperative, perioperative, or postoperative complications, such as loss of valgus correction, bone fractures, or metallic plate failures, were detected at follow-up.

DISCUSSION

HTO is a reliable surgical technique for the treatment of symptomatic varus malaligned knees.1-3 The entity of the correction of the malalignment is the keypoint for a long-term successful treatment: it is well documented how even a small alteration of the mechanical axis may change the load distribution of the knee, leading to long-term unsatisfactory results.8,27 Hankemeier et al,9,13 as well as Keppler et al,14 recently showed in cadavers and in vivo
how traditional intraoperative measurement techniques often provide high intraobserver variability and low reproducibility. Moreover, undercorrection or overcorrection of the varus deformity might lead to alteration of the normal limb alignment, not only on the coronal plane, which is the only plane that can be corrected with traditional techniques, but also in the sagittal plane, altering the normal tibial slope. Giffin et al\textsuperscript{20} have demonstrated the effects of altering the normal tibial slope on the biomechanics of the knee, showing how an increase of the slope facilitates the anterior translation and subluxation of the tibia in a posterior cruciate ligament–deficient knee. Navigation systems are of increasing importance in the orthopedic field.\textsuperscript{28,30} They are already successfully used in total knee arthroplasty operations because of the high reliability they provide in terms of alignment of the prosthesis components in the 3 planes.\textsuperscript{30,33} Koshino et al\textsuperscript{34} in a 15- to 28-year follow-up study of patients treated with high tibial valgus osteotomy, showed that the survival rates of the operation diminish with time, ranging from 73\% to 97\% at 5 years, 51\% to 96\% at 10 years, and 39\% to 87\% at 15 years.\textsuperscript{35,36} Lower limb alignment and level and orientation of the osteotomy seem to be crucial for a positive long-term follow-up of the treatment. The conventional estimation of about 1\textdegree of correction for each millimeter of bone wedge removed is an oversimplification. Although fluoroscopic control is used to increase accuracy, a long leg radiograph for measuring the exact leg alignment is difficult to obtain intraoperatively. Similarly, the Fujisawa intersection method is difficult to apply and is subject to individual variability of the surgeon’s ability.\textsuperscript{2} The only factor that can be controlled intraoperatively is knee alignment, which entails a moderate over-correction of 2\textdegree to 6\textdegree in the frontal plane.\textsuperscript{11,35} However, as stated earlier, correction of the normal alignment of the lower limb on the coronal plane is not the only focus of attention on during such types of operations. Indeed, HTO may unintentionally change the tibial slope in the sagittal plane,\textsuperscript{37,40} thus altering the tension of the anterior and posterior cruciate ligaments, and consequently altering the normal biomechanics of the knee.

Navigation has been shown to be accurate in determining the coronal leg alignment during HTO and in determining the tibial slope.\textsuperscript{13} Navigation techniques provided valuable information during the actual HTO procedure, allowing greater control of the dynamic valgisation process, intraoperatively, thus allowing the surgeon to obtain the degree of valgus desired.

The first aspect we focused our attention on was the accuracy of the mechanical axis and tibial slope detected through the use of the navigation system, as well as the values detected at the preoperative radiologic evaluation on the lower limb radiographic images. We found a satisfactory reliability of the angles measured, which had been assumed in order to validate the use of such type of surgical technique.

The results of this study show a very high accuracy from the use of the navigation system, both in terms of continuous intraoperative visualization of the corrections performed and in terms of the results obtained from the immediate postoperative follow-up and at the final follow-up. Through the use of such type of surgery, we were able to calculate the corrections performed not only in the coronal plane, but also in the sagittal plane, allowing us to focus on the final alignment of the inferior limb in terms of both mechanical axis (with the coronal plane valgus correction desired) and final tibial slope. In our study, we found a smaller increase of the posterior tibial slope in the group of patients in whom we navigated this parameter than in the patients in whom this parameter was not considered. The use of the tracker pin fixed on the proximal third of the tibia indeed helped us to perform a corrective osteotomy directed from the medial to the lateral side, rather than, as often happens, from the anteromedial to the posterolateral aspect of the tibia.

Similarly, the use of the navigation system has provided a satisfactory result in terms of limb lengthening, in that we did not detect a significant increase in the affected limb.

Drawbacks of this study are represented by the small number of patients treated (13 patients and 14 knees) and by the short follow-up (12.6 months).

CONCLUSIONS

From the preliminary results of our study, there seems to be great accuracy with the use of the navigation system in patients treated for varus knee deformity with HTO, both in terms of mechanical axis correction and especially in terms of preventing an increase of the tibial slope.

REFERENCES

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