

The Results of Patient-Specific Instrument Guided Chevron-cut Distal Femur Osteotomy: A Retrospective Analysis

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Abstract

Background

Distal femur osteotomy (DFO) has been gaining popularity in treating subjects with genu valgum and the associated lateral compartment osteoarthritis. However, the risk of non-union and a period of protective weight bearing still remain unsolved even with the advent of locking plates. To improve the inherent stability of medial close-wedge DFO, we create bone cut in chevron shape with the guidance of a patient-specific instrument (PSI). The patients were allowed immediate weight-bearing as tolerated. The objective of the study was to assess the results of this technique.

Methods

Twenty-five knees in twenty-three consecutive patients with genu valgum and lateral compartment osteoarthritis received chevron-cut medial close-wedge DFO. The alignment parameters of the knee, including the weight-bearing line (WBL) ratio, hip-knee-ankle angle (HKA), and mechanical lateral distal femoral angle (mLDFA) were assessed. We defined outliers as those with a difference of more than 10% from the targeted 50% WBL ratio. Patient-reported evaluation included the Oxford Knee Score (OKS), Knee Society Score (KSS), and a visual analog scale (VAS) pain scale.

Results

The WBL ratio, HKA, and mLDFA were corrected from a mean of $78.7\% \pm 12.0\%$, $9.3^\circ \pm 2.8^\circ$ valgus, and $83.6^\circ \pm 1.9^\circ$ to $48.7\% \pm 2.9\%$, $0.5^\circ \pm 1.1^\circ$ varus, and $91.4^\circ \pm 3.5^\circ$ (respectively) postoperatively. A mean operative time of 58.8 ± 18.3 minutes, and 6.2 ± 1.3 intraoperative radiographs were taken. A mean Hb drop of 1.4 g/dl was found, while no patient required transfusion. Only one knee (4%) postoperatively fell in the defined range of correction outliers. Consolidation of the osteotomy was achieved at 11.3 ± 2.8 weeks. The OKS, KSS, and VAS pain scale were significantly improved compared with the pre-operative data. Complications developed in three patients, including one periprosthetic fracture, one loss of fixation, and a case of non-union.

Conclusion

The PSI-guided chevron-cut close-wedge DFO, followed by immediate weight-bearing as tolerated is accurate, safe, and effective in the correction of genu valgum deformity and the associated lateral compartment osteoarthritis.

Level of evidence IV

Background

Distal femur osteotomy (DFO) has been gaining popularity in treating subjects with genu valgum deformity and the associated lateral compartment osteoarthritis. Although genu valgum deformity can

also be corrected with a high tibial osteotomy, deformity greater than 10° is better corrected with DFO to avoid iatrogenic joint line obliquity [1, 2].

The valgus correction with DFO can be performed with either a medial close-wedge or lateral open-wedge technique. Although survival rates after the two procedures are similar, medial close-wedge DFO offers the advantage of native bone-to-bone healing and inherent stability, and thus an earlier start of weight-bearing [3, 4]. Nevertheless, the conventional close-wedge technique is troubled with a 3%-25% rate of delayed union or non-union, a 5% rate of loss of correction, and malrotated correction [5, 6] [7, 8]. The rate of delayed union or non-union hovered around 4%-5% even with the advent of locking plates [8, 9].

To further improve the inherent stability, as well as to increase the contact area of the osteotomized bone, we attempted cutting in a chevron-shape. After the surgery, we allowed weight bearing as tolerated by the patients. Chevron-cut close-wedge osteotomy requires four accurate bone cuts converging to the hinge point, while the bone cuts are not perpendicular to the AP view of intraoperative radiographs. It is therefore hardly practical with a conventional freehand technique, but may be feasible with the guide of a patient-specific instrument (PSI).

The objective of this study was to assess the results of the first 23 consecutive patients with 25 knees, having symptomatic osteoarthritis related to genu valgum, who were operated on using this technique.

Materials And Methods

This study was a retrospective review, and approved by an institutional board. Twenty-three consecutive patients with 25 knees undergoing PSI guided chevron-cut DFO were identified from June 2017 to April 2019. The inclusion criteria of surgery were patients with valgus deformity of the knee with pain at the lateral side, attributable to lateral compartment osteoarthritis. Exclusion criteria of the surgery included inflammatory arthritis, ligamentous instability of the knee, osteonecrosis of the lateral femoral condyle, or severe multicompartamental arthritis [10]. All patients were operated on by a single surgeon (JCSY).

Preoperative planning

A commercialized patient-specific alignment guide and associated locking plate system was utilized (Anatomic Precision PSI DFO; A-plus Bio., New Taipei City, Taiwan). The osteotomy was first planned on the full-length weight-bearing anteroposterior (AP) radiograph with the aid of software (OsteoMaster; 2017 Luo Chu An). The hinge was set on the internal cortex of the lateral epicondyle of the femur and targeting the corrected WBL ratio to 50% (Figure 1).

Subsequently, the plan on AP radiograph and 3D reconstructed computer tomography (CT) images was sent to the manufacturer of the plating system. With the aid of software, a virtual 3D model was created, transferring the 2D planning to the 3D-reconstructed CT images by correlating anatomy landmarks. The chevron cut was set at a 110-degree angle, with the axis parallel to the medullary canal, the apex pointing distally. Then the wedge thickness, correction angle, and depth of bone cut were calculated on the virtual

3D model. A disposable, single-use, 3D-printed cutting jig made of polyamide was then manufactured to guide the planned osteotomy. The parameters of cutting were printed on the guide as a reminder during the surgery (Figure 2).

Surgical technique

Spinal anesthesia was used in all patients. The patient was placed in a supine position, and a standard medial approach to the distal femur was used [11]. The periosteum was elevated from the target femoral surface. Then the customized cutting jig was placed onto the medial cortex, identifying the ideal spot with an anatomical fit of the guide. Two orientation K-wires were then inserted through the K-wire holes at the apexes of the chevron cut. Positioning was confirmed with a C-arm. Then four K-wires were inserted, fixing the guide on the bone. Subsequently, the orientation K-wires were removed. Osteotomy was performed with an oscillating saw with a length scale. The cutting guide was removed after the osteotomy. We then closed the osteotomy with gentle manual bending, and fixed the associated locking plate system. An alignment rod was not used (Figure 3).

Postoperative care

Oral analgesics were administered according to the standard pain protocol. Thrombo-embolic prophylaxis was not used. All patients received continuous passive motion of the knee twice a day, and ice-packing every 2 hours. Weight-bearing as tolerated was allowed immediately postoperatively. The use of a walker was suggested during the admission time, until the patient could stay balanced while walking. Standard AP and lateral radiographs were taken every 4 weeks until union of the osteotomy gap was evident. Full-length weight-bearing AP radiographs were taken preoperatively, 2-days postoperatively, and on clinical follow-up every 3 months until consolidation of the osteotomy, and then every year.

Outcome assessment

The operative time, the number of intra-operative radiographs, the hemoglobin (Hb) level preoperatively, and on the second day postoperatively, as well as complications were collected from the medical charts. Parameters of alignments, including mechanical lateral distal femur angle (mLDFA), hip-knee-ankle angle (HKA), and WBL ratio were measured automatically with software (OsteoMaster; 2017 Luo Chu An). The parameters were compared between the preoperative, 2-day postoperative, and final full-length weight-bearing radiographs. We defined outliers as those with a difference of more than 10% from the targeted 50% WBL ratio.

Union of the osteotomy was evaluated clinically by the absence of pain and radiographically by diminished osteotomy gap. The active range of motion (ROM) of the knee joint was measured with a goniometer. The patient-reported evaluation included the Knee Society Score (KSS), the Oxford Knee Score (OKS), and a pain score on a visual analogue scale (VAS) ranging from zero to ten, with zero denoting no pain and ten the worst possible pain.

Statistics

Data were analyzed with SPSS (IBM Corp. Released 2013. IBM SPSS Statistics for Windows, Version 22.0. Armonk, NY: IBM Corp).

Descriptive data were summarized using means and standard deviations. To compare the changes of alignment parameters (pre-operative versus post-operative versus final) and patient-reported evaluation (KSS and OKS), a paired t-test and nonparametric sign test were used. Correlation between the HKA and WBL ratio was analyzed using linear regression analysis.

Results

Twenty-three patients with 25 knees were included in this study. The mean age was 65 ± 8 years-old and the percentage of female patients was 78.2%. The mean follow-up duration was 17 ± 8 months (range 12-37). The baseline characteristics are shown in Table 1.

The mean operative time was 58.8 ± 18.3 minutes, while an average of 6.2 ± 1.3 radiographs was taken intraoperatively. The patients were admitted for an average of 6.9 ± 2.1 days. The Hb dropped from a mean of 13.5 ± 1.3 g/dl preoperatively to 12.1 ± 1.2 g/dl postoperatively ($p=0.001$). No patient received blood transfusion (Table 2).

Consolidation of the osteotomy was achieved at a mean of 11.3 ± 2.8 weeks. The OKS improved from a mean of 27.6 ± 11.7 preoperatively to a mean of 39.1 ± 7.5 on the final follow-up ($p=0.03$). The KSS improved from a mean of 63.8 ± 4.5 preoperatively to a mean of 91.8 ± 6.4 on the final follow-up ($p<0.001$). The VAS pain scale improved from a mean of 4.0 ± 1.0 preoperatively to a mean of 0.9 ± 0.8 on the final follow-up ($p<0.001$). The final active ROM was unchanged from 131 ± 4 to 128 ± 10 ($p=0.18$) (Table 3).

Radiological results

The WBL ratio was corrected significantly from a mean of $78.7\% \pm 12.0\%$ preoperatively to $48.7\% \pm 2.9\%$ by day 2 postoperatively ($p<0.001$). Meanwhile, the HKA was corrected significantly from a mean of $9.3^\circ \pm 2.8^\circ$ valgus to $0.5^\circ \pm 1.1^\circ$ varus ($p<0.001$). The mLDFA changed significantly from a mean of $83.6^\circ \pm 1.9^\circ$ to $91.4^\circ \pm 3.5^\circ$ ($p<0.001$). The WBL ratio, HKA, and mLDFA remained unchanged from 2-days postoperatively to the final radiographs ($p=0.44$, $p=0.58$, and $p=0.32$, respectively). Only one knee (4%) at 2-days postoperatively and two knees (8%) in the final radiographs fell in the defined range of correction outliers (Table 4, Figure 4).

Postoperative complications

Three complications were identified. One case (4%) of loss of fixation resulted from a fall 6-weeks postoperatively. The patient received revision medial plating using the same implants. One patient (4%) experienced periprosthetic fracture, due to a traffic accident, superior to the implants 5 weeks postoperatively. The patient received removal of plate and fixation with a retrograde interlocking nail. Non-union happened in one knee of a patient (4%) with a smoking habit, who received simultaneous

bilateral DFO. The patient received bone grafting and additional plating at the lateral side seven months after the initial surgery.

Discussion

The present study demonstrated that PSI guided chevron-cut close-wedge DFO, followed by immediate weight bearing as tolerated achieved targeted correction in 92% of patient, and consolidation of the osteotomy at 11.3 weeks. There was a short mean operative time of 58.8 minutes, 6.2 intraoperative radiographs, and no blood transfusion was required.

DFO is a widely accepted treatment option for lateral uni-compartmental arthritis associated with valgus deformity. It improves pain and function of the affected knee [6, 12, 13], as well as patellar tracking and patellofemoral arthritis [14]. Satisfactory results and a high rate of survivorship with total knee arthroplasty as the endpoint was found across studies at 10 years, ranging from 78% to 89 %. The rate generally declined to 45-71% at 15 years, and 24% at 20 years [12, 14-16].

We planned the target with a WBL ratio instead of HKA, since the WBL ratio is more subtle in minor corrections [17]. In the current study, a linear regression study evaluating the association between the WBL ratio and HKA found a correlation coefficient of 3.2.

The medial close-wedge and lateral open-wedge provide similar union, survival, and complication rates [3, 4, 11]. However, after lateral open-wedge DFO, a 4-12 weeks period of non-weight bearing is typically required, while immediate partial weight bearing was allowed after medial close-wedge DFO in most series.[4] Besides, bone grafting is often required, and the plate seating under the iliotibial band commonly irritates and leads to a 40-86% rate of removal [4, 5, 13, 18, 19]. We therefore prefer to perform medial close-wedge DFO.

Although close-wedge osteotomy theoretically offers the advantage of native bone-to-bone healing and inherent stability, the conventional technique is not without associated complications. A 3%-25% rate of delayed union or non-union, a 5% rate of loss of correction, and malrotated correction have been mentioned in several studies [5, 6] [7, 8]. Union of the osteotomy ranged from 2-9 months [4]. The rate of delayed union or non-union hovered around 4%-5%, even with the advent of locking plates [8, 9].

To improve the inherent stability of osteotomy, biplanar osteotomy had been proposed [9]. Further saw-bone studies found the femoral contact surface of biplanar osteotomy increase more than two-fold in comparison to the uniplanar technique [20]. However, a subsequent biomechanical study found that biplanar osteotomy, counter-intuitively, is less stable under torsion force than the single-plane technique [21]. This may be explained by the observation in a clinical study by Nha et al., which found that the anterior wedge of osteotomy is prone to fracture in patients with a small size of the femur [22]. Without a solid anterior wedge, the contact area is not different from single plane osteotomy.[20]

To address the shortcoming of the weak anterior wedge, chevron-shape osteotomy seems to be a reasonable design. It has been shown to be one of the biomechanically superior constructs, and is utilized in various sites of the body [23-25]. In comparison to the biplanar technique, the chevron-cut technique avoids the posterior condyle in addition to the femoral trochlea. Therefore, it bears the potential to place the osteotomy site more distally, into the area of cancellous bone in the femur, a region with better healing potential (Figure 5).

In our study, the mean time to union was 11.3 weeks. The rate of non-union or loss of fixation (both 4%) were non-inferior in comparison with the literature. Notably, the patients were allowed immediate weight bearing as tolerated, in contrast with a typical 6-8 weeks of partial weight bearing in most series of close-wedge DFO [4]. Furthermore, the age of the current studied population averaged 65 years, which was older than that in most studies. In addition, two factors that likely contributed to the non-union were the smoking habit of the patient, and simultaneous bilateral surgery. Further mechanical studies and a control group may be required to demonstrate whether chevron-cut osteotomy leads to better mechanical property or clinical outcomes.

Chevron-cut close-wedge osteotomy requires four accurate bone cuts converging to the hinge point, while the bone cuts are not perpendicular to the AP view of intraoperative radiographs. It is therefore hardly practical with a conventional freehand technique, as the closing-wedge technique is already known to be difficult, and highly reliant on preoperative planning and accurate bone cutting [3, 4, 26].

Several techniques have been proposed to increase the accuracy of DFO, such as computer-assisted navigation surgery [27]. But the technique is currently limited by the longer learning curve, prolonged operative time, as well as the rather expensive cost [28].

The use of PSI is another promising technique. It has been compared in three studies with conventional DFO techniques. Arnal-Burró et al. and Jacquet et al. studied the application in the uniplanar open-wedge technique (a single bone cut). The PSI groups in both studies achieved less alignment deviation in comparison with the conventional groups (0.28° v.s. 1.8° and 0.52° v.s. 3.1°) [29, 30]. Shi et al. performed the uniplanar close-wedge technique (two bone cuts) with cutting guides with a bolt to ensure an accurate reduction. They reported less deviation from the surgical plan in comparison with the conventional group (4.9% v.s. 7.6%) [17]. The current study attempted the use of PSI in a chevron-cut close-wedge technique (four bone cuts). The deviation from the plan was 1.3% in terms of the WBL ratio, and 0.5° in terms of HKA. The results were non-inferior to the PSI groups of previous studies.

In the current study, a mean operative time of 58.8 minutes, and an average of 6.2 intraoperative radiographs were required. The results were also similar to the previous studies, finding the PSI groups take 39.5-77.7 minutes (7.7-32 minutes less time than the freehand groups), and 5-6 intraoperative images (7-59 less than the freehand groups) [29-31].

Limitations

The limitations of the present study were the relatively low number of patients included, and the lack of a control group. Secondly, this cohort consisted of the first patients who were operated on with this new technique, and it is therefore likely that there was a learning curve. Thirdly, union of the fracture was evaluated clinically and on radiographs, instead of CT-scans. The alignment measurements were also made on radiographs, instead of CT-scans.

Conclusion

This study showed that PSI-guided chevron-cut close-wedge DFO, followed by immediate weight-bearing as tolerated is accurate, safe, and effective in the correction of genu valgum deformity and the associated lateral compartment osteoarthritis.

Declarations

Ethics approval and consent to participate: Approval was obtained from the ethics committee of Taipei Veterans General Hospital. No. 2020-04-011AC

Consent for publication: All individuals are consent to publication of the article

Availability of data and materials: The dataset supporting the conclusions of this article is included within the article and its additional file

Competing interests: The authors have no relevant financial or non-financial interests to disclose.

Funding: No funding was received for conducting this study.

Authors' contributions: JCSY was the operating surgeon of all cases and conceived of the study. KJC researched literature, designed the study, and wrote the first draft of the manuscript. KYL involved in literature review, measurements, and data analysis. YCH involved in literature review and created the figures. OKL were involved in literature review, data analysis, and aid in designing the study. All authors reviewed and edited the manuscript and approved the final version of the manuscript.

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Tables

Table 1. Demographic data of patients

Characteristic	Value
Sex (men:women ratio)	3:20
Age (years, mean and range)	64 (47-80)
Involved extremity (Right: Left)	15:11
BMI (mean \pm SD and range)	27 \pm 5 (19-37)
Smoking	3
Medical comorbidities	
Hypertension	10
Diabetes mellitus	6
Peptic ulcer	3
Chronic obstructive pulmonary disease	3
Dyslipidemia	2
Kellgren Lawrence grade	
1	12
2	11
3	2
Follow up (months, mean \pm SD and range)	17 \pm 8 (12-37)

BMI = Body mass index

Table 2. Intraoperative and Perioperative parameters

	Value
Operative time (minute)	58.8 \pm 18.3
Intraoperative radiograph (number)	6.2 \pm 1.3
Hospital stay (day)	6.9 \pm 2.1
Preoperative Hb (g/dL)	13.5 \pm 1.3
Hb level on day 1 (g/dL)	12.1 \pm 1.2

Values presented in mean \pm standard deviation

Hb = hemoglobin

Table 3. Clinical and Patient-rated outcomes before and after operation

Outcomes	Values		
	Pre-operation	Post-operation	p-value
Active ROM (°)	131 ± 4	128 ± 10	0.18
OKS score	27.6 ± 11.7	39.1 ± 7.5	0.03*
KSS score	63.8 ± 4.5	91.8 ± 6.4	<0.001*
VAS pain scale	4.0 ± 1.0	0.9 ± 0.8	<0.001*

Values presented in mean ± standard deviation

ROM = range of motion, OKS = Oxford Knee Score, KSS = Knee Society Score, VAS = visual analogue scale

*statistically significant

Table 4. Radiological results before and after operation

Outcomes	Values		
	Pre-operation	2-day Post-operation (p value, comparing with Pre-operation)	Final (p value, comparing with 2-day Post-operation)
WBL ratio (%)	78.7 ± 12.0	48.7 ± 2.9 (<0.001) *	48.1 ± 3.8 (0.44)
HKA (°)	9.3 ± 2.8 valgus	0.5 ± 1.1 (<0.001) varus *	0.3 ± 1.4 (0.58) varus
mLDFA (°)	83.6 ± 1.9	91.4 ± 3.5 (<0.001) *	90.8 ± 3.7 (0.32)

Values presented in mean ± standard deviation

WBL = weight bearing line, HKA = hip-knee-ankle angle, mLDFA = mechanical lateral distal femoral angle

*statistically significant

Figures

Figure 1

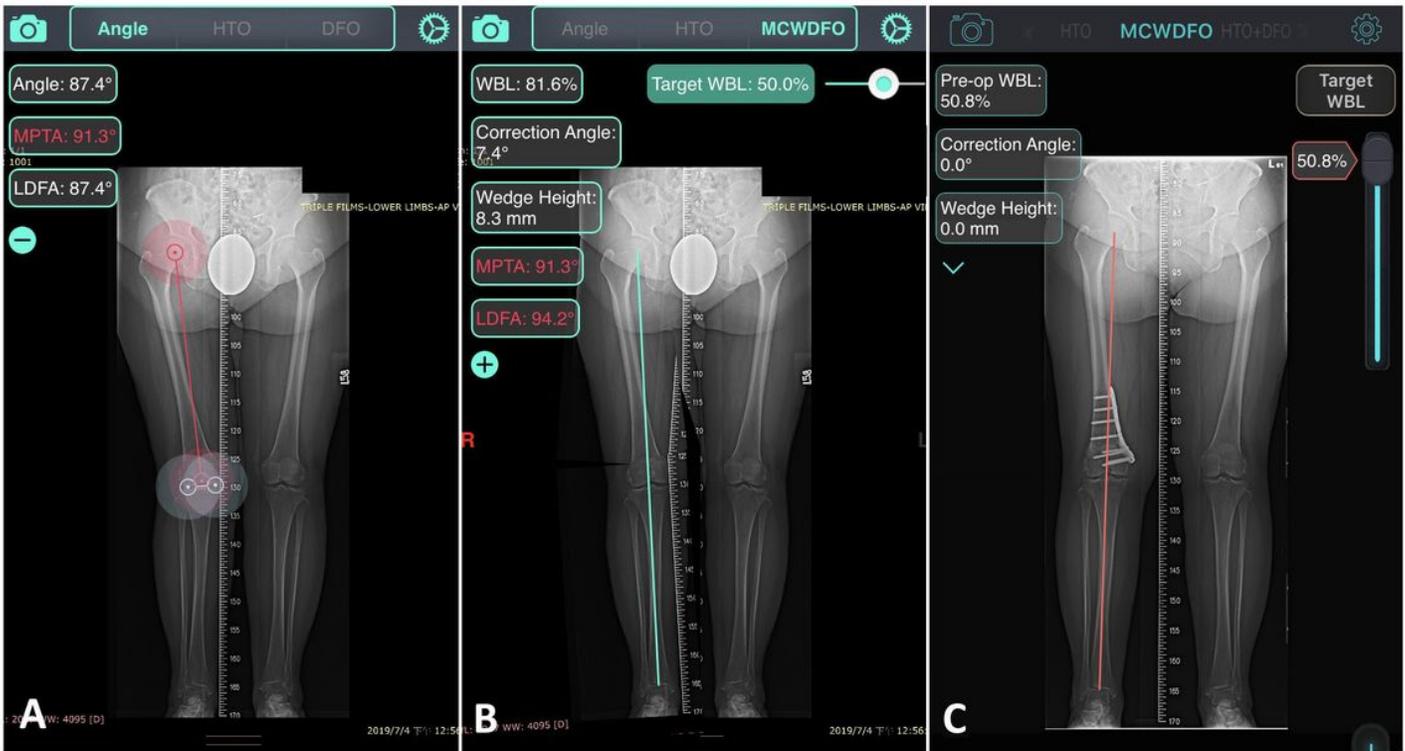


Figure 1

Digital Preoperative Planning. (A) The full-length weight-bearing AP radiograph of a 67 year old female with valgus deformity of the right knee. With the aid of software, the femorotibial angle, MPTA, and LDFA were measured automatically. (B) A 2D simulation of the osteotomy, setting the target of correction at 50% on the WBL ratio. The correction angle, wedge height, and LDFA after correction were simulated by the software. (C) The full-length weight-bearing AP radiograph of the same patient one year after DFO. The WBL ratio was corrected to 50.8%.

Figure 2

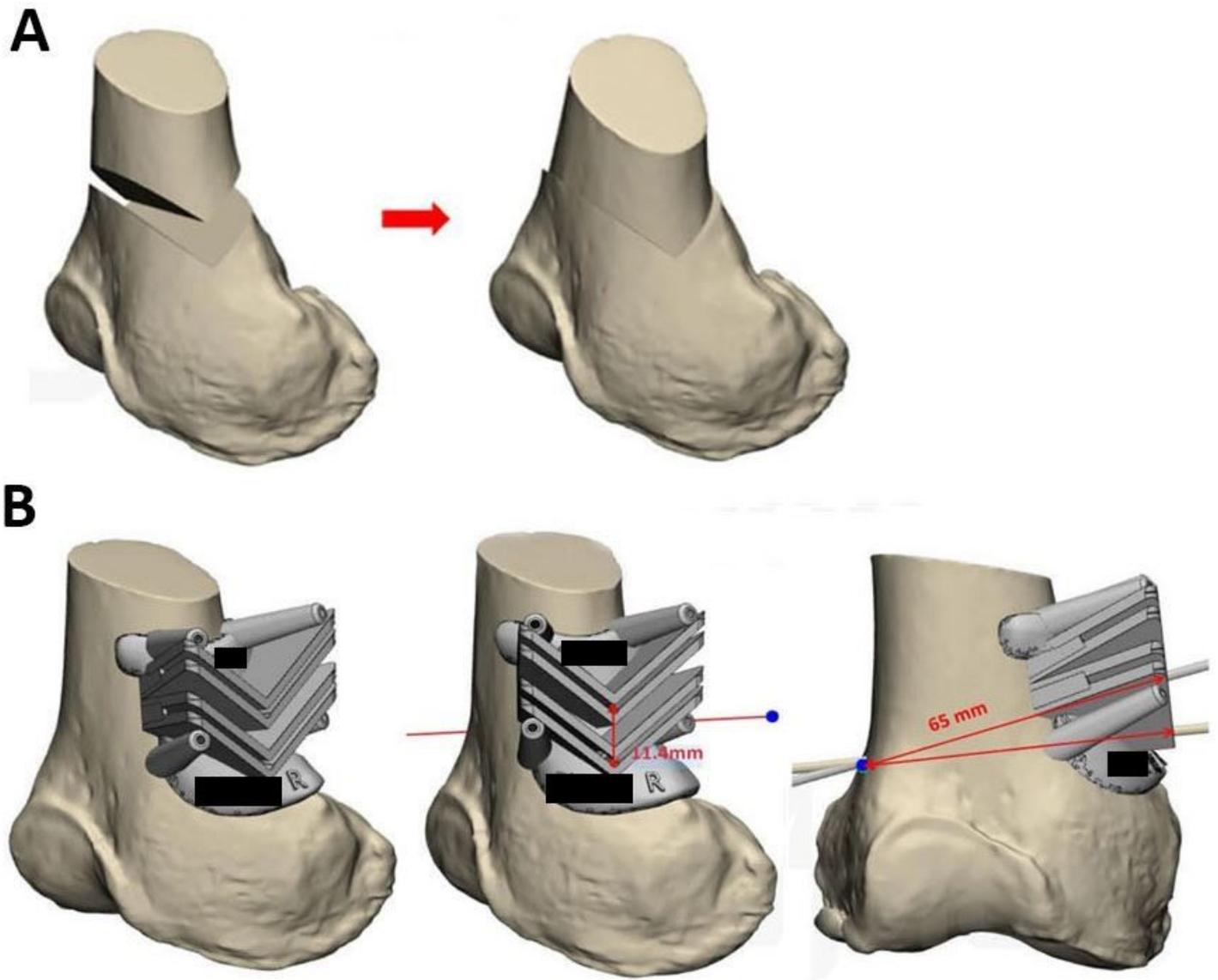


Figure 2

Digital 3D Model Simulation of DFO. (A) The 3D virtual model of the patient in Figure 1. The osteotomy and correction after close-wedge DFO were simulated. (B) A 3D simulation of the 3D-printed cutting jig. The wedge thickness, correction angle, and depth of bone cut was calculated on the virtual 3D model and printed on the guide as a reminder during the surgery.

Figure 4

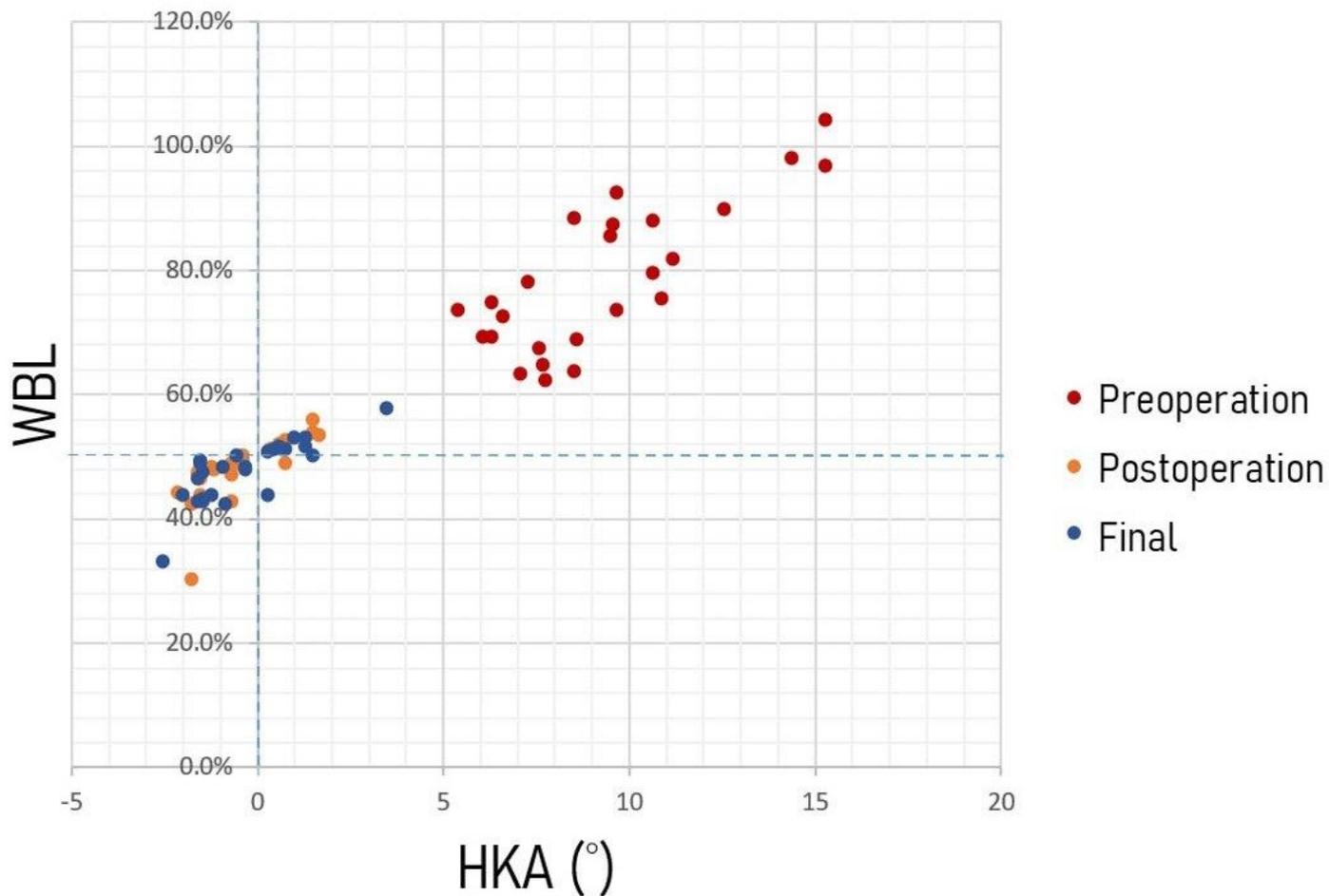


Figure 4

The scattered plot of HKA and WBL ratio. The scattered plot of the patients' HKA and WBL ratio preoperatively, 2-days postoperatively, and at the final follow-up. Only one knee (4%) at 2-days postoperatively and two knees (8%) in final radiographs fell in the defined range of correction outliers. A linear regression study evaluating the association between the WBL ratio and HKA found a correlation coefficient of 3.2. ($p < 0.001$).

Figure 5

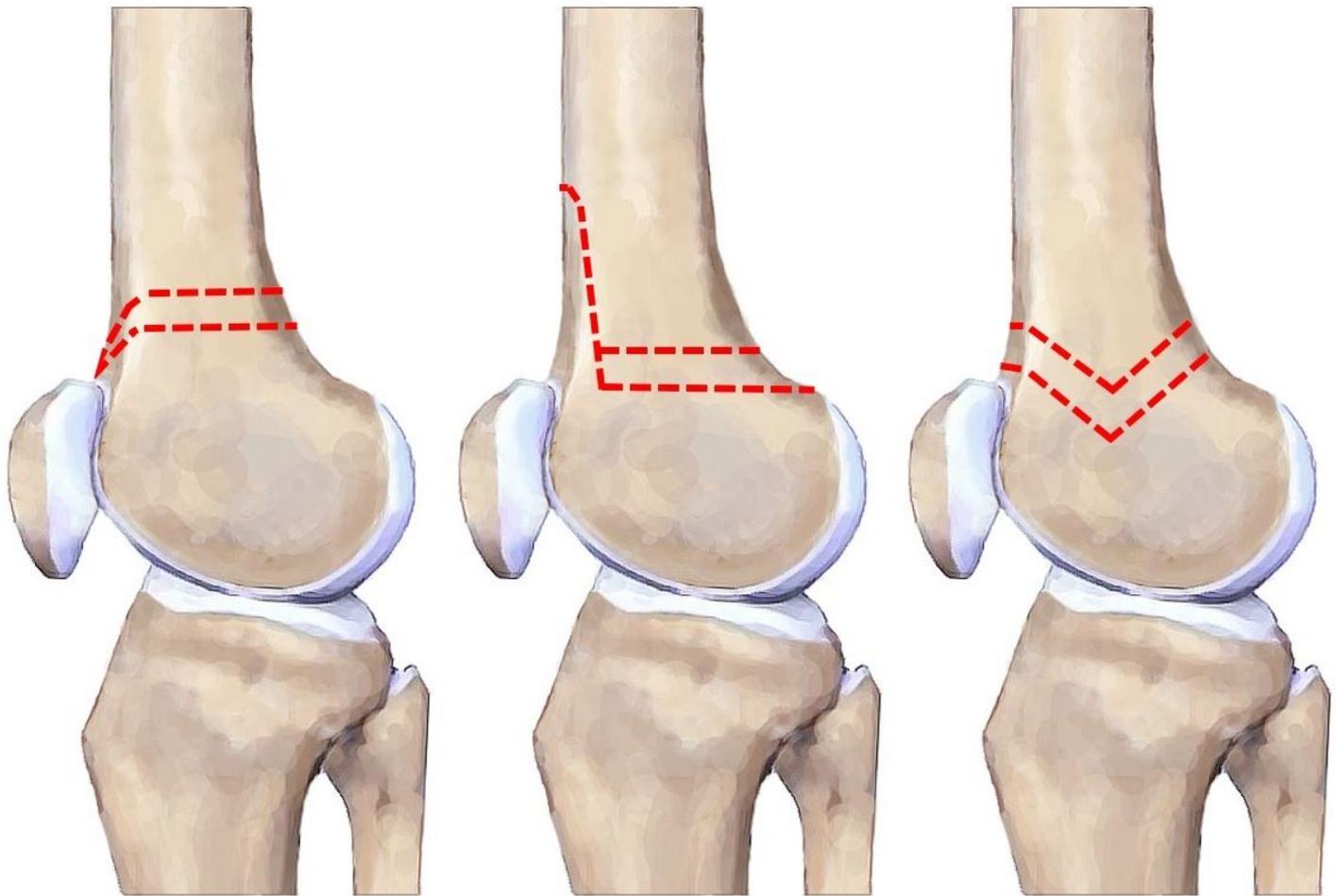


Figure 5

A comparison of the uniplanar technique (A), the “three-cut” biplanar technique (B), and the “four-cut” chevron-cut technique of DFO (C). Note that the distal-most possible site of the biplanar is farther than in the uniplanar technique, since it avoids the femoral trochlea. The chevron-cut technique may be performed even more distally, since it also avoids the posterior condyle of the femur.

Supplementary Files

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- [Additionalfile1.xlsx](#)