Open-wedge high tibial osteotomy: comparison between manual and computer-assisted techniques

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Abstract

Purpose The purpose of our study was to compare clinical and radiological results of two groups of patients treated for medial compartment osteoarthritis of the knee with either conventional or computer-assisted open-wedge high tibial osteotomy (HTO). Goals of surgical treatment were a correction of the mechanical axis between 2° and 6° of valgus and a modification of posterior tibial slope between −2° and +2°.

Methods Twenty-four patients (27 knees) affected by varus knee deformity and operated with HTO were prospectively followed-up. They were randomly divided in two groups, A (11 patients, conventional treatment) and B (13 patients, navigated treatment). The American Knee Society Score and the Modified Cincinnati Rating System Questionnaire were used for clinical assessment. All patients were radiologically evaluated with a comparative lower limb weight-bearing digital radiograph, a standard digital anteroposterior, a latero-lateral radiograph of the knee, and a Rosenberg view.

Results Patients were followed-up at a mean of 39 months. Clinical evaluation showed no statistical difference (n.s.) between the two groups. Radiological results showed an 86% reproducibility in achieving a mechanical axis of 182°–186° in group B compared to a 23% in group A ($p = 0.0392$); furthermore, in group B, we achieved a modification of posterior tibial slope between −2° and +2°

in 100% of patients, while in group A, this goal was achieved only in 24% of cases ($p = 0.0021$).

Conclusion High tibial osteotomy with navigator is more accurate and reproducible in the correction of the deformity compared to standard technique.

Level of evidence Therapeutic study, Level II.

Keywords Open-wedge high tibial osteotomy · mFTA · Tibial slope · Computer-assisted technique

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Introduction

High tibial osteotomy (HTO) is a common procedure for the treatment for symptomatic varus malaligned knees [6, 11, 19, 27, 52]. It provides good pain relief and restoration of function [8, 19, 24, 25, 32, 39, 42, 43, 46, 49, 55]. Traditional intraoperative measurement technique has frequently shown both intraobserver variability and low reproducibility, even when considering the coronal plane alone [17, 18, 31]. Consequently, conventional high tibial osteotomy technique has demonstrated quite a high variability with regard to postoperative alignment. This may be due to imprecise preoperative planning, inaccurate wedge cuts, or poor control of intraoperative realignment [16, 30]. In addition, multi-planar deformity may be present and can be either under or overcorrected during the procedure.

High tibial osteotomy provides the best results when it is well indicated and the planned correction is reproduced [8, 19, 32, 37, 46, 48]. Normally, surgeons plan an overcorrection into valgus of 3°–6°, giving a mechanical axis (center femoral head through center of tibial spines to center of the ankle) of 183°–186° [19, 37, 48].

HTO may inadvertently change the tibial slope in the sagittal plane [4, 9, 28], thus altering the tension of the

anterior and posterior cruciate ligaments as well as the biomechanical environment inside the knee joint. In fact, an increase in tibial slope enhances anterior–posterior instability of the knee [1, 5, 14, 15, 28, 30, 36] and leads to an increase in contact pressure in the posterior femoro-tibial compartment in the case of ACL deficiency [1, 5, 14, 15, 28, 36, 38, 47].

Navigation, therefore, could become an important device for intraoperative control, and early literature reported encouraging results [40, 41]. Recently, HTO computer-assisted technique was shown to be capable of accurately measuring leg alignment intraoperatively with especially high precision in the coronal plane [2, 18, 30, 51, 53, 54].

The purpose of this study was to compare short-term clinical and radiological results between two groups of patients treated by HTO with either standard or navigated technique to assess whether we obtained a postoperative mechanical axis between 2° and 6° valgus and an increase or decrease in posterior tibial slope between −2° and +2°.

The null hypothesis in our study was that the use of a navigation system would have provided a better radiological accuracy in intra- and postoperative lower limb alignment than conventional technique.

Materials and methods

In this study, 24 patients (27 knees) affected by symptomatic medial compartment osteoarthritis of the knee with varus deformity were operated with HTO and followed-up at a median of 39 months (range: 12–72). Inclusion criteria for surgical treatment reflected the directions outlined in literature for this procedure: (1) age <65 years, (2) grade III or lower radiograph Kellgren-Lawrence symptomatic isolated medial knee compartment osteoarthritis, (3) failed conservative treatment, (4) absence of additional cartilaginous procedures (autologous chondrocyte transplantation, microfractures), and (5) concomitant ligamentous lesions. The surgical technique used was the same for all patients.

Group A included 11 patients (13 knees) with varus knee deformity, surgically treated with open-wedge high tibial osteotomy without navigation system: there were 7 men (63.6%) and 4 women (36.3%), aged between 38 and 67 years (median age: 54.8 years). According to the comparative lower limb weight-bearing digital radiograph, the median preoperative varus angle was 5.6° ± 1.9° (range: 3°–9.5°).

In group B, the same procedure was performed with the aid of a navigation system (OrthoPilot; B. Braun Aesculap, Tuttlingen, Germany), and 13 patients (14 knees) were prospectively followed-up. There were seven men and six women with an age of 56.5 ± 6.2 years (range: 40–62 years). The right knee was involved in ten cases and the left knee in four cases. According to the comparative

lower limb weight-bearing digital radiograph, the median preoperative varus angle was 6.8° ± 3.3° (range: 3°–13°).

High tibial osteotomy was performed using an opening wedge medial high tibial osteotomy with a dehydrated equine wedge (Ostoplant, Bioteck, Italy) and a Puddu-like plate (B. Braun Aesculap, Tuttlingen, Germany) for fixation. For each of the two groups, a preoperative plane was made on the radiographs that included drawings of the axis, the required hypercorrection, and the opening wedge to provide a 2°–6° valgus or 182°–186° mechanical axis (hip–knee–ankle angle).

The perioperative control of correction was evaluated differently between the two groups. In group A, a cardiac electrode was placed on the skin in the center of the femoral head. Under image intensifier guidance, a suture was set from this electrode along the length of the lower limb to the medial malleolus, passing through the center of the knee. In group B, correction was evaluated using the OrthoPilot. All patients had a follow-up radiograph at 3 months with the same protocol used for preoperative evaluation of the goniometry.

At follow-up, patients underwent physical examination in which they were accurately evaluated and they were recorded for inferior limb alignment (side to side; S/S), range of motion (S/S), and knee stability. Two questionnaires were also administered—the American Knee Society Score and the Modified Cincinnati Rating System Questionnaire—and used the Visual Analog Scale Score (VAS: 0-unbearable pain and 10-no pain).

Both preoperatively and postoperatively, weight-bearing full-length AP radiographs were performed in the lower limbs under load, and AP radiographs and LL Rosenberg view of the knee were used to assess the following parameters: (1) alignment of the lower limb (by defining the femoral mechanical axis and diaphyseal axis of the tibia; in fact, the angle (mFTA) that has been generated by intersection of these two lines expresses the degree of angular deformity); (2) proximal medial tibia angle (mMPTA); (3) lateral distal femoral angle (mLDFA); (4) the posterior tibial slope (was determined as the angle between the line perpendicular to the line passing tangentially to the posterior tibial cortex) and the slope of the tibial plateau (by using the Brazier and associates method); (5) The Insall–Salvati index to evaluate the height of the patella; and (6) inferior limb length.

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

Surgical technique

All patients underwent medial open-wedge high tibial osteotomy by the same surgeon.

Fig. 1 Femoral and tibial transmitters used to calculate mechanical leg axis and acquisition kinematic knee joint data

A kinematics-based image-free navigation system (OrthoPilot; B. Braun Aesculap, Tuttlingen, Germany) with HTO software version 1.4 (3D Open-wedge; B. Braun Aesculap) was used for 13 patients (14 knees). The transmitters were fixed on the distal femur and on the distal tibia (tibial shaft) with a bicortical screw on the lateral side. To determine the mechanical leg axis, kinematic data including hip, ankle, and knee joints were registered (Fig. 1). 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 six patients, an additional transmitter was fixed on the proximal third of the tibia with 2.5-mm k-wire to monitor the tibial slope (Fig. 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 subperiosteal. The osteotomy began approximately 3 cm distal to the medial 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 changing the tibial slope with the use of a 3D navigator, the osteotomy was

Fig. 2 Additional proximal tibial transmitter used to monitor tibial slope
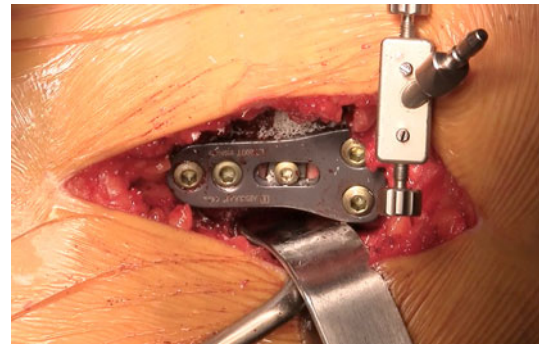
Fig. 3 Dehydrated bovine wedge and metallic plate used to fill up the bone gap and to stabilize the osteotomy

stabilized using a plate (POSITION HTO Plate; B. Braun Aesculap) with a rectangular spacer block varying in size according to the degree of correction.

The plate was placed in a more anterior or posterior position according to the correction desired. Dehydrated equine wedge was used in all patients (Fig. 3).

Postoperative rehabilitation

Patients wore a brace for the first two 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 the patient began passive and active exercises to recover complete range of motion (ROM). Patients were prohibited to fully weight-bear until the 8th postoperative week. Partial progressive weight-bearing was allowed only after the fifth postop week.

Statistical analysis

The Student's 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% (CI 95%) and the level of significance was $p < 0.05$. Statistical evaluation was done using SPSS for Microsoft Windows 7.0 (SPSS, Inc., Chicago, Illinois).

Results

Clinical evaluations showed satisfactory results in all the patients with no statistically differences between group A and group B (Table 1).

Postoperative range of motion was complete both in flexion and in extension in all cases.

Table 1 Pre- and postoperative clinical results of both groups

Clinical results (p = n.s.)	Group A		Group B	
	Preop.	Postop.	Preop.	Postop.
Visual Analog Scale	3	7	4	8
	(Range 1–6)	(Range 5–9)	(Range 3–6)	(Range 8–10)
American Knee Society Score	54.7 ± 11.8	79.4 ± 6.2	51.4 ± 9.9	85.1 ± 7.3
	(Range 40–70)	(Range 71–89)	(Range 40–67)	(Range 71–95)
Modified Cincinnati Rating System Questionnaire	46.1 ± 7.9	67.7 ± 13.3	46.5 ± 7.2	84.6 ± 8
	(Range 36–65)	(Range 44–88)	(Range 35–58)	(Range 69–96)

The mean Insall–Salvati index changed from 1.1 preoperatively (range: 0.9–1.3) to 1.1 postoperatively (range: 0.8–1.3) in group A and from 51.4 ± 9.9 (range: 40–67) to 85.1 ± 7.3 (range: 71–95) in group B: even in this case, no significant differences were detected between two groups (n.s.).

Radiological results showed an 86% reproducibility in achieving a mechanical axis of 182°–186° in group B and a 23% reproducibility in group A ($p = 0.0392$) (Fig. 4).

According to the data obtained by the lower limb weight-bearing X-ray images on the coronal plane, the mean proximal medial tibia angle (mMPTA) index changed from 89.1 ± 1.7 preoperatively (range: 86–92) to 90.1 ± 1.9 postoperatively (range: 88–94) ($p = 0.014$) in group A and from 86.8 ± 2.5 preoperatively (range: 82–90) to 90.4 ± 3.2 postoperatively (range: 84–93) ($p = 0.003$) in group B.

The mean lateral distal femoral angle (mLDFA) index changed from 88.8 ± 1.0 preoperatively (range: 87–90) to 89.3 ± 1.2 postoperatively (range: 87–91) (n.s.) in group A and from 89.5 ± 2.6 preoperatively (range: 85–96) to 89.7 ± 2.4 postoperatively (range: 86–95) (n.s.) in group B.

Statistical analysis showed significant differences between the two groups regarding mMPTA (n.s.), but not regarding the mLDFA index (n.s.).

The posterior tibial slope showed a significant modification ($p = 0.0021$) in patients in whom the navigation system was not used. We found a mean increase in the slope of $2.8° \pm 1.6°$.

The goal of this study is to obtain a modification of the tibial slope within 2°: this goal was achieved in 6 patients of group B (100%) and only in 5 patients of group A (24%) ($p < 0.003$) (Fig. 5).

Lower limb lengthening was no statistically significant between the two groups (n.s.).

Operative time was 23 min shorter after the conventional open-wedge high tibial osteotomy ($p < 0.001$).

As for complications, a broken screw was observed in two patients of group A. One of them reported pain and required the removal of such a screw, which led to symptoms resolution. In the second patient, no pain was reported; therefore, we decided not to operate on him.

Results of the study confirmed the null hypothesis.

Fig. 4 Radiological results of both groups of patients. Postoperative mechanical axis (°)
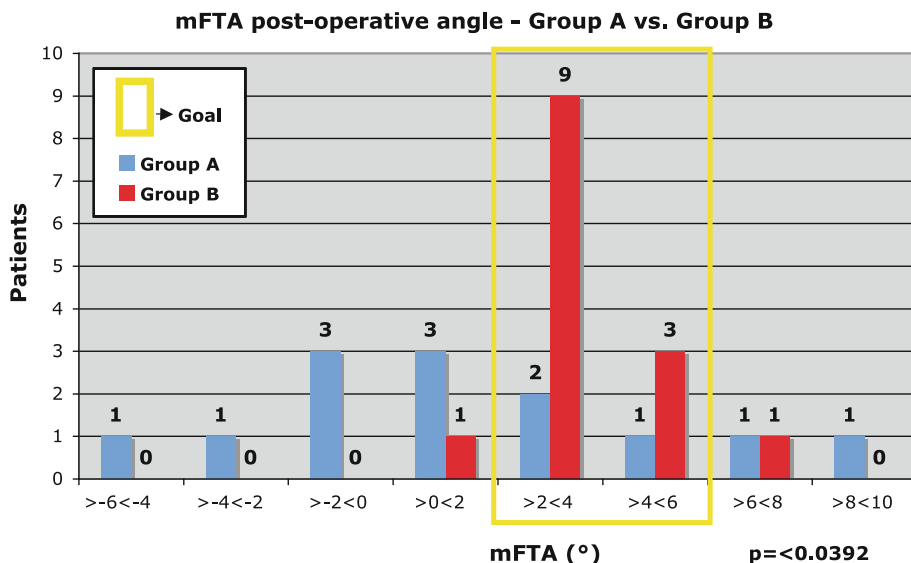
Fig. 5 Variation (°) of tibial slope. Postoperative radiological results
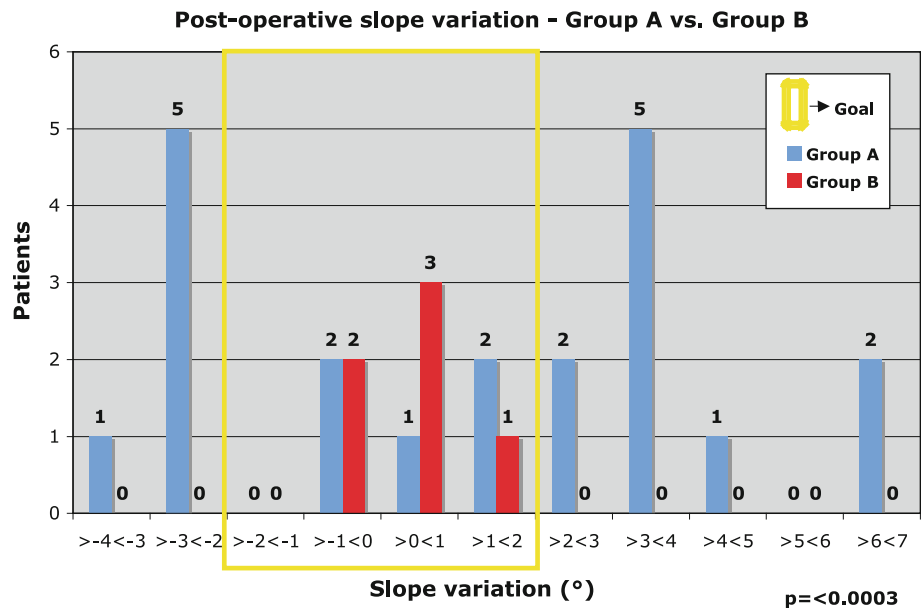
Discussion

The most important finding of the present study was the accuracy and reliability provided by the use of the navigation system in the correction of the deformity in the coronal and sagittal plane.

The amount of the correction of the malalignment is the key point for a long-term successful treatment: it is well documented in literature how even a small alteration of the mechanical axis may change the load distribution of the knee, bearing a significant cause of early degenerative changes and dysfunction and leading to long-term unsatisfactory results [21, 50].

More commonly, under- or overcorrections are due to insufficient intraoperative visualization of the mechanical axis. A crucial factor is represented by the preoperative X-ray films that give the size of the wedge to add. In order to achieve this goal, some surgeons use accurate angular cutting guides [3], while others try to get the most accurate preoperative X-ray films for the angle of resection or the opening angle [34]. Some others evaluate the correction intraoperatively with a suture wire or metal rod that is set from the center of the femoral head to the ankle and passes through the middle of the knee [34].

The navigation system has shown to be an excellent device for intraoperative control of the amount of correction achieved [22, 50].

There is considerable controversy regarding the ideal valgus correction angle. For many authors, a hypercorrection of at least 3°–6° is required for good results [19, 37, 55]. Insall et al. [23] reported that a postoperative valgus position ranging from 5° to 14° was acceptable. Coventry and Bowman recommended that an overcorrection of a normal 5° of anatomical valgus improves the long-term results [7].

No publication has evaluated methods of achieving hypercorrection, even though hypercorrection has a significant effect on the result of the osteotomy. In our study, we decided to define as a goal of correction a postoperative mechanical axis between 2° and 6° valgus. Currently, with this hypercorrection, all patients of both groups showed satisfactory clinical results even though the goal of the range we decided to achieve was achieved in the vast majority of the cases in the navigated group (86%) than in group A (23%), where the mean correction was 7.2° ± 3.9°. However, only a longer follow-up will determine whether the correction achieved will lead to the appearance of new symptoms.

The tibial slope is another important parameter that influences the knee biomechanics. The proximal antero-medial tibial cortex has an oblique or triangular shape when viewed in cross-section, whereas the lateral tibial cortex is almost perpendicular to the posterior margin of the tibia. Because of this configuration, an open-wedge osteotomy with an anterior tibial tubercle gap equal to the gap at the posteromedial crest would increase the tibial slope, alter the femoro-tibial contact point, decrease the knee extension, and potentially increase the ACL tensile load [10, 38, 44]. The variation of tibial slope after conventional procedure varies in the literature according to the authors. Chae et al. [5] found results with no significant changes in tibial slope. In contrast, Marti et al. [38] and recently Jung et al. [28] reported an alteration of tibial slope with an increase of about 3°, whereas Lerat et al. [35] showed for the same procedure a decrease of 0.6° in tibial slope. Brouwer et al. [4] have showed HTO may

inadvertently change the tibial slope in the sagittal plane. Giffin et al. [13] demonstrated the effects of altering the normal tibial slope on the biomechanics of the knee: they showed how an increase in the slope facilitates the anterior translation and subluxation of the tibia in a PCL deficient knee.

Conventional open-wedge HTO has been associated with increased posterior tibial slope. When the wedge is placed too anteriorly, the posterior tibial slope increases and vice versa.

Some authors have proposed few techniques to prevent the tibial slope modification [20, 26].

A navigation system allows continuous visualization not only of the frontal but also of the sagittal and transverse axes and detects undesired changes of the tibial slope during the correction [9, 38], which influence knee kinematics and stability [1, 27, 38].

In consideration of the absence in the literature of uniform results concerning the variation of posterior tibial slope after HTO, in this study, we thought that a postoperative increase or decrease in the posterior tibial slope within 2° could be considered satisfactory.

As well as for the coronal alignment, in our study, patients operated on with the use of the navigation system showed a modification of the tibial slope within the 2° desired in all the patients. On the contrary, the vast majority of patients treated with the conventional technique obtained a mean variation of the tibial slope of 2.8° ± 1.6°.

A limitation we found in many studies present in literature was that the reported deviations from the planned leg axis were partially influenced by the fact that intraoperatively the final leg axis was evaluated on the resting leg, whereas the postoperative X-ray control is done on the weight-bearing leg, which automatically means 1° or 2° of difference. In addition, the long-standing X-rays may give an error up to 2° depending on full knee extension and inward/outward orientation of the leg. To reduce this additional error, all long-standing X-rays have been analyzed for these technical aspects as well [12].

Also, weight-bearing full-length radiographs present the current gold standard for measuring lower extremity deformities [44].

Limitations of this study are certainly represented by the small number of patients treated (24 patients—27 knees) and by the short-term follow-up (39 months).

In our study, no intra-, peri- or postoperative complications, such as loss of valgus correction, bone fractures, infections, or metallic plate failures were detected but only a longer follow-up will establish the actual clinical benefit of this procedure.

The use of navigation system might be useful for the young surgeons approaching this type of pathology.

Conclusions

High tibial osteotomy with the use a navigator system seems to be a safe and reproducible method to treat varus knee malalignment pathology. Compared to the conventional standard technique, it is more accurate and reproducible in providing the correction desired both in the coronal and sagittal plane.

Conflict of interest The authors declare that they have no conflict of interest with this study.

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