

# Clinical Efficacy of Distal Tibial Tuberosity High Tibial Osteotomy Using The $\pi$ -Plate in Obese Patients With Varus Knee Osteoarthritis: A Retrospective Study

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## Research article

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# Abstract

**Background:** High tibial osteotomy (HTO) is an effective treatment for varus knee osteoarthritis. However, obese patients require reinforced internal fixation materials to prevent internal fixation fractures and hardware failure after osteotomy. Thus, the purpose of our study was to evaluate the clinical efficacy of distal tibial tuberosity high tibial osteotomy (DTT-HTO) using the new patented  $\pi$ -plate in obese patients with varus knee osteoarthritis.

**Methods:** Thirty-four obese patients (39 knees) with varus knee osteoarthritis who underwent DTT-HTO with the  $\pi$ -plate and second-look arthroscopy when implant removal occurred from September 2017 to June 2020 were retrospectively reviewed. There were 9 males and 25 females, with body mass index (BMI) values ranging from 30.3 to 38.5 kg/m<sup>2</sup> and ages ranging from 50 to 75 years old. The radiological assessment was performed with the weight-bearing line ratio (WBLR). The clinical outcomes were evaluated by the Hospital for Special Surgery (HSS) knee score and the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC). The status of the cartilage was evaluated by the International Cartilage Repair Society (ICRS) grading system.

**Results:** All patients were followed up for 18-30 months. The WBLR significantly increased from 16.85±2.20 to 55.41±2.46% from before surgery to the last follow-up after surgery (P<0.001). The HSS score significantly improved from 56.65±5.27 preoperatively to 68.79±2.61, 77.82±2.15, and 86.12±2.78 at the 6-month, 12-month, and last follow-up after surgery (P<0.001). The WOMAC score significantly decreased from 105.47±3.89 preoperatively to 80.50±4.20, 71.44±4.65, and 52.44±3.14 at the 6-month, 12-month, and last follow-up after surgery (P<0.001). During implant removal, no internal fixation fractures occurred in any patient. The articular cartilage grade in the medial compartment of the knee were significantly higher in the second arthroscopy than in the first arthroscopy, according to the ICRS grading system (P < 0.001). The articular cartilage grade in the lateral compartment of the knee showed no statistical differences from the first- to the second-look arthroscopy (p > 0.05).

**Conclusions:** The new patented  $\pi$ -plate is an effective internal fixation material to provide good structural stability in DTT-HTO. And DTT-HTO using the  $\pi$ -plate can yield excellent clinical results in obese patients with varus knee osteoarthritis.

## Background

Knee osteoarthritis (KOA) is a disease with a degenerative lesion morphology, and its incidence rate increases significantly with an increasing body mass index (BMI). The incidence of KOA increases by 15% for every one-unit increase in BMI in people with a heavier body weight [1, 2]. BMI is currently an internationally recognized index for assessing the degree of body fat and thinness. According to the classification standards of the World Health Organization, obesity is defined as 30.0 < BMI ≤ 34.9 kg/m<sup>2</sup>, severe obesity is defined as 35.0 < BMI ≤ 39.9 kg/m<sup>2</sup>, and extreme obesity is defined as ≥ 40.0 kg/m<sup>2</sup> [3]. In

China, the number of obese patients with KOA is 2.06 times higher than that of the non-obese patients with KOA [4].

High tibial osteotomy (HTO) is considered an effective treatment for varus knee osteoarthritis and has been reported to yield good long-term clinical outcomes [5, 6]. However, some studies [7, 8] have shown that obesity is one of the main factors leading to surgical failure after HTO, and the postoperative failure rate increases by 10 times when the patient has a BMI greater than 30 kg/m<sup>2</sup>. Thus, it is still controversial whether obesity should be an exclusion criterion for HTO due to the supposed increased risk of osteotomy angle loss, internal fixation fracture and delayed wound healing.

With the development of new surgical techniques and instruments, many shortcomings of HTO in terms of indications have been gradually overcome. Here, we present a surgical technique, distal tibial tuberosity high tibial osteotomy (DTT-HTO), with the new patented  $\pi$ -plate for fixation in obese patients with varus knee osteoarthritis. The  $\pi$ -plate can effectively prevent angle loss and internal fixation fractures due to its high levels of strength and stability, and simultaneously, more screws can be added to support knee loads [9].

To our knowledge, no studies have yet assessed the efficacy of DTT-HTO in treating obese patients with varus knee osteoarthritis. Therefore, the present study aimed to evaluate the clinical efficacy of distal tibial tuberosity high tibial osteotomy using the  $\pi$ -plate in obese patients with varus knee osteoarthritis.

## Methods

### Patients selection

This study was a retrospective review of thirty-four patients and thirty-nine knees (from 9 males and 25 females) who underwent DTT-HTO using the  $\pi$ -plate and second-look arthroscopy when implant removal occurred from September 2017 to June 2020 at our institution. The inclusion criteria for this study were as follows: (1) BMI [3]  $\geq 30$  kg/m<sup>2</sup>, (2) having undergone DTT-HTO and arthroscopy twice during surgery and implant removal and at least 18 months of follow-up, (3) flexion contracture  $\leq 15^\circ$ ,  $5^\circ \leq$  varus deformity  $\leq 20^\circ$ , active range of motion of the knee  $> 90^\circ$ , and (4) medial knee pain, Kellgren-Lawrence grade [10]  $\geq$  II. The exclusion criteria were as follows: (1) postoperative follow-up weight loss and a BMI less than 30 kg/m<sup>2</sup>, (2) severe wear of the lateral compartment or a torn or ruptured cruciate ligament; (3) a history of knee surgery, and (4) severe osteoporosis and rheumatoid arthritis. The patients' demographic characteristics are listed in Table 1.

Table 1  
Demographics of the patients

Demographics	
Number of patients (n)	34(39knees)
BMI (kg/m <sup>2</sup> )	34.64 ± 2.37
Age (years)	63.97 ± 6.06
Sex(male/female)	9/25
Side(left/right)	22/17
Disease course (years)	5.44 ± 2.85
Duration of follow-up (months)	22.76 ± 3.38
Kellgren-Lawrence grade (grade II/III/IV)	15/11/8

## Surgical techniques

All surgical procedures were performed by a single orthopedic senior surgeon. Under combined lumbar and epidural anesthesia, the patient was placed in the supine position, and an inflatable tourniquet was attached to the root of the affected thigh (for backup). Before DTT-HTO, an arthroscopic examination was performed to evaluate the cartilage of the medial and lateral compartments and the patellofemoral joint. The lesion was treated accordingly when necessary. After arthroscopy was completed, the patients underwent locking plate internal fixation for distal tibial tuberosity. Anatomical landmarks (proximal medial joint line, lantern, medial collateral ligament row direction and tibial tubercle) were marked on the skin approximately 2 cm under the joint, and approximately 3 cm from the medial tibial tubercle, an approximately 4 cm long longitudinal incision was made in the distal direction; the medial collateral ligament of the shallow and goose foot tendons were cut incrementally, approximately 1 cm of the proximal medial goose foot tendon was cut longitudinally, and the medial collateral ligament of the shallow tendon and periosteum were moved to reveal the tibia. A Kirschner needle was inserted along the proximal medial tibia joint space approximately 4 cm below the oblique tibiofibular joint margin, and the osteotomy was started after the osteotomy line was confirmed to be satisfactory according to C-arm fluoroscopy of the Kirschner needle (the Kirschner needle was 30° from the vertical line of the tibial axis) (Fig. 1a and b). First, a blunt hook was placed into the tibia from the inside toward the outside of the tibia along the osteotomy line. Then, a horizontal osteotomy was performed with the pendulum saw, and a Kirschner wire was used to reach the osseous hinged area on the outside of the tibia measuring approximately 1 cm. Then, the Kirschner wire was used to drill five holes from the inside toward the outside along the incision plane to reduce the stress on the lateral cortical bone. An assistant held the patient's ankle with one hand and touched the end of the osteotomy with the other hand, slowly stretching the osteotomy surface in a bow-like manner (Fig. c and d). C-arm fluoroscopy was performed to make the tangent angle of the femur and the extension line of the fibular shaft 93° (Fig. e and f). Allograft bone was then filled between the two osteotomies and fixed with a locking metal plate. After

satisfactory fixation was confirmed by C-arm fluoroscopy, a negative pressure drainage ball was placed, and the wound was sutured layer by layer, covered with sterile dressing, and covered with an elastic bandage under pressure (Fig. g and h).

## **Postoperative rehabilitation**

The preoperative planning, intraoperative operation, postoperative rehabilitation exercises and follow-up review were completed by the same group of experienced physicians. On the first day after the operation, active contractile training of the quadriceps and ankle pumps were performed. On the second day after the operation, the passive activity of the knee joint was increased. On the third day after the operation, the drainage tube was removed according to the drainage volume, and a walker was used to assist walking. In the later stage, the patient was asked to use double crutches or single crutches instead of a walker, depending on the patient's recovery state, and eventually, patients walked with full weight bearing.

## **Clinical evaluation**

The Hospital for Special Surgery (HSS) scores, including the pain, function, mobility, muscle strength, stability, and flexion deformity scores, were recorded. The total score possible was 100, and the higher the score, the better the knee function. In addition, the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), including 24 items on pain, stiffness, and joint function, was used to assess knee function preoperatively and at the 6-month, 12-month, and last follow-up after surgery.

## **Radiological evaluation**

The weight-bearing line ratio (WBLR) was measured and recorded preoperatively and at the last follow-up after surgery on full-length standing anteroposterior radiographs. The weight-bearing line was defined as a line drawn from the center of femoral head to the center of ankle joint. The tibial plateau was divided into 100 (the medial tibial edge at 0% and the lateral tibial edge at 100%). The WBLR was defined as the tibial insertion of the WBL/ the tibial width, which was expressed as a percentage.

## **Arthroscopic evaluation**

The articular cartilage of the medial and lateral compartments were evaluated according to the International Cartilage Repair Society (ICRS) [11] grading system through arthroscopy at the initial operation and implant removal. The ICRS grading system classified normal as Grade 0, softening of the articular cartilage and superficial lacerations and fissures as Grade 1, a defect < 50% of the cartilage thickness as Grade 2, a defect > 50% of the cartilage thickness as Grade 3, complete loss of the articular cartilage thickness as Grade 4.

## **Statistical analysis**

SPSS (version 20.0, IBM China) was used for statistical verification, and GraphPad Prism 8.0 software was used for mapping. The WBL values measured preoperatively and at the last follow-up after the surgical procedure were compared by the paired-samples T test. Repeated measures ANOVA was used to

analyze the changes in the HSS score and WOMAC score preoperatively and at the 6-month, 12-month and last follow-up after the surgical procedure. To compare the ICRS grades of the articular cartilage in the medial and lateral compartments based on the arthroscopic findings, the chi-square test or Fisher's exact test was used.  $P < 0.05$  was considered statistically significant.

## Results

### Clinical and radiographic results

All patients were followed up for 18–30 months. The WBLR significantly changed from  $16.85 \pm 2.20$  preoperatively to  $55.41 \pm 2.46\%$  at the last follow-up after surgery ( $t = -66.931$ ,  $P < 0.001$ ) (Fig. 5). The HSS score significantly improved from  $56.65 \pm 5.27$  preoperatively to  $68.79 \pm 2.61$ ,  $77.82 \pm 2.15$ , and  $86.12 \pm 2.78$  at the 6-month, 12-month, and last follow-up after surgery ( $F = 495.614$ ,  $P < 0.001$ ). The WOMAC score significantly decreased from  $105.47 \pm 3.89$  preoperatively to  $80.50 \pm 4.20$ ,  $71.44 \pm 4.65$ , and  $52.44 \pm 3.14$  at the 6-month, 12-month, and last follow-up after surgery ( $F = 1078.898$ ,  $P < 0.001$ ) (Table 2).

Table 2  
HSS score and WOMAC score of 34 obese patients with knee varus osteoarthritis

		Value	p value
HSS score			
Preoperatively	$56.65 \pm 5.27$		
6 months postoperatively	$68.79 \pm 2.61$		
12 months postoperatively	$77.82 \pm 2.15$		
Last follow-up after surgery	$86.12 \pm 2.78$	$F = 495.614$	$P < 0.001$
WOMAC score			
Preoperatively	$105.47 \pm 3.89$		
6 months postoperatively	$80.50 \pm 4.20$		
12 months postoperatively	$71.44 \pm 4.65$		
Last follow-up after surgery	$52.44 \pm 3.14$	$F = 1078.898$	$P < 0.001$

### Secondlook arthroscopic evaluations

At the second-look arthroscopic examination, 6 knees (17.6%) had grade 1 medial femoral condylar cartilage findings, 21 knees (61.8%) had grade 2 findings, 5 knees (14.7%) had grade 3 findings, and 2 knee (5.9%) had grade 4 findings. 5 knees (14.7%) had grade 1 medial tibial plateau articular cartilage findings, 19 knees (55.9%) had grade 2 findings, 7 knees (20.6%) had grade 2 findings, and 3 knee (8.8%) had grade 4 findings (Table 3).

Table 3  
ICRS grades of 34 obese patients with knee varus osteoarthritis

		Value	p value
ICRS grade in the medial femoral condyle (0/1/2/3/4)			
1st look	0/0/7/17/10		
2nd look	0/6/21/5/2	$\chi^2 = 24.879$	$P \leq 0.001$
ICRS grade in the medial tibial plateau (0/1/2/3/4)			
1st look	0/0/9/19/6		
2nd look	0/5/19/7/3	$\chi^2 = 15.110$	$P \leq 0.001$
ICRS grade in the lateral femoral condyle (0/1/2/3/4)			
1st look	31/3/0/0/0		
2nd look	30/4/0/0/0	$\chi^2 = 0.159$	1.000
ICRS grade in the lateral tibial plateau (0/1/2/3/4)			
1st look	30/4/0/0/0		
2nd look	28/6/0/0/0	$\chi^2 = 0.469$	0.734

## Complications

No internal fixation fractures occurred in any patient. No severe complications, such as infection, nonunion of the osteotomy area or deep vein thrombosis, were found in any of the patients. Postoperative incision delayed healing was observed in two patients and was considered to be related to fat liquefaction. After regular dressing changes, suture removal was postponed for one week.

## Discussion

Due to the modern lifestyle, the overweight and obese populations are gradually increasing. Some studies [12, 13] have shown that from 1976 to 2016, there was an increasing trend in obesity globally, with an increase of 5.6% in adult women and 7.8% in men, and 230 million children and adolescents were overweight. In addition, the increase in the prevalence of overweight and obesity was larger than the decrease in the prevalence of underweight. Five percent of individuals with disability due to a high BMI also had musculoskeletal diseases. A number of studies have proven that obesity is a high-risk factor leading to the onset and progression of KOA [14, 15]. Adipose tissue can release a variety of inflammatory factors that affect cartilage matrix synthesis and metabolism, thereby damaging cartilage, causing subchondral bone proliferation, and increasing the risk of knee osteoarthritis [16, 17].

Due to the anatomical structure of the knee joint, the medial compartment is more likely to wear than is the lateral compartment. The medial compartment bears 2/3 of the weight of the whole knee joint, which leads to the narrowing of the medial space and wear, resulting in varus knee deformities. Moreover, obesity can lead to an increase in the angle of the lower limb line of force and aggravate the progression of KOA [18]. HTO is an effective treatment for varus knee osteoarthritis and can effectively correct varus deformities of the knee.

This operation transfers the joint load from the medial compartment affected by osteoarthritis to the relatively healthier lateral compartment, which consequently decompresses the medial compartment of the knee joint. Owing to the realignment of the mechanical alignment of the lower limb, the load on the knee joint is ultimately redistributed to relieve pain and restore knee function. Moreover, HTO combined with arthroscopy can further eliminate articular lesions, can restore the internal environment, and is considered efficacious [19, 20]. Gedam and Supe [5] conducted a 3-year follow-up of 32 patients who underwent HTO combined with arthroscopy and found that 96.9% of the patients had significant improvements in knee joint function and fewer complications.

DTT-HTO is an improved and easier surgical procedure to perform and has some obvious advantages. First, this technique requires only one singular plane transverse osteotomy at the bottom third of the distal tibial tubercle, and the neurovascular and soft tissue near this area requires fewer osteotomies than that above the tibial tubercle. Second, this technique modifies the intersecting angle between femoral condyles and the fibula axis to  $93^\circ$ . A large number of clinical cases have verified Antonescu's claim that the optimal surgical results can last at least 10 to 15 years when overcorrection by  $3^\circ$  to  $6^\circ$  is performed [21]. Third, five holes are drilled along the transverse plane to lessen the stress on the cortical bone and thus prevent bone fractures during the surgical procedure.

Meidinger et al. [22] believe that a higher BMI is associated with a higher risk of postoperative internal fixation loosening. In this operation, the osteotomy area was fixed with a new patented  $\pi$ -plate (Fig. 6). The special two-leg design was used to disperse stress to lessen the load on the main leg and to prevent rotation of the tibia after surgery. Both legs were arranged in a three-point plane with the head to resist the tendency of external rotation. The multiscrew locked design offers superior strength and stability to prevent the screws from breaking or loosening. For obese patients, the high internal fixation force can reduce the extent of correction angle loss, and good stability promotes the early healing of the osteotomy end.

Postoperative rehabilitation for obese patients with varus knee osteoarthritis has received increasing attention from many scholars. Due to insufficient lower limb support and internal fixation loosening, postoperative rehabilitation exercises are commonly delayed. DTT-HTO with the  $\pi$ -plate can prevent the internal fixation instruments from breaking or loosening easily because three-dimensional multi-screw locked fixation is performed, which offers superior strength and stability. At the same time, it allows obese patients to exercise the next day, which is conducive to early postoperative recovery.

## Limitations

This study has several limitations. First, there may have been patient selection bias because this study was not a prospective study, and the data were retrospectively extracted from medical records. Second, this study had a small sample size and a short follow-up time, so only the efficacy in the short and medium term can be confirmed to be good. Additional clinical studies with larger sample sizes and long-term follow-up periods need to be conducted. Third, the maximal BMI in this study was only 38.5 kg/m<sup>2</sup>, and additional studies are required to reach a strong conclusion on the efficacy of DTT-HTO using the  $\pi$  plate in patients with a higher BMI.

## Conclusions

The new patented  $\pi$ -plate is an effective internal fixation material to provide good structural stability in DTT-HTO. And DTT-HTO using the  $\pi$ -plate can yield excellent clinical results in obese patients with varus knee osteoarthritis.

## Abbreviations

HTO: High tibial osteotomy; DTT-HTO: Distal tibial tuberosity high tibial osteotomy; BMI: Body mass index; WBLR: Weight-bearing line ratio; HSS: Hospital for Special Surgery knee score; WOMAC: Western Ontario and McMaster Universities Osteoarthritis Index; ICRS: International Cartilage Repair Society; KOA: Knee osteoarthritis

## Declarations

### *Ethics approval and consent to participate*

The ethics committee of the Third Affiliated Hospital of Beijing University of Chinese Medicine approved this study.

### *Consent for publication*

Signed informed consent for publication was obtained from all authors.

### *Competing interests*

All authors declare no conflicts of interest.

### *Funding*

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## ***Authors' contributions***

Study design: XDT, JW, YH, and YTT. Administrative support: XDT. Surgery performance: XDT, JW, YTT, SM, and YYH. Data collection: YH, CXH, HDC, and TSD. Data analysis: YH, CXH, and HDC. Writing manuscript: YH and YTT. Approving final version of manuscript: XDT and JW. All authors read and approved the final manuscript.

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## ***Authors' information***

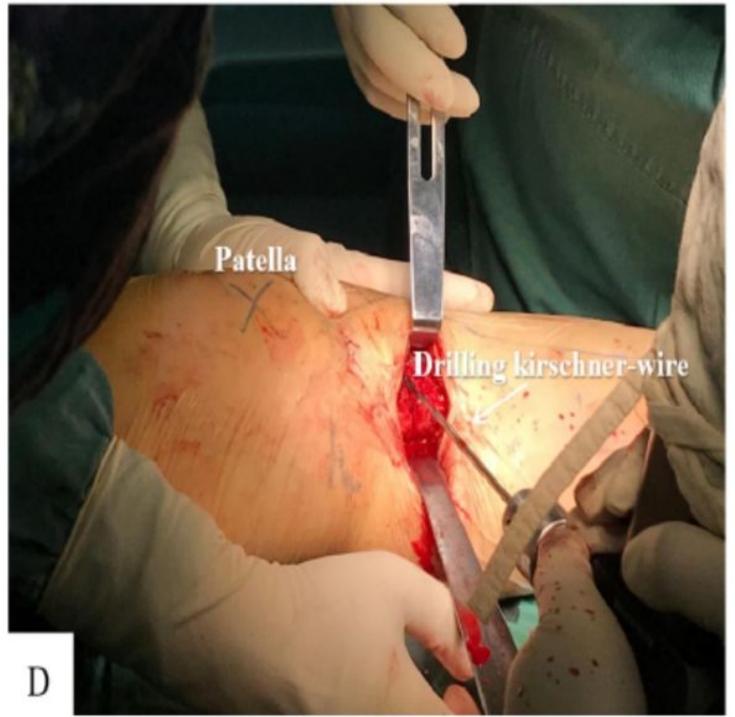
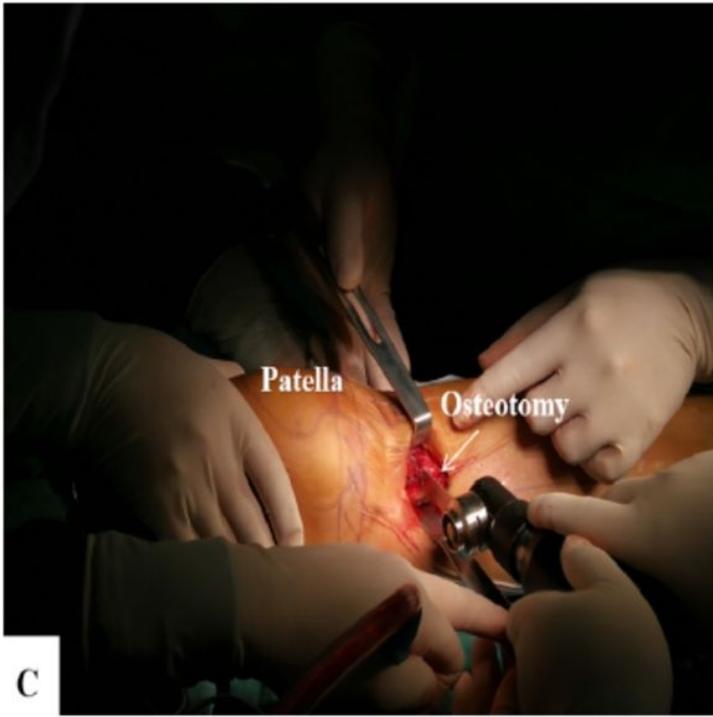
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## Figures



**Figure 1**

c. Osteotomy was performed along the osteotomy line by using electric saw  
d. Five holes are drilled by the Kirschner wire guide along the transverse plane

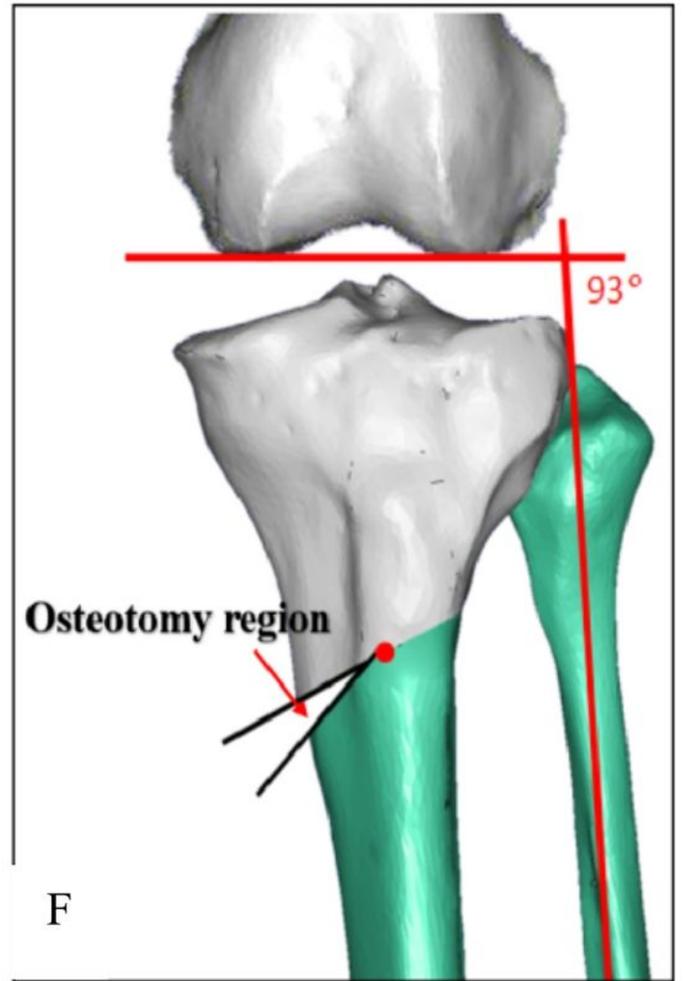


Figure 1

e. The stress distraction device was used to assist to open the osteotomy area f. A 3D model of the bone was shown how to modify the intersecting angle between femoral condyles and the fibula axis to 93°

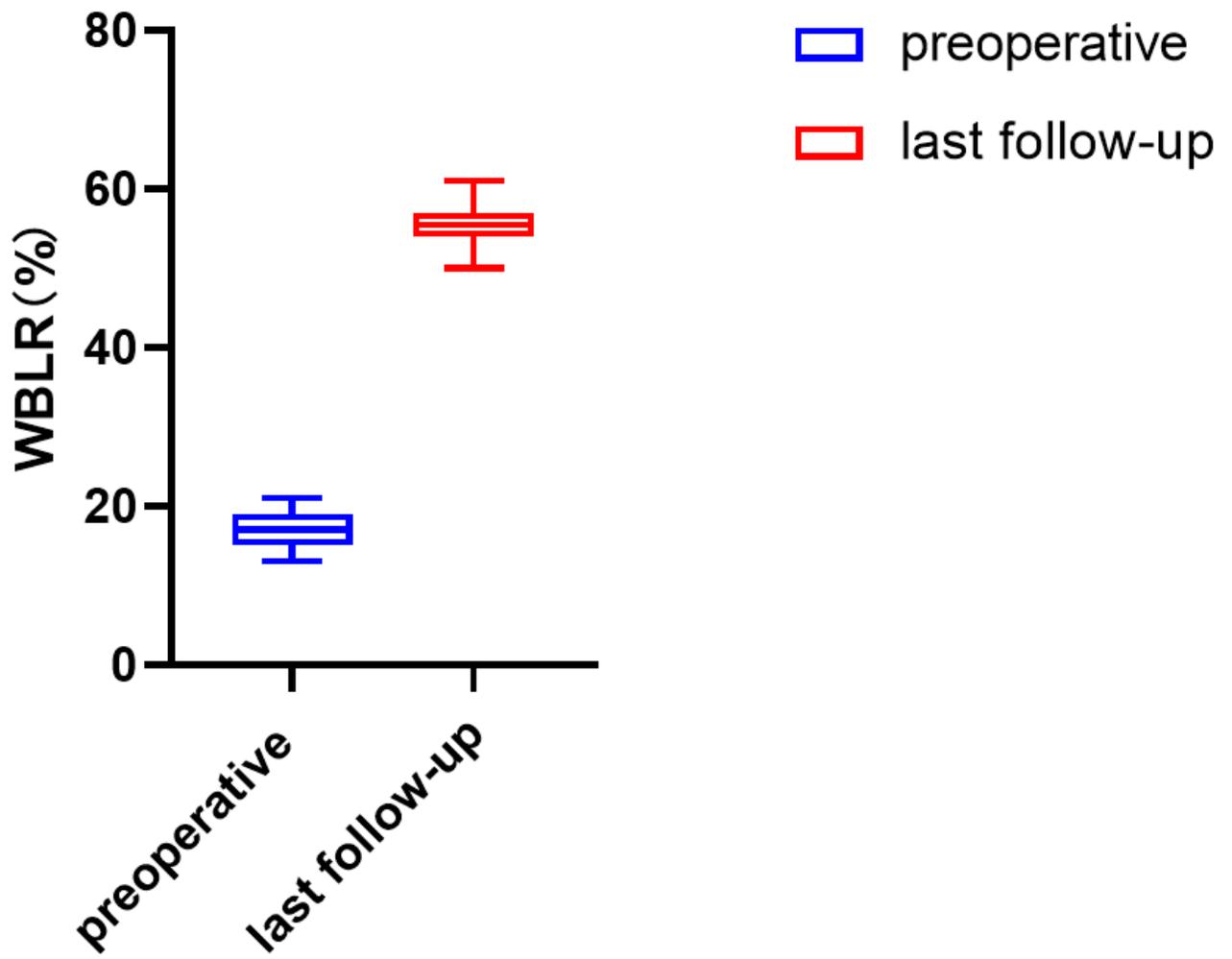


Figure 1

WBLR of obese patients with knee varus osteoarthritis

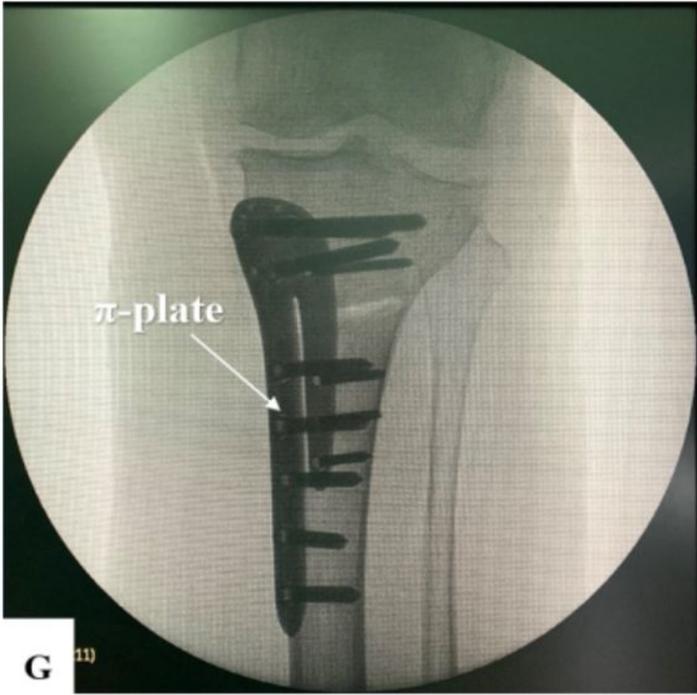


Figure 1

g. C-arm anteroposterior image after the osteotomy region was locked h. C-arm lateral image after the osteotomy region was locked

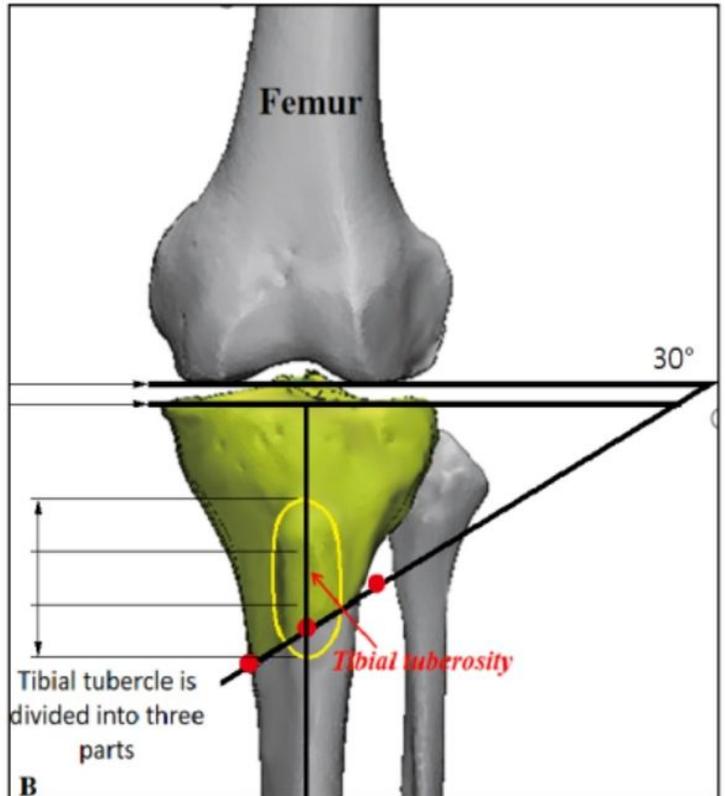


Figure 1

a. The osteotomy line was determined by the Kirschner wire guide through C-arm b. A 3D model of the bone showing where the osteotomy line was located

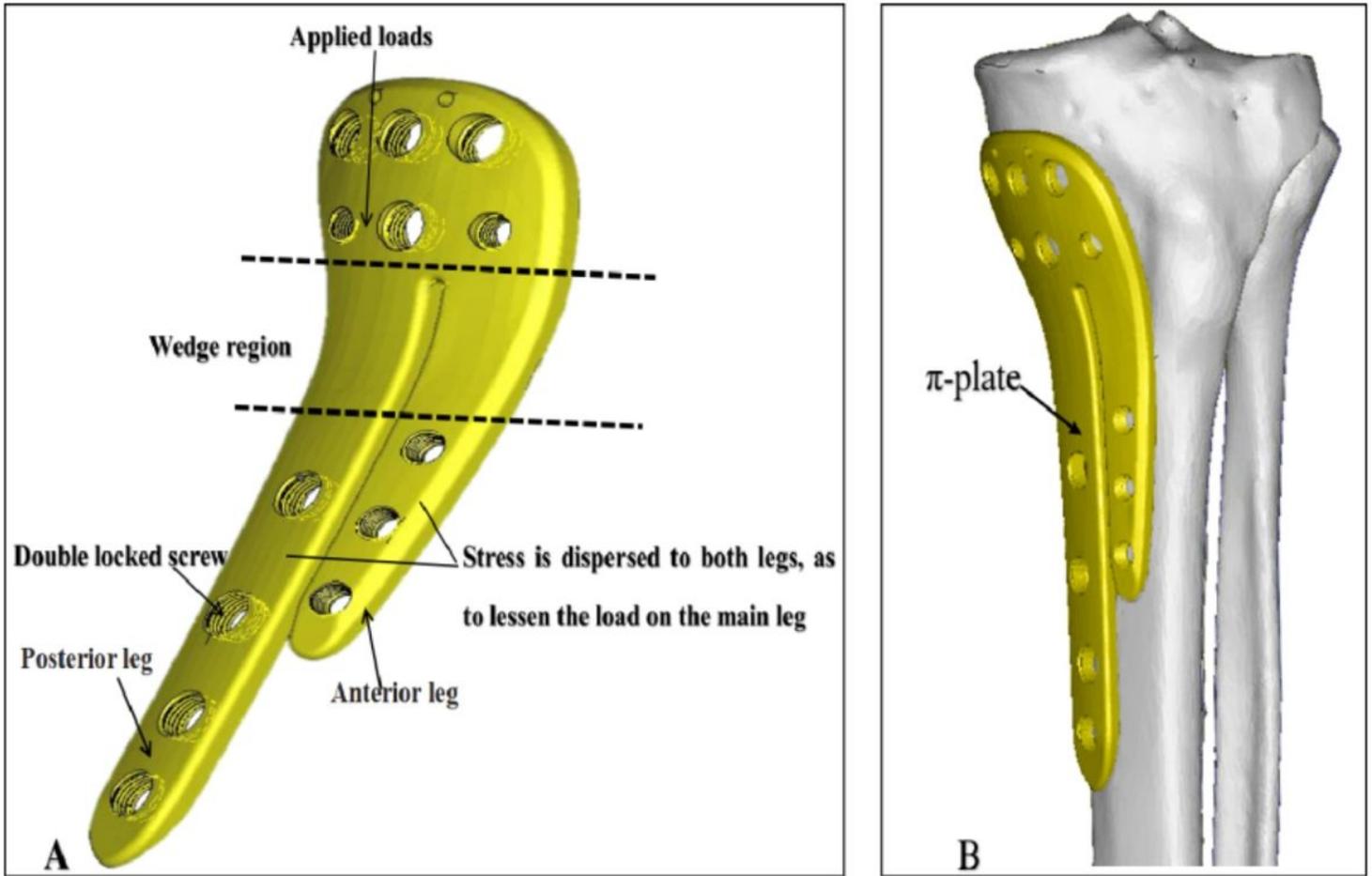


Figure 1

a. A diagrammatic sketch of the patented  $\pi$ -plate b. A 3D model of the patented  $\pi$ -plate.