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Accuracy of the correction obtained after tibial valgus osteotomy. Comparison of the use of the Hernigou table and the so-called classical method

Xavier Nicolau¹ · François Bonnet¹ · Grégoire Micicoi² · David Eichler¹ · Matthieu Ollivier² · Henri Favreau¹ · Matthieu Ehlinger¹ 

Abstract

Introduction Medial valgus-producing tibial osteotomy (MVTO) is classically used to treat early medial femorotibial osteoarthritis. Long-term results depend on the mechanical femorotibial angle (HKA) obtained at the end of the procedure. A correction goal between 3 and 6° valgus is commonly accepted. Several planning methods are described to achieve this goal, but none is superior to the other. **Objective** The main objective was to compare the accuracy of the correction obtained using either the Hernigou table (HT) or a so-called conventional method (CM) for which 1° of correction corresponds to 1° of osteotomy opening. The secondary objective was to analyze the variations observed in the sagittal plane on the tibial slope and on the patellar height. The working hypothesis was that the HT allowed a more accurate correction and that the tibial slope and patellar height were modified in both groups. **Material and method** In this monocentric and retrospective study, two senior surgeons operated on 39 knees (18 in the CM group, 21 in the HT group) between January 1, 2009 and December 31, 2014. The operator was unique for each group and expert in the technique used. The correction objective chosen for each patient, and written in the operative report, was considered as the one to be achieved. The surgical correction was the difference between the pre-operative and immediate post-operative data (< 5 J) for the mechanical tibial angle (MTA) and the hip-knee-ankle (HKA) angle. Surgical accuracy, where a value close to 0 is optimal, was the absolute value of the difference between the surgical correction performed and the goal set by the surgeon. **Results** The median surgical accuracy on the MTA was 3.5° [0.2–7.4] versus 1.4° [0–4.1] in the CM and HT groups, respectively ($p = 0.006$). In multivariate analysis, with the same objective, the CM had a significantly lower accuracy of $1.9^\circ \pm 0.8$ ($p = 0.02$). For HKA, the median accuracy was 3.1° [0.3–7.3] versus 0.8° [0–5] in the CM and HT groups, respectively ($p = 0.006$). Five (5/18, 28%) and 16 (16/21, 76%) knees were within 3° of the target in the CM and HT groups, respectively ($p = 0.004$). The median tibial slope increased in both groups. This increase was significantly greater in the CM group compared with the HT group, with 5.5° [–0.3–13] versus 0.5 [–5.2–5.6], respectively ($p < 0.001$). The median Caton-Deschamps index decreased (patella lowered) in both groups after surgery, by –0.21 [–1.03; –0.05] and –0.14 [–0.4–0.16], but without significant difference ($p = 0.19$). In univariate analysis, changes in tibial slope and patellar height were not significantly related to frontal surgical correction performed according to Δ MTA ($R^2 = 0.07$; $p = 0.055$) and ($R^2 = -0.02$; $p = 0.54$) respectively. **Discussion** The correction set by the surgeons was achieved with greater accuracy and more frequently in the HT group, confirming the working hypothesis. The HT is therefore recommended as a simple way of achieving the set objective; the tibial slope and patellar height were modified unaffected by the frontal correction performed.

Level of proof: retrospective study, III

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Introduction

Gonarthrosis is a main cause of disability [1]. The risk of developing symptomatic osteoarthritis of the knee is favoured by genu varum present of painful patients [2]. The relationship between “varus deformity” on a healthy knee and

“development of gonarthrosis” with an odd ratio of 2 has been highlighted [3], explaining the fact that isolated medial gonarthrosis is ten times more frequent than isolated lateral femorotibial osteoarthritis [4]. For Hanada et al., medial osteoarthritis is associated with varus deformity of the lower limb but also with the morphology of the proximal tibia, particularly its mechanical tibial angle (MTA) [5].

Valgus-producing tibial osteotomy (VTO) is indicated to treat isolated medial osteoarthritis of the knee, with acknowledged efficacy but unfortunately with deterioration over time [6]. Survival at years is of 67% with known risk factors for failure such as age over 46 years, female, presence of comorbidities, and a history of arthroscopy [7]. One of the elements that can guarantee the success of a VTO is the correction obtained with the necessary over-correction and a valgus objective of 3 to 6° [8].

The main objective of this work was to compare the accuracy of the correction obtained during a VTO using the Hernigou table (HT) [8], based on a trigonometric calculation taking into account the correction objective set, but also the existing deformity and the length of the osteotomy line, or using the so-called classical method (CM) for which 1° of correction corresponds to 1° of osteotomy opening. The secondary objective was to analyze the variations observed in tibial slope and patellar height. The working hypothesis was that the use of HT allowed a better accuracy to reach the target set than the CM with a modification of the tibial slope and patellar height for both groups.

Material and method

Study design

A retrospective study was conducted from January 1, 2009 to December 31, 2014 including medial opening VTOs performed by two expert surgeons (FB and ME).

The inclusion criteria were medial opening VTO, one of the two surgeons mentioned above, correction method using the CM or HT, and complete pre- and post-operative radiological file.

Over this period of time, 39 VTOs performed by the 2 surgeons met the inclusion criteria. The patients were divided into two groups: HT group ($n = 21$) and CM group ($n = 18$).

The operative report (OR) of each patient was reviewed to collect the desired correction objective for each operator and for each patient.

No functional clinical outcome was reported, for the objective of this work was solely surgical correction accuracy. Only complications were collected.

Radiological measurement

A non-operator examiner (XN) carried out all measurements and evaluation on the PACS (picture archiving and communication system) [9]: posterior tibial slope according to the

Brazier method [10] and patellar height according to Caton-Deschamps [11], MTA, and hip-knee-ankle angle (HKA).

Series

Table 1 shows the data for the whole series.

Surgical technique and planning method

A medial VTO was performed with an antero-medial skin approach centered on the pes anserinus. The proximal tibial metaphysis sub-periosteum was exposed by detaching in one piece the pes anserinus and the superficial bundle of the medial collateral ligament. A guiding pin was inserted in an oblique upward and lateral direction aiming at the lateral cortex of the tibia at the level of the tip of the head of the fibula or at the proximal tibiofibular joint, ensuring stability of the lateral hinge, while projecting above the tibial tuberosity. The patellar ligament was protected anteriorly as well as the neurovascular axis posteriorly. The osteotomy was then performed and completed with a chisel, keeping the lateral hinge intact.

Two methods for reaching the correction target were used. The use of the Hernigou table [8] was fine-tuned by direct intra-operative measurement of the length of the guiding pin, which corresponded to the length of the osteotomy (Fig. 1). This length of the osteotomy was transferred to the measuring chart to choose the height of the wedge corresponding to the desired correction (Fig. 2). For the CM group, a 1° wedge opening was equivalent to a 1° correction wanted and decided by the surgeon according the pre-operative long X-ray (Fig. 3).

Only seven patients were operated on without tourniquet, all were in the HT group.

In both groups, osteosynthesis was performed using a Surfix® locking plate (Integra, Saint Priest, France). The opening was filled with a DuoWedge® wedge (Integra, Saint Priest, France) and with a DAOA® type wedge (Integra, Saint Priest, France) for the CM group, both made of tricalcium phosphate and hydroxyapatite.

Table 1 Data for global series

	Global series ($n = 39$)
Age (year)	48 [31–61]
Sex (M/F)	24/15
Side (R/L)	16/23
Target of correction (°)	12 [5–14]
ATM (°)	85.5 [79.2–90.1]
HKA (°)	171.2 [160.2–178.3]

F female, *M* male, *R* right, *L* left

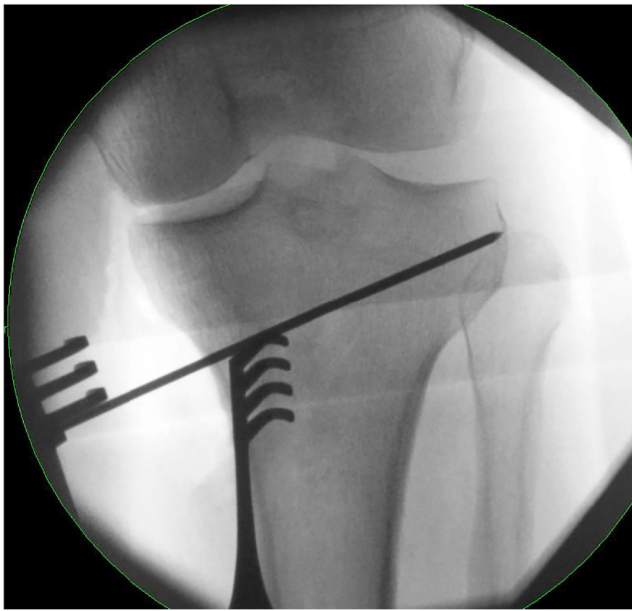


Fig. 1 Intra-operative measurement of the length of the osteotomy line using a wire positioned at the level of the osteotomy path

An arthroscopy was systematically performed first when an unstable meniscal lesion was present. This was the case for two patients in the HT group (10%) for whom a resection was performed.

In both groups, free motion was permitted immediately after surgery. Weight bearing was limited to 10 kg in the CM group for 6 weeks, while it was forbidden for 6 weeks in the HT group.

Correction objective

A correction angle was specific to each patient. This angle written in the OR was considered as the overall desired correction goal. The surgeons, based on pre-operative radiological bipodal and monopodal telemetry data in the CM and HT groups, set the overall correction goal.

“Surgical correction” is the correction performed by the surgeon during the operation. It was calculated on the evolution of the MTA before and after surgery. It was also calculated for the HKA angle. Post-operative measurements were

made on early images (< day 5) in all patients to avoid any bias due to possible loss of correction over time, to different fixation means used or to possible complications involving fixation stability.

“Surgical accuracy” [12] is the absolute value of the difference between the correction goal and the surgical correction performed (difference between post-operative and pre-operative MTA or HKA = Δ MTA and Δ HKA). The closer the value is to 0, the better the accuracy.

Statistical analysis

Surgical accuracies were compared between groups using a Mann-Whitney test with a 5% significance level.

The correction objective set by the surgeon, as well as the comparison of the different quantitative variables between the groups, was carried out using a Mann-Whitney test with a 5% significance level. A univariate linear regression analysis was performed to evaluate the factors that may have influenced surgical accuracy according to Δ MTA and Δ HKA. A multivariate analysis was then performed, using a mixed linear regression model of surgical accuracy according to Δ MTA and HKA on variables that had a statistically significant association ($p < 0.05$) in univariate analysis.

The intraclass correlation (ICC) between Δ MTA and Δ HKA was calculated. The confidence interval and standard deviation of the differences obtained between the radiological measurements of surgical correction following Δ MTA and Δ HKA were calculated to represent the spread of differences according to the surgical accuracy measurement method. In order to evaluate and compare the evolution of the tibial slope and patellar height for each group before and after the VTO was performed, a univariate linear regression was performed.

Then, multivariate regressions with the tibial slope and the Caton-Deschamps index as the explanatory variable and the surgical correction performed according to Δ MTA and the planning groups were performed.

The number of patients within 3° of the objective was analyzed between the groups by an exact Fisher’s test at the 5% threshold.

β	4	5	6	7	8	9	10	11	12	13	14	15	16*	17	18	19
<i>M</i>																
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 Hernigou table used (13). For example (*), if the length (*M*) (measured during the procedure) of the osteotomy is 65 mm, and that the desired correction angle (β) is 16°, the opening wedge will be 18 mm



Fig. 3 On this long X-ray, the HKA angle showed a 6.5° varus. The surgeon wanted a 2.5° correction of valgus. So the opening wedge was 9°

Results

1. Table 2 shows the data for the two different groups. There was a significant difference between the two groups concerning the correction objective ($p < 0.001$) but also concerning the pre-operative deformities (MTA ($p = 0.002$) and HKA ($p < 0.001$)), which were more important in the CM group.
2. Table 3 shows the result for the series and the two groups.

Surgical accuracy according to Δ MTA median was 3.5° [0.2–7.4] in the CM group versus 1.4° [0–4.1] in the HT group, with a significant difference ($p = 0.006$). Univariate analysis isolated pre-operative HKA as the only factor significantly associated ($p = 0.0177$) with surgical accuracy according to Δ MTA for each group and therefore potentially influencing it. The results of the multivariate regression of surgical accuracy according to Δ MTA as a function of pre-operative HKA and the planning method used indicate that for the same objective, the CM has a significantly lower accuracy of $1.9^\circ \pm 0.8$ ($R^2 = 0.23$; $p = 0.02$).

The surgical accuracy according to Δ HKA was 3.1 [0.3–7.3] in the CM group and 0.8 [0–5] in the HT group with a significant difference ($p = 0.006$). The univariate analysis did not find any factor significantly associated with surgical accuracy according to Δ HKA, so no multivariate regression could be built.

Five procedures had been performed with a surgical accuracy $< 3^\circ$ (compared with the targeted objective) in the CM group (28%) versus 16 in the HT group (76%); the difference was significant ($p = 0.004$).

The median tibial slope increased after VTO in both groups. This increase was significantly greater in the CM group compared with the HT group, with a median increase of 5.5° [–0.3–13] versus 0.5° [–5.2–5.6] ($p < 0.001$), respectively.

The median Caton-Deschamps index [11] decreased (patella lowered) in both groups after surgery, by -0.21 [–1.03; –0.05] and -0.14 [–0.4–0.16], but without significant difference ($p = 0.19$). In univariate analysis, changes in tibial slope and patellar height were not significantly related to frontal surgical correction performed according to Δ MTA, ($R^2 = 0.07$; $p = 0.055$) and ($R^2 = -0.02$; $p = 0.54$) respectively.

The ICC between Δ MTA and Δ HKA was 0.673. The assessment of the correction performed according to Δ HKA is overestimated compared with the assessment according to Δ MTA by an average of $2.01^\circ \pm 2.17^\circ$. The scatter plot of the pre- and post-operative angle data pairs (MTA and HKA), obtained by the two different methods (HT and CM), shows that this overestimation is all the more important for angle values greater than 10° .

Table 2 Details of each groups TH and NA

	TH (<i>n</i> = 21)	MC (<i>n</i> = 18)	<i>P</i> <i>TH</i> vs <i>MC</i>
Age (year)	50 [31–60]	47 [38–61]	0.22
Sex (M/F)	10/10	10/3	0.15
Side (R/L/B)	6/13/1	3/5/5	
Target of correction (°)	9 [5–14]	14 [10–14]	< 0.001
ATM (°)	86.9 [80.8–90.1]	84.6 [79.2–88.4]	0.002
HKA (°)	174.7 [166.3–178.3]	169.4 [160.2–174]	< 0.001

R right, *L* left, *B* both sides

Discussion

1. The main result of this work is that the surgical accuracy of the HT group was statistically better than that of the CM group, confirming the working hypothesis. Although the initial deformity and therefore the correction goal were different between the CM and HT groups, the multivariate analysis found no influence of the initial deformity and the correction goal on surgical accuracy. For the secondary objective, the tibial slope increased and the patella lowered, again confirming the working hypothesis. The extent of the correction in the frontal plane had no influence on these two modifications. The CM group had a greater increase in tibial slope compared with the HT group. Finally, no difference was found between the two groups concerning the lowering of the patella.
2. There are strengths and limitations to this work.

Concerning the strengths, to our knowledge, this is the first work reporting surgical accuracy concerning the objective of correcting a VTO using a CM but also a HT, and especially, it is the first study comparing both techniques. Each operator was an expert in the use of one of the two techniques. A non-operating examiner performed the radiological measurements and analyses in a non-automated way, which may be a limitation of this work even if the software used was validated in the literature [9].

Despite these strengths, this study was retrospective with a limited number of cases due to the relative rarity of these indications. Surgical accuracies presented as “average,”

without taking into account the distribution of values, must be interpreted carefully, as they give a false impression of “good surgical accuracy” and as “undercorrected” cases are then compensated by “overcorrected” cases. Converting these “relative values” into “absolute values” avoids this bias and allows comparison between different studies in the literature. Presenting the results as the deviation from an objective, whatever that objective may be, allows a better comparison of surgical accuracy between the different published works. The main element to be discussed in terms of limitation is the choice of radiological measurements. The evaluation according to Δ HKA tends to overestimate surgical accuracy compared with the surgical accuracy according to Δ MTA. This overestimation is even more important for angle values greater than 10°. These observations are confirmed by the literature: indeed the errors of evaluation of the mechanical angle according to HKA are all the more important as the deformation is important [3, 13, 14]. According to Loner et al., this variability in measurement depending on the extent of knee deformation and bending is less noticeable in MTA measurements [13]. It is also possible that this difference is due to the influence of weight bearing, although this has not been clearly demonstrated and remains controversial. For Kendoff et al. this difference is 0.4° for 50% of the body weight [15], and for Specogna et al., there is a difference of 1.6° between supine and bipodal telemetry [16]. Conversely, Siu et al. found no influence of weight bearing on the telemetry results of the HKA angle [17]. In any case, this difference should be included in the frontal plane laxity range that was established by Yaffe et al. at $2.8^\circ \pm 1.1^\circ$, with more than 70%

Table 3 Comparison of 2 groups NA and TH; median (min; max)

Angle	MC (<i>n</i> = 18)	TH (<i>n</i> = 21)	<i>P</i> value
Target of correction (°)	14 [10–14]	9 [5–14]	0.001
Surgical accuracy for Δ ATM (°)	3.5 [0.2–7.4]	1.4 [0–4.1]	0.006
Surgical accuracy for Δ HKA (°)	3.1 [0.3–7.3]	0.8 [0–5]	0.006
Decrease of Caton-Deschamps index (36, 37)	−0.21 [−1.03–0.05]	−0.14 [−0.41–0.16]	0.19
Increase of tibial slope (°)	5.5° [−0.3–13]	0.5 [−5.2–5.6]	0.001

of the knees having an evenly distributed laxity with 1° valgus and varus [14].

3. The main objective of this work was to compare surgical accuracy for the correction of VTO using the CM or the HT. The literature on the accuracy of VTOs has shown rather poor results [18]. The collected data ranged from 23 to 91% with target intervals that varied from one series to another (3° varus to 8° valgus).

Despite the common use of the CM [9], a few articles report its results. Opening the osteotomy by 1 mm for each degree of correction desired is an approximation that does not take into account the tibial width. According to Mihalko and Krackow [19], using this correction rule leads to deviations between 2.9 and 4.4°, for an average correction of 15°, depending on the size of the subjects and the width of the tibial osteotomies. This correction rule would thus only be accurate for osteotomy widths of 5.65 cm. Marti et al. [20] used this method, but taking into account ligament laxity, using complementary stress images (varus and forced valgus), which they added to the correction objective. Despite this, they only had 48% of their corrections within their target range.

For the HT, the literature reported an accuracy around 75% on a series of 246 VTOs for a defined target of 3–6° valgus [8]. The literature remains poor concerning the HT. It is possible to compare the HT method to the planning method known as “gap measurement,” where the correction angle is planned on pre-operative radiographs by measuring the height of the osteotomy and carrying it out intra-operatively. With this method, Brower et al. [21] placed 56% of their cases in the correction target (0–6° of valgus) and Schröter et al. [12] 91% of VTOs within 4°. For Duivenvoorden et al. [22], using a trigonometric table, different from the HT method, 52% of the VTOs were within the target range (2–6° of valgus). Our results are comparable. Both the CM and the HT are based on the fact that the opening angle of the VTO is equivalent to the desired correction on the HKA. However, the rotation in the frontal plane due to the opening of the VTO takes place at the hinge of the VTO located a few centimeters below the centre of the knee where the HKA angle is measured. This approximation leads to additional theoretical errors of 1–2° for corrections of 15° [19] as we have seen previously. On the other hand, this approximation does not affect the evaluation of surgical accuracy according to Δ MTA.

Recently, the use of custom-made cutting guides has been introduced for VTOs [23] and also for distal femoral osteotomies [24]. The objective is simple: ease of surgery, reproducibility, accuracy of correction, and safety of execution. Chaouche et al. [25] carried out the largest series on this technique, with 100 patients suffering from isolated medial femorotibial tibial osteoarthritis on a varus tibial metaphysis. They found a mean accuracy of $1 \pm 0.95^\circ$ on Δ HKA, $0.54 \pm$

0.63° on Δ MTA, and $0.43 \pm 0.8^\circ$ on the posterior tibial slope, with no significant difference from the pre-operative planning performed. The measurements were performed on a scanner with 3D reconstruction. The use of CT scan to check the correction allows a high degree of accuracy but does not take into account the influence of weight bearing since the examination is performed in the supine position. When the evaluation was radiological, the studies reported frontal accuracies of 1–2° [23, 24]. The safety, reproducibility, and ease of use of these cutting guides have been demonstrated.

4. The secondary objective of this work was to analyze and compare the evolution of the tibial slope and patellar height for each group.

The overall tibial slope was increased for the whole series as reported in the literature for medial-opening VTO [12, 26]. This change in slope is not correlated with the importance of the frontal correction [26]. On the other hand, the increase in tibial slope was significantly greater in the CM group compared with the HT group. Several factors were identified, such as insufficient posterior osteotomy, insufficient posterior soft tissue release [20], triangular tibia [27], and anterior plate positioning [27]. To avoid a change in tibial slope, it has been recommended to perform the VTO parallel to the tibial slope to maintain the original slope [28], to open the tibial osteotomy more posteriorly than anteriorly [29], to make a rectangular and symmetrical sagittal opening, or to position the hinge in the centre of the sagittal plane [30].

The patellar height has been reduced in this series as reported [31], without any difference between the two groups. On the other hand, no correlation was found with the size of the correction, contrary to the literature [32]. Biomechanically, medial opening VTOs lead to an increase in medial tilt through lateralization of the tibial tuberosity, which causes greater pressure of the lateral facet of the femoral trochlear groove on the lateral patellar facet. Since the direction of the quadriceps forces on the patella is not altered, lateralization of the tibial tuberosity results in a decrease in the medial rotation of the patella. The opening of the osteotomy also induces a lowering of the tibial tuberosity, leading to an increase in the tension of the patellar ligament and patellar retinaculum, thus increasing the pressure forces on the patellofemoral joint [32].

Compliance with ethical standards

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

Ethical approval This article does not contain any studies with human or animals performed by any of the authors.

Informed consent Informed consent was obtained from all individual participants by phone call.

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