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# Osteotomy around the knee is planned toward an anatomical bone correction in less than half of patients

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## ARTICLE INFO

## ABSTRACT

**Keywords:**  
Knee  
Osteotomy  
Osteoarthritis  
Deformity

**Introduction:** In cases where the femur or tibial deformity is not correctly analysed, the corrective osteotomies may result in an oblique joint line. The aim of this study was to assess the preoperative deformity of patients due to undergo corrective osteotomy and the resulting abnormal tibial and femoral morphologies after the planned correction using 3D software.

**Methods:** CT scans of 327 patients undergoing corrective osteotomy were retrospectively included. Each patient was planned using a software application and the simulated correction was validated by the surgeon. Following the virtual osteotomy, tibial and femoral coronal angular values were considered abnormal if the values were outside 97.5% confidence intervals for non-osteoarthritis knees. After virtual osteotomy, morphological abnormalities were split into two types. Type 1 was an under/overcorrection at the site of the osteotomy resulting in abnormal bone morphology. A type 2 was defined as an error in the site of the correction, resulting in an uncorrected abnormal bone morphology.

**Results:** The global rate of planned abnormalities after tibial virtual osteotomy was 50.7% (166/327) with abnormalities type 1 in 44% and type 2 in 6.7%. After femoral virtual osteotomy the global rate was 6.7% (22/327) with only abnormalities type 1. A lower preoperative HKA was significantly associated with a non-anatomical correction ( $R^2 = 0.12$ ,  $p < 0.001$ ) for both femoral ( $R^2 = 0.06$ ,  $p < 0.001$ ) and tibial ( $R^2 = 0.07$ ,  $p < 0.001$ ) abnormalities.

**Conclusion:** Non-anatomical correction was found in more than half the cases analysed more frequently for preoperative global varus alignment. These results suggest that surgeons should consider anatomical angular values to avoid joint line obliquity.

**Level of evidence:** III; retrospective cohort study.

## 1. Introduction

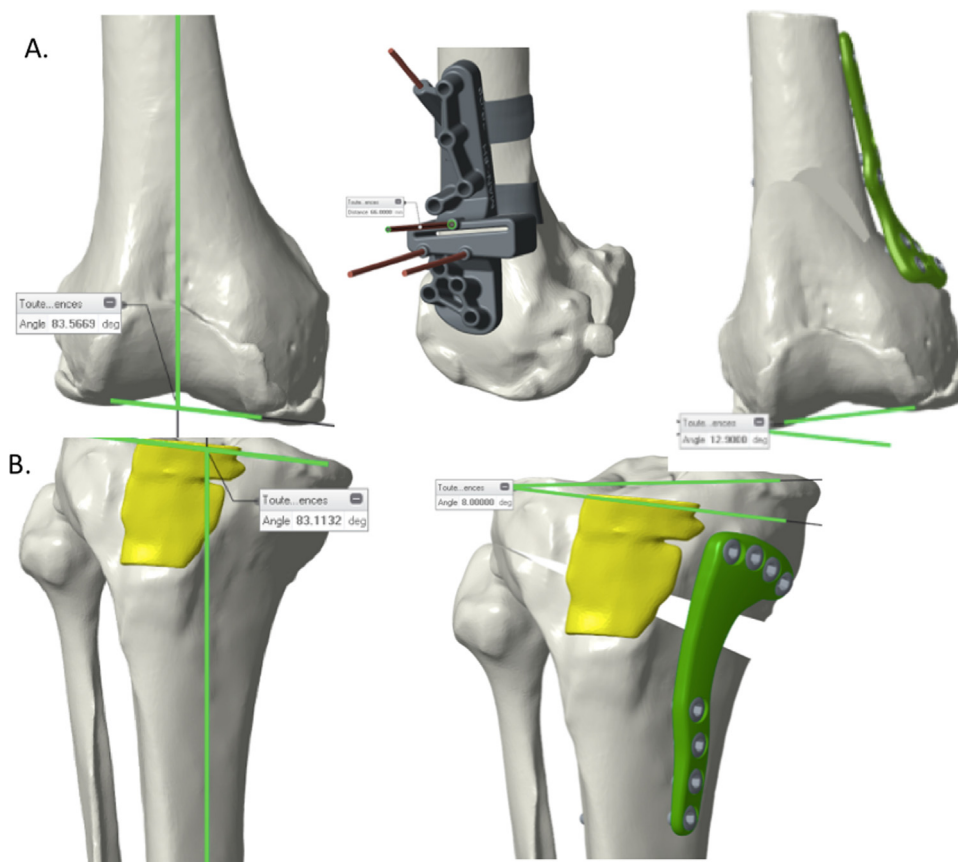
Aims of modern osteotomy can be divided into two categories. Firstly, a morphological objective aiming to correct lower leg malalignment and provide an adequate bone morphology in both the frontal and sagittal planes [1–3]. Secondly, a biomechanical

objective aiming to correct the weight-bearing axis transferring from a painful osteoarthritic compartment to a healthy compartment to allow restoration of function [4–6]. An ideal range of postoperative mechanical axis of 2°–7° valgus is classically advocated to provide favourable clinical outcomes after medial open wedge HTO (OWHTO) [2,3,7,8].

Correction errors and malalignment are well documented in previous studies [9–11] and it is well known that under or overcorrection following OWHTO can lead to complications and patient dissatisfaction [12,13]. Thus, excessive overcorrection of the tibia was associated with lower functional outcomes [14] and may lead

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**Fig. 1.** Three-dimensional planning. Performing the virtual osteotomy. A. After 3D reconstruction and preoperative configurations, the planification with the patient-specific cutting guide is positioned. The surgeon validates the distal femoral osteo after medial closed-wedge distal femoral osteotomy (DFO). B. Planification of a medial open wedge high tibial osteotomy (HTO) according to preoperative tibial deformity with specific plate positioning.

to an excessive joint line obliquity (JLO), which induces detrimental stresses to the articular cartilage [15]. It is still not clear as to what extent an overcorrection of the medial proximal tibial angle (MPTA) after OWHTO is acceptable [16]. To avoid an abnormal tibial or femoral anatomy and an oblique joint line, osteotomies should be performed at the location of the deformity which pre-supposes knowledge of the tibial and femoral normal angular values. Previous studies have shown a mean alignment of 3–4° varus for the tibia and valgus for the femur in a non-osteoarthritic population [17–21]. Kapandji had first described a “normal” mechanical axis later assumed by Hungerford and Krackow with an HKA angle at 180° corresponding to a distal femoral valgus of 3° and proximal tibial varus of 3°, thereby leading to an horizontal joint line parallel to the floor [22,23]. Given these considerations, the overcorrection needed after osteotomy to correct a global alignment deformity may increase the joint line obliquity and previous studies showed the interest of double level osteotomy based more on tibial or femoral segmental deformity rather than global alignment to restore anatomy and avoid excessive JLO [24–27].

One recent study defined the ideal osteotomy level to avoid an oblique joint line and found that in case of desired anatomic correction (MPTA < 90°), only 12% could be corrected with an isolated HTO [28] but this study only analysed patients with global varus > 3°.

No study has reported the proportion of non-anatomical correction after osteotomy around the knee based on previous published tibial and femoral normal angular values and according to the preoperative lower limb alignment.

The aim of this study was to assess the preoperative deformity of patients due to undergo corrective osteotomy and the resulting abnormal tibial and femoral morphologies after the planned

correction using 3D software. The hypothesis was that a consequent number of non-anatomical corrections would be planned with persistent tibial or femoral abnormality or overcorrection whatever the preoperative global lower limb deformity.

## 2. Methods

A multicentre retrospective study was performed using a prospectively collected database of CT scans from the Newclip database (Newclip Technics, Haute-Goulaine, France) realised in patients undergoing osteotomy with patient-specific cutting guides. Only osteotomies performed for non-traumatic arthritis with complete patient dataset including complete morphological measures, planning with surgeon desired correction were included. Patients younger than 18 years old were excluded from the study. Of about 1500 individuals, only 327 were selected based on inclusion criteria. Then, the preoperative alignment analysed with the hip-knee-ankle angle (HKA) and the desired correction according to the site of the planned osteotomy were analysed. The lateral distal femoral angle (LDFA), medial proximal tibial angle (MPTA), posterior plateau tibial angle (PPTA) were assessed before and after virtual osteotomy.

The CT scan protocol consisted of one acquisition centred on the femoral head, one on the knee that captured the distal femur and the proximal tibia, and one centred over the ankle. The slice thickness was 0.625 mm for the knee and 2 mm for the hip and ankle [29].

The HKA angle was defined from the knee centre to the femoral head center and ankle center, respectively. The LDFA was defined as the lateral angle between the distal femoral axis and the

mechanical axis in the coronal plane. The MPTA was defined as the angle between the line joining the center of the ankle with the center of the knee and the axis of the tibial plateau. The PPTA was defined as the angle between the anterior tibial cortex and the axis of the medial tibial plateau on a lateral view of the knee.

CT scans were performed in different institutions utilising the same protocols and processed by Newclip Technics allowing analysing the effect of intended correction after performing a virtual osteotomy with the post-osteotomy bone morphology (Newclip Technics, Haute-Goulaine, France).

The surgeon was then asked to confirm the desired degree of correction and to defined the site of the desired osteotomy (femur, tibia or both) and the type of osteotomy (open vs. closed and medial vs. lateral). The corrective osteotomy was simulated using the 3D software (Newclip Technics) and the final virtual osteotomy was validated by the operating surgeon before creation of a 3D PSI [29–31] (Fig. 1) allowing to accurately reproduce the planned osteotomy in the surgical setting within  $0.2^\circ$  of the frontal plane and  $0.1^\circ$  of the sagittal plane [32]. We assumed that the simulated osteotomy parameters would be within acceptable limits of what it would most likely achieved at the time of surgery. All types of osteotomies and preoperative lower limb global alignments were included to represent all surgical practice.

Medial opening wedge or closing wedge HTO was planned according to the preoperative deformity and femoral osteotomy was carried out by medial closing or lateral opening wedge in case of varus correction and by medial opening or lateral closing wedge in case of valgus correction.

One of the most important part of this study was to set out the anatomical angular values, thus planned correction was compared to the required estimate correction based on the standard values reported on the literature with confidence intervals of 97.5% for native non-osteoarthritic knees [19,20,33]. Based on this previous study, the mean MPTA and LDFA were  $87^\circ$  to be considered as normal and values  $<83^\circ$  or  $>93^\circ$  on virtual osteotomy were abnormal.

After virtual osteotomy, morphological abnormalities were split into two types:

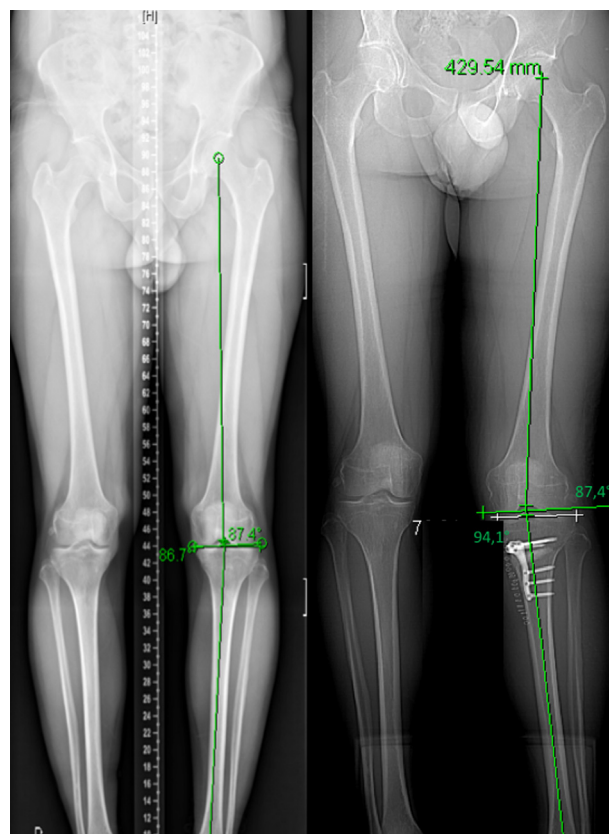
- type 1 was an under/overcorrection at the site of the osteotomy resulting in abnormal bone morphology (Fig. 2);
- type 2 was defined as an error in the site of the correction, resulting in uncorrected abnormal bone morphology (Fig. 3).

From this cohort, 263 (80.4%) HTO, 58 (17.8%) distal femoral osteotomies (DFO) and 6 (1.8%) double level osteotomies (DLO) have been planned. A sagittal plane correction for posterior tibial slope correction was associated in 23 (7.0%) cases depending on the wishes of the surgeon.

To perform this study, all scans were obtained by legal and regulatory requirements, which included ethics board approval and informed patient consent.

### 2.1. Statistical analysis

Means and standard deviations (SDs) were determined for each of the measured and desired anatomic parameters. Normal (Gaussian) distributions were verified to determine adequate statistical testing method (either parametric or non-parametric) to estimate difference between groups in a univariate analysis. Multiple linear regression models were developed to establish the determinants for each of the variables. For each model, variables with a  $p$ -value  $<0.1$  were kept in the final model. Statistical analyses were performed with use of SSPS software (IBM; Armonk, New York).



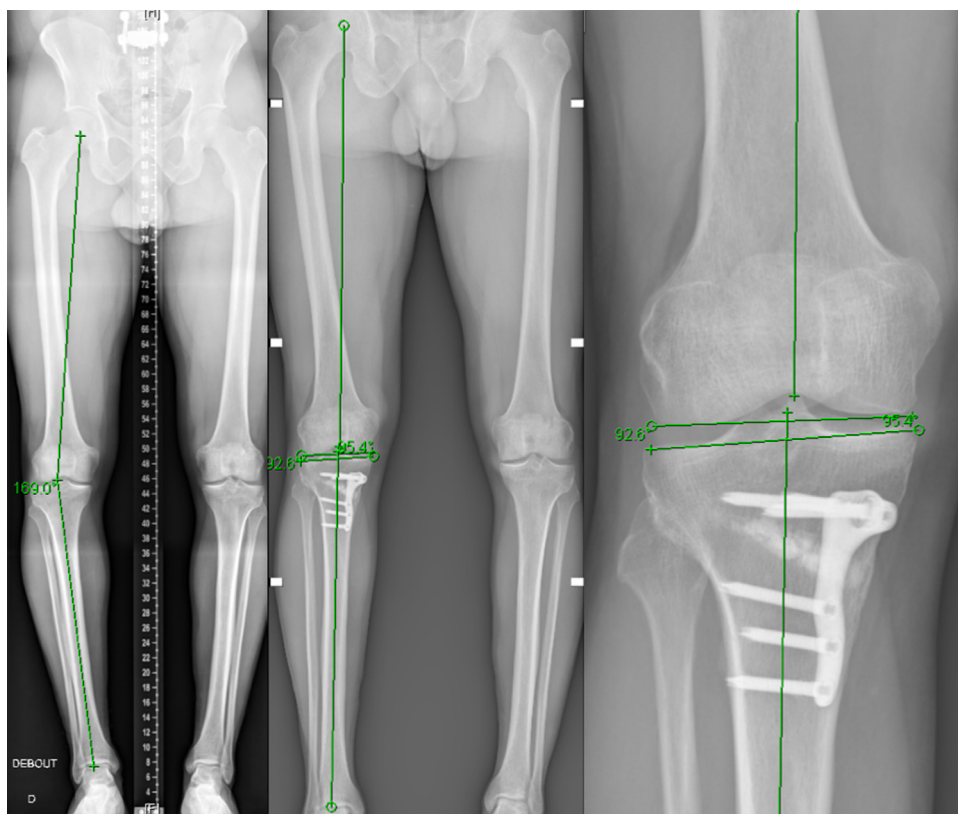
**Fig. 2.** Type 1 abnormality: under- or overcorrection. Tibial overcorrection after high tibial osteotomy (HTO) with a postoperative MPTA at  $94.1^\circ$  ( $7^\circ$  valgus). The mean anatomical medial proximal tibial angle (MPTA) found in the literature is  $87^\circ$  and  $MPTA > 93^\circ$  represents an uncommon bony morphology ( $<0.5\%$  of healthy patients).

### 3. Results

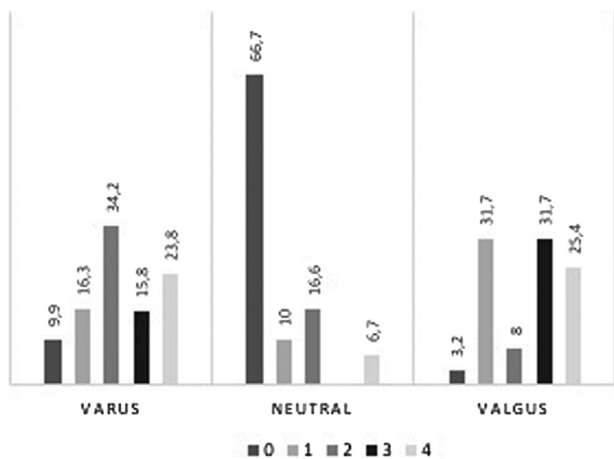
From this cohort of 327 knees, 202 (61.8%) had preoperative varus alignment (HKA angle  $\leq 177^\circ$ ), 60 (18.3%) had neutral alignment (HKA angle =  $180^\circ \pm 3^\circ$ ) and 65 (19.9%) had valgus alignment (HKA angle  $\geq 183^\circ$ ). In cases of preoperative varus alignment, the deformity was found at the tibia in 34.2% (69/202) of patients, an intra-articular deformity in 23.8% (48/202), femoral deformity in 16.3% (33/202), a combined femoral with tibial deformity in 15.8% (32/202) and no substantial deformity was found in 9.9% (20/202). In cases of preoperative neutral alignment, the deformity was found at the tibia in 16.6% (10/60) of patients, an intra-articular deformity in 6.7% (4/60), femoral deformity in 10.0% (6/60) and no substantial deformity was found in 66.7% (40/60). In those with valgus malalignment, the deformity was identified at the femur for 31.7% (21/65) of patients, an intra-articular deformity in 25.4% (16/65), tibial deformity in 8% (5/65), a combined femoral with tibial deformity in 31.7% (21/65) and no substantial deformity was found in 3.2% (2/65) (Fig. 4).

The femoral and tibial preoperative angular values according to global lower limb alignment and desired corrections for HKA, MPTA, LDFA and PPTA when an associated sagittal plane correction for posterior tibial slope correction was planned are given on Table 1. For preoperative varus alignment subgroup, mean intended correction was  $8.3 \pm 2.8^\circ$  for HKA,  $8.7 \pm 3.2^\circ$  for MPTA,  $10.0 \pm 5.6^\circ$  for LDFA. For neutral alignment subgroup, mean intended correction was  $6.8 \pm 2.4^\circ$  for HKA,  $7.1 \pm 2.4^\circ$  for MPTA,  $5.0 \pm 2.4^\circ$  for LDFA. For valgus alignment subgroup, mean intended correction was  $7.9 \pm 3.2^\circ$  for HKA,  $6.6 \pm 1.7^\circ$  for MPTA,  $8.5 \pm 2.8^\circ$  for LDFA and  $5.7 \pm 3.0^\circ$  for PPTA (Table 1).





**Fig. 3.** Type 2 abnormality: error in the site of the correction. Patient with a global varus deformity of 11° has been corrected only at the tibial side despite a persistent abnormal varus deformity at the femur [lateral distal femoral angle (LDFA)=95°] leading to an uncorrected abnormal bone morphology. The mean anatomical LDFA found in the literature is 87° and LDFA >93° represents an uncommon bony morphology (<0.5% of healthy patients).



**Fig. 4.** Preoperative specific deformity according to the alignment phenotype. 0: no femoral or tibial major deformity [global hip-knee-ankle angle (HKA) deformity]; 1: femoral deformity; 2: tibial deformity; 3: femoral and tibial deformity; 4: intra-articular deformity (joint line convergence angle > 2°).

The global rate of planned abnormalities after tibial virtual osteotomy was 50.7% (166/327) with abnormalities type 1 in 44% (144/327) and type 2 in 6.7% (22/327). After femoral virtual osteotomy the global rate was 6.7% (22/327) with only abnormalities type 1.

The type of abnormalities according to the preoperative lower limb alignment and the osteotomy site are given on Table 2. After virtual osteotomy for varus alignment, type 1 abnormalities were found in 4% (8/202) at the femur and 49.5% (100/202) at the tibia, type 2 abnormalities were found in 8.9% (18/202) only after tibial osteotomy. For neutral alignment, type 1 abnormalities were

found in 3.3% (2/60) at the femur and 56.7% (34/60) at the tibia, type 2 abnormalities were found in 3.3% (2/60) only after tibial osteotomy. For valgus alignment, type 1 abnormalities were found in 18.5% (12/65) at the femur and 15.4% (10/65) at the tibia, type 2 abnormalities were found in 3.0% (2/65) only after tibial osteotomy.

A lower preoperative HKA was significantly associated with a non-anatomical correction ( $R^2 = 0.12$ ,  $p < 0.001$ ) for both femoral ( $R^2 = 0.06$ ,  $p < 0.001$ ) and tibial ( $R^2 = 0.07$ ,  $p < 0.001$ ) abnormalities.

Into the HTO group, the rate of type 1 and 2 abnormality was 63.1% (166/263), 37.9% (22/58) into the DFO group and 33.3% (2/6) into the DLO group (Table 3). After virtual DFO, mean LDFA was  $87.7 \pm 2.1^\circ$  for anatomical correction,  $91.0 \pm 6.6^\circ$  for abnormalities type 1 and  $92.4 \pm 5.3^\circ$  for abnormalities type 2. After virtual HTO, mean MPTA was  $88.8 \pm 2.5^\circ$  for anatomical correction and  $92.4 \pm 5.3^\circ$  for abnormalities type 2 (Table 4 and Fig. 5).

#### 4. Discussion

This study highlights that half the cases analysed had non-anatomical correction with persistent bony deformity following osteotomy. A preoperative varus alignment was more associated with postoperative abnormal bone morphology (type 1) and abnormalities were frequently detected following virtual HTO planning compared to others osteotomies. Thus, patients with preoperative varus had 49.5% of abnormal tibial anatomy once the virtual osteotomy was planned.

Hungerford and Krakow described a normal mechanical axis at  $180^\circ$  with LDFA and MPTA of  $87^\circ$  which mean a slightly tibia vara and femoral valga [23], which was confirmed by recent studies finding an average MPTA at  $86-87^\circ$  and LDFA at  $87^\circ$  in non-osteoarthritic patients [17-21]. While satisfactory mechanical alignment is sought, the anatomy may not be appropriate and

**Table 1**  
Anatomic parameters observed and corrected desired values according to phenotype alignment.

Anatomic parameters	Varus ( $n = 202$ ) (HKA $\leq 177^\circ$ )		Neutral ( $n = 60$ ) (HKA = $180 \pm 3^\circ$ )		Valgus ( $n = 65$ ) (HKA $\geq 183^\circ$ )	
	Mean $\pm$ SD	Range (min–max)	Mean $\pm$ SD	Range (min–max)	Mean $\pm$ SD	Range (min–max)
Preoperative HKA angle ( $^\circ$ )	172.6 $\pm$ 5.0	149.8–177.0	179.5 $\pm$ 1.6	177.1–182.4	187.2 $\pm$ 3.1	184.0–196.5
Desired HKA angle ( $^\circ$ )	181.7 $\pm$ 3.1	164.3–188.0	184.9 $\pm$ 3.9	176.5–189.9	180.6 $\pm$ 5.1	170.0–192.3
Desired correction for HKA ( $^\circ$ )	8.3 $\pm$ 2.8	0.4–16.5	6.8 $\pm$ 2.4	3.0–12.0	7.9 $\pm$ 3.2	4.0–19.0
Preoperative MPTA ( $^\circ$ )	83.6 $\pm$ 3.6	66.9–90.0	86.2 $\pm$ 2.4	82.5–94.0	89.6 $\pm$ 3.2	83.0–96.5
Desired MPTA ( $^\circ$ )	91.6 $\pm$ 3.9	79.9–102.0	92.0 $\pm$ 4.6	79.1–101.4	87.8 $\pm$ 3.6	80.6–97.3
Desired correction for MPTA ( $^\circ$ )	8.7 $\pm$ 3.2	3.7–20.0	7.1 $\pm$ 2.4	3.0–12.0	6.6 $\pm$ 1.7	4.0–10.0
Preoperative LDFA ( $^\circ$ )	88.8 $\pm$ 3.5	79.2–99.7	86.7 $\pm$ 2.2	83.0–93.0	82.8 $\pm$ 3.2	72.8–87.0
Desired LDFA ( $^\circ$ )	88.5 $\pm$ 3.2	74.6–98.8	87.2 $\pm$ 2.3	84.0–93.0	88.6 $\pm$ 0.5	82.0–98.0
Desired correction for LDFA ( $^\circ$ )	10.0 $\pm$ 5.6	4.0–22.0	5.0 $\pm$ 2.4	3.0–8.0	8.5 $\pm$ 2.8	5.0–14.8
Preoperative PPTA ( $^\circ$ )	82.5 $\pm$ 4.7	72.3–103.0	83.0 $\pm$ 4.4	72.4–92.7	83.4 $\pm$ 6.0	66.4–92.0
Desired PPTA ( $^\circ$ )	83.5 $\pm$ 4.1	76.0–103.0	84.4 $\pm$ 5.2	72.4–102.4	84.6 $\pm$ 5.0	74.3–94.7
Desired correction for PPTA ( $^\circ$ )	7.3 $\pm$ 4.5	2.0–24.0	8.3 $\pm$ 6.4	2.0–24.0	5.7 $\pm$ 3.0	2.0–8.7

HKA: hip-knee-ankle angle; LDFA: lateral distal femoral angle; MPTA: medial proximal tibial angle; PPTA: posterior plateau tibial angle.

**Table 2**  
Rate of abnormalities according to preoperative phenotype alignment and site of osteotomy (femur or tibia).

	Varus ( $n = 202$ ) (HKA $\leq 177^\circ$ )	Neutral ( $n = 60$ ) (HKA = $180 \pm 3^\circ$ )	Valgus ( $n = 65$ ) (HKA $\geq 183^\circ$ )	All alignments considered
<b>Femur</b>				
No abnormality	176 (87.1%)	56 (93.3%)	51 (78.5%)	283 (86.5%)
Abnormality type 1	8 (4%)	2 (3.3%)	12 (18.5%)	22 (6.7%)
Abnormality type 2	0 (0%)	0 (0%)	0 (0%)	0 (0%)
<b>Tibia</b>				
No abnormality	102 (50.5%)	26 (43.3%)	55 (84.6%)	183 (56%)
Abnormality type 1	100 (49.5%)	34 (56.7%)	10 (15.4%)	144 (44%)
Abnormality type 2	18 (8.9%)	2 (3.3%)	2 (3.0%)	22 (6.7%)

HKA: hip-knee-ankle angle; abnormality type 1: creating bone morphology's out of the normal range; abnormality type 2: leaving bone morphology's out of the normal range.

**Table 3**  
Rate of abnormalities according to the type of osteotomy (femoral tibial or double level).

	No abnormality	Abnormality types 1 and 2
HTO ( $n = 263$ )	97 (36.9%)	166 (63.1%)
DFO ( $n = 58$ )	36 (62.1%)	22 (37.9%)
DLO ( $n = 6$ )	4 (66.7%)	2 (33.3%)

HTO: high tibial osteotomy; DFO: distal femoral osteotomy; DLO: double level osteotomy; abnormality type 1: creating bone morphology's out of the normal range; abnormality type 2: leaving bone morphology's out of the normal range.

osteotomy can lead to altered JLO or unexpected overcorrection due to intra-articular deformity [34,35]. In others cases, bone deformity is associated with intra-articular deformity and prosthesis should

**Table 4**  
Mean values of LDFA and MPTA values in patients anatomically corrected and those with abnormalities.

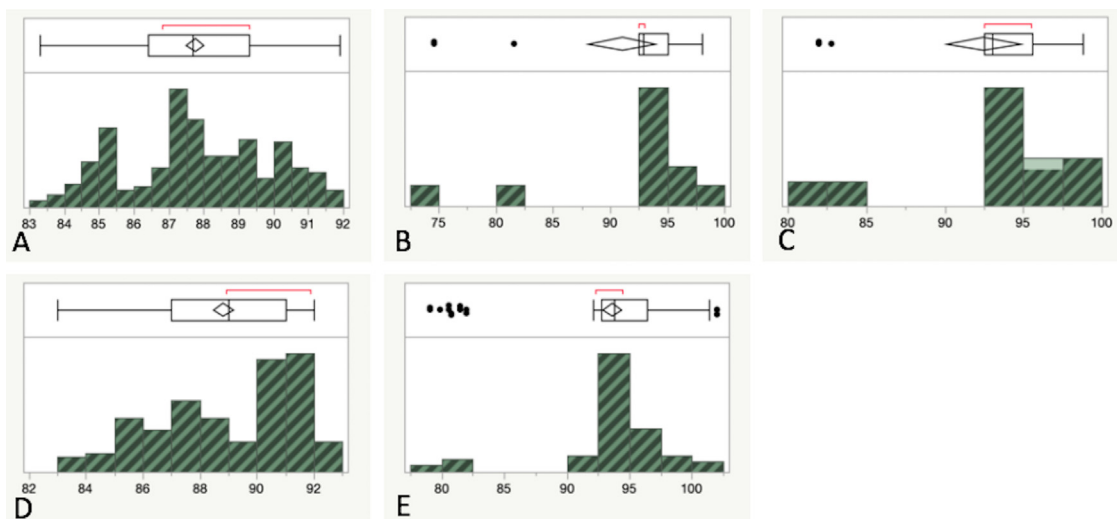
	No abnormality		Abnormality type I	
	Mean $\pm$ SD	Range (min–max)	Mean $\pm$ SD	Range (min–max)
<b>Varus alignment</b>				
Desired MPTA ( $^\circ$ )	89.3 $\pm$ 2.4	83.6–92.0	94.0 $\pm$ 3.6	79.9–102.0
Desired LDFA ( $^\circ$ )	87.7 $\pm$ 3.5	74.6–98.8	89.3 $\pm$ 2.7	84.0–98.0
<b>Neutral alignment</b>				
Desired MPTA ( $^\circ$ )	89.1 $\pm$ 2.6	84.0–92.0	94.1 $\pm$ 4.6	79.1–101.4
Desired LDFA ( $^\circ$ )	87.1 $\pm$ 2.8	84.1–93.0	87.3 $\pm$ 1.8	84.0–90.6
<b>Valgus alignment</b>				
Desired MPTA ( $^\circ$ )	87.9 $\pm$ 2.3	83.0–91.7	87.4 $\pm$ 7.8	80.6–97.3
Desired LDFA ( $^\circ$ )	89.4 $\pm$ 3.4	83.3 $\pm$ 98.0	84.2 $\pm$ 1.3	82.0–85.3

LDFA: lateral distal femoral angle; MPTA: medial proximal tibial angle.

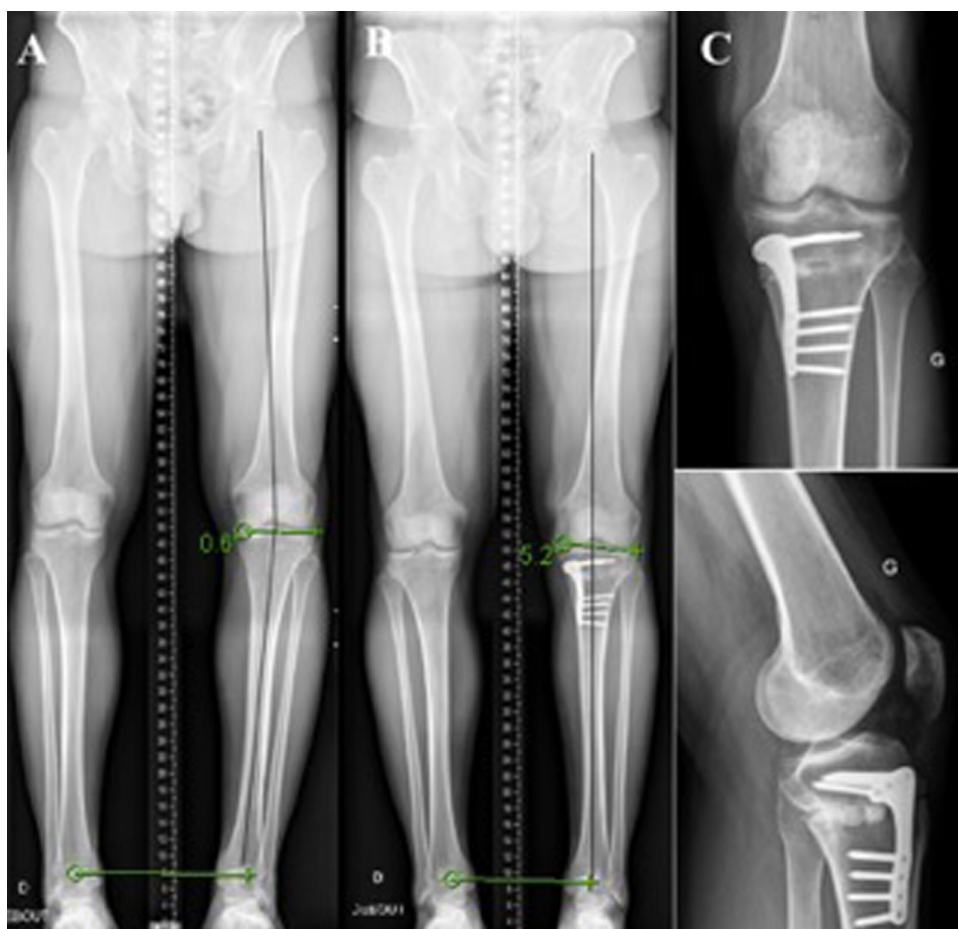
be considered [36,37]. The reasons that might explain why abnormalities are planned before osteotomy may be due to a wrong site osteotomy, thus 8.9% of patient with varus malalignment planned for HTO should probably have a DFO or a DLO. Secondly, the effective degree of correction required to achieve satisfactory offloading is not established.

Traditionally, a valgus correction to achieve a weight-bearing axis between 65–70° [2,38] is recognised but should not be carried out at the expense of too much degree of tibial correction, because it would lead to a non-anatomical JLO [34,39,40] (Fig. 6). Nakayama et al. concluded that detrimental stress to the articular cartilage is induced by JLO over 5° after HTO [15] and an increase of 1° of correction angle during HTO increases by 0.46° the JLO suggesting that tibial correction angle is the only factor that may be controlled [41]. Similarly, it was found that MPTA > 95° was associated with JLO greater than 4° [14].

Feucht et al. recently showed that 57% of patients could be corrected with an isolated HTO and 33% will required a DLO when



**Fig. 5.** Distribution of lateral distal femoral angle (LDFA) and medial proximal tibial angle (MPTA) values in patients anatomically corrected and those with abnormalities. A. LDFA distribution in anatomical correction subgroup. B. LDFA distribution in abnormality type 1 subgroup. C. LDFA distribution in abnormality type 2 subgroup. D. MPTA distribution in anatomical correction subgroup. E. MPTA distribution in abnormality type 2 subgroup.



**Fig. 6.** Illustrative case of increase joint line obliquity after osteotomy. A. Preoperative global varus deformity of 8° with a tibial [medial proximal tibial angle (MPTA) = 85°] and femoral [lateral distal femoral angle (LDFA) = 93°] varus, obliquity of the joint line was almost parallel to the floor [joint line obliquity (JLO) = 0.6°]. B. Correction of the global alignment based on the mechanical axis [neutral postoperative alignment with hip-knee-ankle angle (HKA) angle about 180°]. All the correction was performed on the tibia (MPTA = 94°) with the creation of an oblique joint line (JLO = 5.2°). C. Standard radiographs of the osteotomy showing that no technical error explain the increase of the JLO. A double level osteotomy could be considered to correct the femoral varus and avoid an oblique joint line.

slight tibial “overcorrection” is simulated ( $90^\circ \leq \text{MPTA} \leq 95^\circ$ ), he advocated that in case of “anatomic” tibial correction ( $\text{MPTA} \leq 90^\circ$ ), only 12% of patients could be corrected with isolated HTO, and 63% would require a DLO [28]. In the present study, 49.5% of the

tibia with global varus were corrected to an abnormal value and 8.9% of the femur were not corrected while a preoperative deformity existed, which mean that an isolated HTO would be ideal for at most 50.5% (100–49.5) and at least 41.6% (100–49.5–8.9)

supposing that the correction was realised to obtain a neutral HKA angle target. This results were different to those from Feucht et al. [28] explained by the fact that we did not include healthy patients and patients with severe osteoarthritis but only patients with mild to moderate osteoarthritis and that we measured angular values on 3D-reconstructed CT scans allowing more accuracy than full-leg standing radiographs.

More contemporary techniques are analogous to moving towards a kinematic osteotomy concept and avoid an “all in the tibia” correction for varus without consideration of the femur or intra-articular deformity. There is even less consensus when it comes to planning osteotomy surgery for preoperative genu valgum, with all degrees of correction (neutral, under and over) proposed [5,42,43]. In large corrections for valgus alignment, DLO can also be needed because excessive JLO following proximal tibial varus osteotomy for valgus osteoarthritis which leading to unsatisfactory outcome [44]. This concept of double level osteotomy has been well described by Saragaglia et al. who showed that it was a reliable and reproducible technique in severe genu varum with computer-assistance especially to avoid oblique joint line and restore anatomical morphology [24–26].

There are several limitations to this study. Firstly, the retrospective nature of the study which could lead to selection bias, for example a proportion of patients had a neutral alignment without femoral or tibial major deformity ( $n=40$ ) for which indications for HTO may be debatable, but the distribution for angular values was normal suggesting that population was well represented. Secondly, the threshold standard values for MPTA and LDFA have been arbitrarily selected but based on the mean published values with their 97.5% confidence intervals. Thirdly, given that this study was a projection analysis of desired planning, it was not possible to evaluate the effective postoperative correction but it was assumed that surgeons mostly followed the preoperative planning with patient-specific guide allowing an accuracy closed to  $1^\circ$  [32], in the same way, a loss of correction is possible at long-term follow-up [45] but does not affect the preoperative planning.

A future study examining the real postoperative correction of a large cohort of surgeons would give valuable information about non-anatomical correction and correlation with clinical outcomes. The exact indications for osteotomy and osteoarthritis status were not known, thus some surgeons might have performed osteotomy with slight correction for patients with advanced arthritis with the sole objective of relieving the pain. In these cases undercorrection might have occurred.

Despite these limitations, this study showed that anatomical correction is obtain in less than a half of patients planned for corrective osteotomy using a 3D software and that errors are preferentially made at tibial side after OWHTO as it constitute a privileged area comparing to femur to perform osteotomy due to its accessibility. While errors committed by the surgeons may indeed concern an overcorrection of the tibia, this is explained by the desire to correct a global lower limb deformity represented by the HKA angle in the tibia. This “all in the tibia” correction may lead to an excessive joint line obliquity or to the correction of an intra-articular deformity with unexpected postoperative correction errors and also greater risk of JLO. Even advanced systems allowed accurate correction, the site of osteotomy and degree of correction remains at the discretion of the surgeon, DFO or DLO should be considered in cases of the expected correction would induce a non-anatomical tibia with higher joint obliquity.

## 5. Conclusion

Non-anatomical correction was found in more than half the cases analysed more frequently for preoperative global varus

alignment. These results suggest that surgeons should considered anatomical angular values to avoid joint line obliquity.

## Ethical approval

The local ethics committee approved our study protocol prior to investigation.

## Informed consent

NA.

## Disclosure of interest

GM, FG, HF, RK, CJ and ME declare that they have no competing interest.

KK and MO are educational consultant for Stryker, Arthrex and Newclip.

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## Authors' contribution

MO designed the protocol and performed statistical analysis. FG and GM collected the data. GM wrote the initial draft and performed revisions of subsequent drafts. MO, KK and RK corrected the different versions of the draft. HF, CJ and ME assisted in writing and revised the manuscript. All the authors approved the submitted version.

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## References

- [1] Coventry MB. Proximal tibial varus osteotomy for osteoarthritis of the lateral compartment of the knee. *J Bone Joint Surg Am* 1987;69:32–8.
- [2] Fujisawa Y, Masuhara K, Shiomi S. The effect of high tibial osteotomy on osteoarthritis of the knee. An arthroscopic study of 54 knee joints. *Orthop Clin North Am* 1979;10:585–608.
- [3] Sprenger TR, Doerzbacher JF. Tibial osteotomy for the treatment of varus gonarthrosis. Survival and failure analysis to twenty-two years. *J Bone Joint Surg Am* 2003;85:469–74.
- [4] Van den Bempt M, Van Genechten W, Claes T, Claes S. How accurately does high tibial osteotomy correct the mechanical axis of an arthritic varus knee? A systematic review. *Knee* 2016;23:925–35.
- [5] Zilber S, Larrouy M, Sedel L, Nizard R. Distal femoral varus osteotomy for symptomatic genu valgum: long-term results and review of the literature. *Rev Chir Orthop Reparatrice Appar Mot* 2004;90:659–65.
- [6] Bouguennec N, Mergenthaler G, Gicquel T, Briand C, Nadau E, Pailhé R, et al. Medium-term survival and clinical and radiological results in high tibial osteotomy: factors for failure and comparison with unicompartmental arthroplasty. *Orthop Traumatol Surg Res* 2020;106:S223–30 [S1877056820302267].
- [7] Hernigou P, Medevielle D, Debeyre J, Goutallier D. Proximal tibial osteotomy for osteoarthritis with varus deformity. A ten to thirteen-year follow-up study. *J Bone Joint Surg Am* 1987;69:332–54.
- [8] Jung W-H, Takeuchi R, Chun C-W, Lee J-S, Ha J-H, Kim J-H, et al. Second-look arthroscopic assessment of cartilage regeneration after medial opening-wedge high tibial osteotomy. *Arthroscopy* 2014;30:72–9.
- [9] Kyung BS, Kim JG, Jang K-M, Chang M, Moon Y-W, Ahn JH, et al. Are navigation systems accurate enough to predict the correction angle during high tibial osteotomy? Comparison of navigation systems with 3-dimensional computed tomography and standing radiographs. *Am J Sports Med* 2013;41:2368–74.
- [10] Lee D-H, Han S-B, Oh K-J, Lee JS, Kwon J-H, Kim J-I, et al. The weight-bearing scanogram technique provides better coronal limb alignment than the navigation technique in open high tibial osteotomy. *Knee* 2014;21:451–5.
- [11] Tsuji M, Akamatsu Y, Kobayashi H, Mitsugi N, Inaba Y, Saito T. Joint line convergence angle predicts outliers of coronal alignment in navigated open-wedge high tibial osteotomy. *Arch Orthop Trauma Surg* 2019;140:707–15.
- [12] Dowd GSE, Somayaji HS, Uthukuri M. High tibial osteotomy for medial compartment osteoarthritis. *Knee* 2006;13:87–92.



- [13] Sim JA, Kwak JH, Yang SH, Choi ES, Lee BK. Effect of weight-bearing on the alignment after open wedge high tibial osteotomy. *Knee Surg Sports Traumatol Arthrosc* 2010;18:874–8.
- [14] Akamatsu Y, Kumagai K, Kobayashi H, Tsuji M, Saito T. Effect of increased coronal inclination of the tibial plateau after opening-wedge high tibial osteotomy. *Arthroscopy* 2018;34 [2158–2169.e2].
- [15] Nakayama H, Schröter S, Yamamoto C, Iseki T, Kanto R, Kurosaka K, et al. Large correction in opening wedge high tibial osteotomy with resultant joint-line obliquity induces excessive shear stress on the articular cartilage. *Knee Surg Sports Traumatol Arthrosc* 2018;26:1873–8.
- [16] Kuriyama S, Watanabe M, Nakamura S, Nishitani K, Sekiguchi K, Tanaka Y, et al. Classical target coronal alignment in high tibial osteotomy demonstrates validity in terms of knee kinematics and kinetics in a computer model. *Knee Surg Sports Traumatol Arthrosc* 2020;28:1568–78.
- [17] Bellemans J, Colyn W, Vandenuecker H, Victor J. The Chitranjan Ranawat Award: is neutral mechanical alignment normal for all patients? The concept of constitutional varus. *Clin Orthop Relat Res* 2012;470:45–53.
- [18] Cooke D, Scudamore A, Li J, Wyss U, Bryant T, Costigan P. Axial lower-limb alignment: comparison of knee geometry in normal volunteers and osteoarthritis patients. *Osteoarthritis Cartilage* 1997;5:39–47.
- [19] Hirschmann MT, Moser LB, Amsler F, Behrend H, Leclercq V, Hess S. Phenotyping the knee in young non-osteoarthritic knees shows a wide distribution of femoral and tibial coronal alignment. *Knee Surg Sports Traumatol Arthrosc* 2019;27:1385–93.
- [20] Micicoi G, Jacquet C, Sharma A, LiArno S, Faizan A, Kley K, et al. Neutral alignment resulting from tibial vara and opposite femoral valgus is the main morphologic pattern in healthy middle-aged patients: an exploration of a 3D-CT database. *Knee Surg Sports Traumatol Arthrosc* 2021;29:849–58.
- [21] Shetty GM, Mullaji A, Bhayde S, Nha KW, Oh HK. Factors contributing to inherent varus alignment of lower limb in normal Asian adults: role of tibial plateau inclination. *Knee* 2014;21:544–8.
- [22] Kapandji I. *Physiologie articulaire. Fascicule II. Quatrième édition : membre inférieur*. Paris: Maloine; 1974.
- [23] Hungerford DS, Krackow KA. Total joint arthroplasty of the knee. *Clin Orthop Relat Res* 1985;192:23–33.
- [24] Saragaglia D, Rubens-Duval B, Chaussard C. Doubles ostéotomies assistées par ordinateur dans les grands genu varum. *Rev Chir Orthop Reparatrice Appar Mot* 2007;93:351–6.
- [25] Saragaglia D, Mercier N, Colle P-E. Computer-assisted osteotomies for genu varum deformity: which osteotomy for which varus? *Int Orthop* 2010;34:185–90.
- [26] Saragaglia D, Blaysat M, Mercier N, Grimaldi M. Results of forty two computer-assisted double level osteotomies for severe genu varum deformity. *Int Orthop (SICOT)* 2012;36:999–1003.
- [27] Saragaglia D, Chedal-Bornu B. Computer-assisted osteotomy for valgus knees: medium-term results of 29 cases. *Orthop Traumatol Surg Res* 2014;100:527–30.
- [28] Feucht MJ, Winkler PW, Mehl J, Bode G, Forkel P, Imhoff AB, et al. Isolated high tibial osteotomy is appropriate in less than two-thirds of varus knees if excessive overcorrection of the medial proximal tibial angle should be avoided. *Knee Surg Sports Traumatol Arthrosc* 2020 [Open Access / Published 20 July 2020].
- [29] Munier M, Donnez M, Ollivier M, Flecher X, Chabrand P, Argenson J-N, et al. Can three-dimensional patient-specific cutting guides be used to achieve optimal correction for high tibial osteotomy? Pilot study. *Orthop Traumatol Surg Res* 2017;103:245–50.
- [30] Jacquet C, Sharma A, Fabre M, Ehlinger M, Argenson J-N, Parratte S, et al. Patient-specific high-tibial osteotomy's 'cutting-guides' decrease operating time and the number of fluoroscopic images taken after a Brief Learning Curve. *Knee Surg Sports Traumatol Arthrosc* 2020;28:2854–62.
- [31] Tardy N, Steltzlen C, Bouguennec N, Cartier J-L, Merti P, Bataillé C, et al. Is patient-specific instrumentation more precise than conventional techniques and navigation in achieving planned correction in high tibial osteotomy? *Orthop Traumatol Surg Res* 2020;106:S231–6 [S1877056820302358].
- [32] Donnez M, Ollivier M, Munier M, Berton P, Podgorski J-P, Chabrand P, et al. Are three-dimensional patient-specific cutting guides for open wedge high tibial osteotomy accurate? An in vitro study. *J Orthop Surg Res* 2018;13:171.
- [33] Moser LB, Hess S, Amsler F, Behrend H, Hirschmann MT. Native non-osteoarthritic knees have a highly variable coronal alignment: a systematic review. *Knee Surg Sports Traumatol Arthrosc* 2019;27:1359–67.
- [34] Babis GC, An K-N, Chao EYS, Rand JA, Sim FH. Double level osteotomy of the knee: a method to retain joint-line obliquity. Clinical results. *J Bone Joint Surg Am* 2002;84:1380–8.
- [35] Goto N, Akasaki Y, Okazaki K, Kuwashima U, Iwasaki K, Kawamura H, et al. The influence of post-operative knee coronal alignment parameters on long-term patient-reported outcomes after closed-wedge high tibial osteotomy. *J Orthop* 2020;20:177–80.
- [36] Catonné Y, Khiami F, Sariali E, Ettori M-A, Delattre O, Tillie B. Same-stage total knee arthroplasty and osteotomy for osteoarthritis with extra-articular deformity. Part II: femoral osteotomy, prospective study of 6 cases. *Orthop Traumatol Surg Res* 2019;105:1055–60.
- [37] Catonné Y, Sariali E, Khiami F, Rouvillain J-L, Wajsfisz A, Pascal-Moussellard H. Same-stage total knee arthroplasty and osteotomy for osteoarthritis with extra-articular deformity. Part I: tibial osteotomy, prospective study of 26 cases. *Orthop Traumatol Surg Res* 2019;105:1047–54.
- [38] Goshima K, Sawaguchi T, Shigemoto K, Iwai S, Fujita K, Yamamuro Y. Comparison of clinical and radiologic outcomes between normal and overcorrected medial proximal tibial angle groups after open-wedge high tibial osteotomy. *Arthroscopy* 2019;35 [2898–2908.e1].
- [39] Hofmann S, Lobenhoffer P, Staubli A, Van Heerwaarden R. Osteotomies of the knee joint in patients with monocompartmental arthritis. *Orthopade* 2009;38:755–69 [quiz 770].
- [40] Lee KM, Chang CB, Park MS, Kang S-B, Kim TK, Chung CY. Changes of knee joint and ankle joint orientations after high tibial osteotomy. *Osteoarthritis Cartilage* 2015;23:232–8.
- [41] Park J-Y, Chang CB, Kang D-W, Oh S, Kang S-B, Lee MC. Development and validation of a prediction model for knee joint line orientation after high tibial osteotomy. *BMC Musculoskelet Disord* 2019;20:434.
- [42] Healy WL, Anglen JO, Wasilewski SA, Krackow KA. Distal femoral varus osteotomy. *J Bone Joint Surg Am* 1988;70:102–9.
- [43] Zarrouk A, Bouzidi R, Karray B, Kammoun S, Mourali S, Kooli M. Distal femoral varus osteotomy outcome: is associated femoropatellar osteoarthritis consequential? *Orthop Traumatol Surg Res* 2010;96:632–6.
- [44] Shoji H, Insall J. High tibial osteotomy for osteoarthritis of the knee with valgus deformity. *J Bone Joint Surg Am* 1973;55:963–73.
- [45] Dares M, Putman S, Brosset T, Roumazielle T, Pasquier G, Migaud H. Opening-wedge high tibial osteotomy performed with locking plate fixation (Tomofix) and early weight-bearing but without filling the defect. A concise follow-up note of 48 cases at 10 years' follow-up. *Orthop Traumatol Surg Res* 2018;104:477–80.