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Original article

Accuracy of the correction achieved after a valgus high tibial osteotomy: Comparison of the Hernigou table and navigation

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ABSTRACT

Introduction: The outcome of a medial opening wedge valgus high tibial osteotomy indicated for the treatment of isolated medial tibiofemoral osteoarthritis depends mainly on the accuracy of the correction of the hip-knee-ankle angle (HKAA) and the mechanical medial proximal tibial angle (mMPTA). Most authors aim for a desired correction target between 2° and 4° of valgus. Several planning and surgical techniques have been described to achieve this target value that is specific to each surgeon.
Objective: The purpose of this study was to compare the accuracy of the correction achieved using either the Hernigou table (HT) planning method or a computer-assisted navigation system (CAS). It was hypothesized that no difference would be found between these 2 techniques.
Materials and Methods: This retrospective single-center study involved 43 knees: 21 in the HT group and 22 in the CAS group. Two surgeons (ME, JYJ), who were experts in 1 of the 2 planning methods performed these procedures, with a single surgeon assigned to each group. The correction was noted in the operative report and was considered to be the desired correction target. The surgical correction was calculated by comparing preoperative and immediate postoperative mMPTA measurements. The surgical accuracy, where a value close to 0 represented optimal accuracy, was defined as the absolute value of the difference between the correction target set by the surgeon and the surgical correction achieved. The median accuracy between the 2 groups was compared by a Mann-Whitney U test (significance level at 5%). The number of patients deviating from the target by > 3° was analyzed with a Fisher exact test (significance level at 5%). Pre- and postoperative comparisons of the HKAA measurements could not be used because the measurement was not performed postoperatively for the CAS group.
Results: The median surgical accuracy on the mMPTA was 1.4° (0–4.1) for the HT group versus 1.9° (0.2–6.7) for the CAS group ($p = 0.85$). Sixteen procedures (76%) were performed with an accuracy of < 3° in the HT group versus 15 in the CAS group (68%) ($p = 0.73$).
Discussion-Conclusion: The working hypothesis was confirmed: no differences were found between the HT and CAS groups regarding the surgical accuracy in achieving the corrections set in this series. We therefore demonstrated that HT was a highly accessible, simple and reliable technique for achieving the planned target. It can be used widely.
Level of Evidence: III; comparative retrospective series.

1. Introduction

The risk of developing symptomatic osteoarthritis of the knee is significant and is one of the leading causes of disability worldwide. The genu varum morphotype appears to be the most common deformity and is considered a risk factor for the progression of osteoarthritis of the medial tibiofemoral (MTF) compartment.

The results of medial opening wedge high tibial osteotomy (MOWHTO) in the treatment of isolated osteoarthritis of the medial compartment are satisfactory [1], even when performed bilaterally during the same operative session. However, deterioration over

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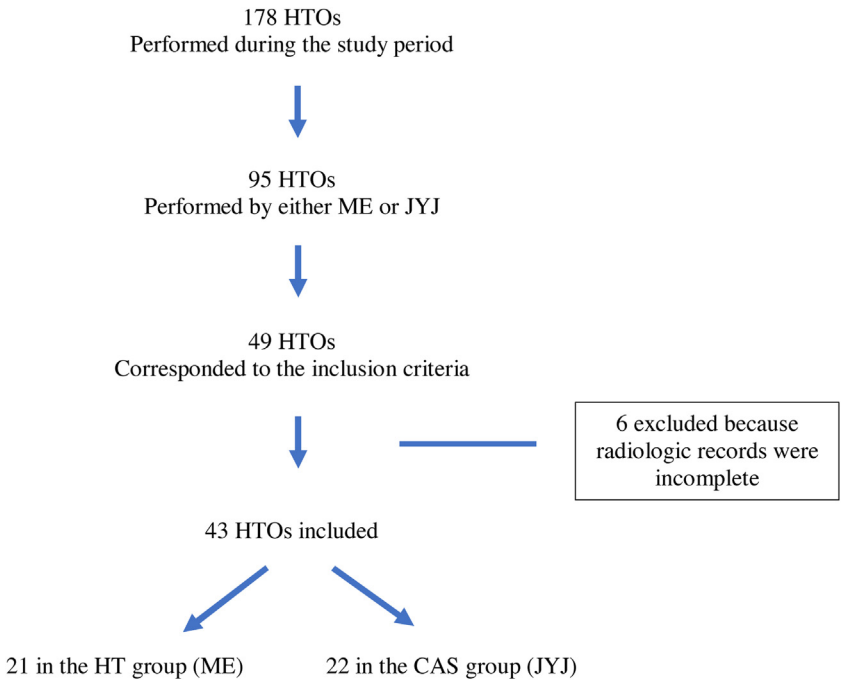


Fig. 1. Flowchart.

time is common [2,3]. For instance, Khoshbin et al. [4] reported a 10-year survivorship of 67% with the following risk factors: female, comorbidities, older than 46 years of age, and a history of arthroscopy. Bouguennec et al. [5], on the other hand, reported a 10-year survivorship of 75% with the following risk factors: male, older than 54 years of age, a body mass index (BMI) > 25, severe MTF osteoarthritis, lateral hinge fracture, a hip-knee-ankle angle (HKAA) correction of < 8°, and a postoperative HKAA of < 180°. The desired correction target and, consequently the accuracy of the correction obtained, are key factors. Several planning methods have been described to achieve this correction target, in particular the use of the Hernigou table (HT) [6,7] or a computer-assisted navigation system (CAS) [8]. Accuracy was around 75% for HT with a target set between 3° and 6° of valgus [6], and around 80% for CAS [8].

The primary purpose of this study was to compare the accuracy of the correction achieved during MOWHTO using either HT or CAS. The working hypothesis was that no differences would be found in terms of correction accuracy between these 2 techniques.

2. Materials and methods

2.1. Study design

This retrospective study covered the period from January 1, 2009, to December 12, 2014.

Only patients that underwent a MOWHTO performed by ME and JYJ were enrolled. These 2 surgeons are experts in both knee surgery and the techniques used: ME for the HT technique and JYJ for the CAS technique. Consequently, a "HT" group and a "CAS" group were created with a single surgeon assigned to each group.

Over this period, 49 MOWHTOs used the same planning methods that were specific to each group and surgeon (ME, JYJ).

The inclusion criteria were patients who had undergone a MOWHTO performed by 1 of these 2 surgeons, unique planning methods that were specific to each group and surgeon, and complete pre- and postoperative radiologic records. Of the 49 cases selected during this study period, only 43 knees of 39 patients who had complete pre- and postoperative radiologic records were included in this study (Fig. 1).

Table 1
Preoperative characteristics of the entire series; values expressed as median [min–max] and standard deviation (SD).

	Overall series ($n = 43$)
Age (years)	50 [32–67]
Sex (M/F)	25/18
BMI (kg/m^2)	30 [21–40]
Side (R/L)	24/19
Correction target (°)	8 [5–14], SD 2.34
mMPTA (°)	86.6 [80.8–90.1], SD 2.23
HKA (°)	175 [166.3–180], SD 3.27

BMI: body mass index; mMPTA: mechanical medial proximal tibia angle; HKA: hip-knee-ankle angle.

2.2. Radiologic measurement of analyzed parameters

The following measurements were performed on the picture archiving and communication system (PACS) by an observer who did not perform the surgery (XN) [9]: pre- and postoperative mechanical medial proximal tibial angle (mMPTA), preoperative HKAA measured on weight bearing full-length lower limb X-rays [6,7], and degree of preoperative osteoarthritis according to the modified Ahlbäck classification [8] in Schuss views. The immediate postoperative images included X-rays that were taken in the supine position and centered over the knee, which showed at least 20 cm of the proximal tibia, and long-leg views to measure the mMPTA. The surgeon of the CAS group chose not to measure the postoperative HKAA.

2.3. Series

The series included 43 patients: 21 in the HT group and 22 in the CAS group. The demographic data of the overall series are reported in Table 1 and those of the different groups in Table 2.

Table 2
Preoperative characteristics of cases of HT and NAV groups; values expressed in median [min–max] and standard deviation (SD).

	HT ($n = 21$)	CAS ($n = 22$)	p
Age (years)	50 [32–60]	50 [32–67]	0.68
Sex (M/F)	10/10	12/8	0.75
BMI (kg/m^2)	32 [25–40]	29 [21–37]	0.04
Side (R/L/Bilat.)	6/13/1	14/4/2	
Correction target (°)	9 [5–14], SD 2.46	8 [5–13], SD 1.95	0.08
mMPTA (°)	86.9 [80.8–90.1], SD 2.3	86.5 [81.8–89.6], SD 2.77	0.7
HKA (°)	174.7 [166.3–178.3], SD 3.06	175.5 [167–180], SD 3.38	0.39

BMI: body mass index; mMPTA: mechanical medial proximal tibia angle; HKA: hip-knee-ankle angle.

Table 3
Osteoarthritis grades according to the Ahlbäck classification [8].

	Complete series ($n = 43$)	HT ($n = 21$)	CAS ($n = 22$)
MTF			
Grade 1	25 (58%)	10 (48%)	15 (68%)
Grade 2	16 (37%)	9 (43%)	7 (32%)
Grade 3	2 (4.5%)	2 (9%)	
LTF			
Grade 1	4 (9%)	1 (5%)	3 (14%)

MTF: medial tibiofemoral compartment; LTF: lateral tibiofemoral compartment.

The groups were comparable except for BMI. The patients had mainly grade 1 and 2 osteoarthritis of the MTF compartment and hardly any in the lateral compartment (Table 3).

2.4. Surgical technique and planning methods

The high tibial osteotomy (HTO) was performed through a medial wedge opening. The anteromedial approach was centered over the pes anserinus. The tendons of the pes anserinus and the superficial bundle of the medial collateral ligament were then detached as a single piece by subperiosteal stripping.

2.4.1. Two techniques were used to achieve the correction target

HT group: the trigonometric table developed by Hernigou [6] determined the height of the opening required to achieve the desired correction angle based on the size of the proximal tibia. This prevented overcorrections (for small tibias) and undercorrections (for large tibias). The length of the osteotomy was measured intraoperatively with an intraosseous pin placed under fluoroscopic guidance. This pin also made it possible to visualize the cut with a saw blade sliding over it. This length (in mm) (table column) and the desired correction (in degrees) (table row) are reported in the original HT. The intersection of the 2 corresponds to the height (in mm) of the HTO required to obtain the desired correction (Fig. 2).

CAS group: an OrthoPilot® image-free computer navigation system (B. Braun-Aesculap, Tuttlingen, Germany) was used with its HTO software (version 1.5 for 7 cases and version 1.3 for 5 cases).

Only 7 patients were operated on without a tourniquet, and they were all from the HT group. Internal fixation was performed in the HT group with a Surfix® locking plate (Integra, Saint-Priest, France) and the opening was filled with a DuoWedge® (Integra, Saint-Priest, France). Internal fixation was performed in the CAS group with an Otis-C® locking plate (SBM, Lourdes, France) and a Biosorb® beta-tricalcium phosphate wedge (SBM, Lourdes, France). An arthroscopy was conducted in conjunction with the MOWHTO when there was an unstable meniscus tear. When indicated, the arthroscopy was systematically performed prior to the MOWHTO. This was the case for 2 patients in the HT group (10%) and 9 in the CAS group (41%). In each case, a resection was performed.

Range of motion was started immediately after the surgical procedure in both groups. While weight bearing was restricted to 20 kg for 4 weeks in the CAS group, it was forbidden for 6 weeks in the HT group.

2.5. Correction target

The planned correction, which is unique to each patient, was noted in the operative report and was considered the "desired correction target". For the HT group, this target was set according to preoperative weight bearing full-length lower limb X-rays taken in the single and double leg stances. Although a weight bearing full-length lower limb X-ray was taken in the single leg stance in the CAS group to determine the surgical indication, the correction target was based on the intraoperative data from the computer-assisted navigation system before the osteotomy was performed. The correction target was the same for each surgeon: a postoperative valgus between 2° and 4° corrected in the proximal tibia.

The "surgical correction" was the correction achieved by the surgeon during the procedure and was calculated by comparing pre- and postoperative mMPTAs for both groups (ΔmMPTA). Measurements were performed on early postoperative X-rays for all patients to avoid biases related to a loss of correction over time, the different fixations used, or complications that could have potentially jeopardized the stability of the fixation. Schröter et al. [10] described "surgical accuracy" in MOWHTO as the difference between the absolute values of the correction target and the surgically achieved correction (ΔmMPTA). Consequently, the closer the value is to 0, the better the accuracy.

2.6. Statistical analyses

Surgical accuracies were compared using a Mann-Whitney U test with a significance level at 5%. The correction target set by the surgeon, as well as the comparison of the different quantitative variables between groups, were performed by a Mann-Whitney U test with a significance level at 5%. A univariate linear regression was performed to assess factors that might have influenced the surgical accuracy according to the mMPTA. A multivariate analysis was then conducted with a mixed linear regression model of the surgical accuracy according to the ΔmMPTA on variables that showed a statistically significant association ($p < 0.05$) in the univariate analysis.

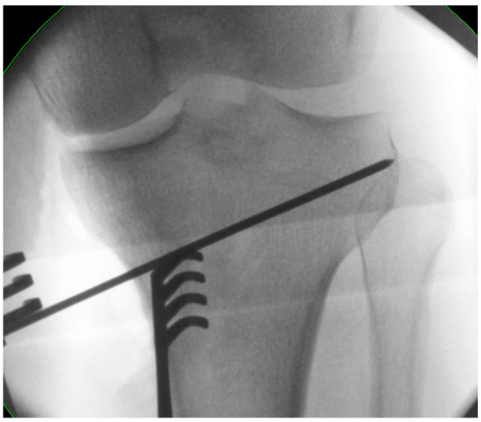
The number of patients with a correction of < 3° of the target were analyzed between groups by a Fisher exact test with a significance level set at 5%.

3. Results

There were no significant differences in the median correction target between the 2 groups: 8° (5–13) in the CAS group and 9° (5–14) in the HT group.

There was no significant difference ($p = 0.85$) in surgical accuracy according to the ΔmMPTA, with a median accuracy of 1.9° (0.2–6.7) in the CAS group versus 1.4° (0–4.1) in the HT group. No multivariate regression could be built because the univariate analysis did not

A



B

β	4	5	6	7	8	9	10	11	12	13	14	15	16*	17	18	19
M																
50	3	4	5	6	7	8	9	10	10	11	12	13	14	15	16	16
55	4	5	6	7	8	9	10	10	11	12	13	14	15	16	17	18
60	4	5	6	7	8	9	10	11	12	14	15	16	17	18	19	20
65*	5	6	7	8	9	10	11	12	14	15	16	17	18*	19	20	21
70	5	6	7	8	10	11	12	13	15	16	17	18	20	21	22	23
75	5	6	8	9	10	12	13	14	16	17	18	20	21	22	24	25
80	6	7	8	10	11	13	14	15	17	18	19	21	22	24	25	26

Fig. 2. Using the Hernigou table [6]. A. Intraoperative measurement of osteotomy length. B. Table reproduced from the original publication. For example, if the length (M) of the osteotomy measures 65 mm and the correction angle (β) is 16°, the opening will be 18 mm.

Table 4
Alignment parameter between the NAV and HT groups; values expressed in median [min–max] and standard deviation (SD).

Angles	CAS (n = 22)	HT (n = 21)	p-value
Correction target (°)	8 [5–13] SD 1.95	9 [5–14] SD 2.46	0.08
Surgical accuracy according to ΔmMPTA (°)	1.9 [0.2–6.7] SD 1.7	1.4 [0–4.1] SD 1.23	0.85
Values of postoperative mMPTA angles	92.9 [88.3–98] SD 2.42	94.8 [89.3–99.1] SD 2.61	0.055

mMPTA: mechanical medial proximal tibia angle.

find any significant factors associated with the surgical accuracy in the ΔmMPTA. Fifteen procedures were performed with an accuracy of < 3° (compared to the set target) in the CAS group (15/22, 68%) versus 16 in the HT group (16/21, 76%), with no significant difference (p = 0.73) (Table 4).

The pre- and postoperative comparison of the HKAA measurements could not be performed because the postoperative measurement was not taken for the CAS group.

4. Discussion

The most important finding of this study was that the hypothesis was confirmed: no differences were found between the HT and CAS groups regarding surgical accuracy and the achievement of the planned correction.

The main objective of this study was to compare the surgical accuracy obtained using 2 methods to plan and perform MOWHTO. According to a recent meta-analysis, the accuracy of MOWHTO is not very good, occurring in 23% to 91% of cases, with disparate targets ranging from 3° varus to 8° valgus [11].

There is little literature on the use of HT [6]. In this series, its accuracy was around 75% with a planned target set between 3° and 6° of valgus [6]. However, it can be compared to the "gap measurement" planning method, which reproduces intraoperatively the preoperatively planned opening angle by plotting the previously measured height of the osteotomy. Brower et al. [12] reported that with this technique 56% of their cases fell into the correction target range (0° to 6° of valgus). Schröter et al. [10] also reported very good accuracy using this gap measurement technique, with 91% of cases at < 4° of their target. Finally, Duivenvoorden et al. [13] published a MOWHTO series of an operative technique that used a trigonometric table to calculate the height of their MOWHTO openings that was different than HT. They reported that 52% of their cases fell within their target correction range that was between 2° and 6° of valgus. The findings of this study were comparable since 15 procedures in the CAS group (68%) and 16 in the HT group (76%) had an accuracy of < 3°, with no significant difference (p = 0.73). The strength of the HT, used as originally described, is that the width of the osteotomy is measured intraoperatively, which is similar to the CAS conditions.

Theoretically, CAS eliminates measurement approximations. It achieved the MOWHTO target correction in 71% to 96% of cases [8,11]. These findings were slightly better than the ones we found in the CAS group, with 68% of cases at < 3° of the target.

No difference was observed between the HT and CAS groups regarding the accuracy of the planned correction. A recent meta-analysis of 12 studies compared the accuracy of navigated and conventional techniques (except for patient specific instrumentation (PSI)) [14]: 5 reported better accuracy in coronal alignment correction with navigation, 6 found no difference, and 1 reported better accuracy in the conventional group. When pooling these study results, navigation helped reduce the risk of outliers (odds ratio (OR) 0.42; 95% confidence interval (CI), 0.21–0.85). A subgroup analysis of conventional techniques used to plan the necessary

opening was conducted by separating studies using the gap measurement and cable method: a significant difference was found between the CAS and cable method but not between CAS and gap measurement. Tardy et al. [15] recently published a retrospective study comparing correction accuracy in 126 MOWHTOs that were either planned with conventional X-rays, computer-assisted navigation or PSI. Although PSI appeared to be more accurate, no statistical difference was found when comparing these 3 techniques. However, it is important to note that there was a statistical difference between the accuracy of the PSI and the navigation group ($p = 0.011$).

This study had both limitations and strengths.

This was a retrospective study with a limited number of cases, which could make interpreting results and drawing conclusions difficult. Moreover, the radiologic measurements were made without using an automated measurement software even if it was validated in the literature [9]. These results may have been influenced by extreme values, mainly in the CAS group, with a maximum surgical accuracy value of 6.7°. The surgical accuracies presented as "averages," without taking into account the distribution of values, must be carefully interpreted [10], as they can give a false impression of "good surgical accuracy" because "undercorrected" cases are compensated by "overcorrected" cases [16]. By converting these "relative values" into "absolute values", we avoided this bias and were able to compare the different studies on the accuracy of MOWHTO corrections. The key limitation of this study is the choice of radiologic measurements and, in particular, the need for the mMPTA measurement since the accuracy of CAS correction is difficult to assess with HKAA. Furthermore, compared to the ΔmMPTA, the ΔHKAA tends to overestimate surgical accuracy with even more errors when the initial deformity is significant [17–21]. Indeed, the effects of deformity and knee flexion seem to be less noticeable on mMPTA measurements [19]. Although the impact of weight bearing on the measurement of HKAA remains controversial, it is important to have a precise idea of the initial deformity before surgery and therefore the desired correction to achieve. While some reported a difference in measurement of 0.4° for half of the body weight [20] or a difference of about 1.6° [22], others found no effect of weight bearing [23]. Nevertheless, this difference should theoretically be included in the coronal range laxity established by Yaffe et al. at 2.8° ± 1.1° [20].

Although there were limitations, this study also presented strengths. To the best of our knowledge, this is the first study to compare surgical accuracy in achieving planned correction with HT and navigation. Each surgeon was an expert in the use of 1 of the 2 planning methods, which made it possible to reproduce the surgical technique and confirm the working hypothesis. However, we should be careful in extrapolating the results of non-expert surgeons. Finally, the radiologic measurements were conducted by a single observer who did not perform the surgery.

5. Conclusion

The working hypothesis was confirmed: no differences were found between the HT and CAS groups regarding the surgical accuracy in achieving the corrections set in this series. It was therefore demonstrated that HT is a highly accessible, simple and reliable method to achieve the correction. It can be widely used.

Disclosure of interest

ME: is an educational consultant for Lépine, Amplitude, Newclip, and an associate editor for the SoFCOT instructional course lectures.

FB: is an educational consultant for Serf, Amplitude, and a member of the SFHG executive board.

MO: is an educational consultant for Arthrex, Stryker and Newclip.

JYJ: is a consultant at Globus Medical and a member of the CAOS International and GECO executive boards.

XN, HF: declare that they have no competing interest.

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Author contributions

Study conception and design: ME.
Data collection: XN, HF.
Drafting of the manuscript: XN, ME.
Proofreading: FB, MO, JYJ.

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