Feasibility of a Novel Tibial Sighting Device Combined with Intramedullary Femoral Localisation on the Rotational Alignment of the Tibial Component for Oxford Unicompartmental Knee Arthroplasty

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Technical note

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Abstract

Background The success of unicompartmental knee arthroplasty (UKA) depends on perfect prosthesis component alignment. However, it is difficult to identify the anteroposterior axis and implant components in the correct rotational position in a narrow operating field in a UKA. Thus, we invented a novel tibial sighting device and explored whether combining it with intramedullary femoral localisation could be feasible on the rotational alignment of the tibial component for the Oxford UKA.

Methods: Twenty consecutive knees were treated with UKA using a novel tibial sighting device combined with intramedullary femoral localisation. An equal number of patients who underwent UKA with the conventional technique were matched to the control group. Radiographic accuracy was evaluated based on the implant position in the tibial CT transverse sections. The α angles were measured between the tibial component line and the vertical line of TEA', which was projected to the trans-epicondylar axis (TEA).

Results: The absolute value of the test group's α angle was significantly smaller than the respective values of the control group (P=0.006). The ratio of △α > 3° in the test group was also significantly smaller than that of the control group (P=0.048).

Conclusion: The novel tibial sighting device combined with intramedullary femoral localisation provided the surgeon a better surgical view in sagittal tibial osteotomy and improved the accuracy of tibial implant alignment in UKA. This method makes the vertical osteotomy of the tibial platform simpler, more precise and highly repeatable.

Background

Rotational alignment of the tibial component is important in unicompartmental knee arthroplasty (UKA) [1]. The trans-epicondylar axis (TEA) is the line from the medial epicondylar sulcus and the highest point of the femoral external epicondyle, and is recognised as the rotational axis when the knee joint is extended and flexed [2]. Therefore, the rotational axis of the tibial component should be strictly consistent with the TEA, and the tibial component's anteroposterior line should be perpendicular to the TEA to achieve a good rotational alignment. Patients with UKA tibial component rotation angles within an external rotation of 3° to an internal rotation of 3° of a neutral component alignment reported better functional outcomes [3].

Many scholars have proposed methods to ensure a perfect rotational alignment. Kawahara et al. stated that at a 90° flexion, the medial wall of the intercondylar notch is nearly parallel to the anteroposterior (AP) axis of the tibia in normal healthy knees, which is a reasonable candidate for a rotational reference of tibial placement in UKA [1]. However, that landmark should be confirmed in more populations and in patients with osteoarthritis. Berend et al. recommended the reciprocating saw toward the anterior superior iliac spine (ASIS) during sagittal tibial resection in Oxford unicompartmental knee arthroplasty (OUKA), although no scientific evidence supports this notion [4]. Furthermore, determining the tibial component rotation according to the far proximally located anatomy seems inappropriate. Recently, it has been reported that the ASIS should not be recommended for the guidance of sagittal tibial resection because of its wide variation and its inherent difficulty to be identified during the UKA [5]. Goodfellow and O'Connor have recommended that sagittal tibial resection be directed toward the femoral head centre [6]. However, it is difficult to define the surface marking for the femoral head centre [7].

Presently, the conventional methods to determine the direction of sagittal tibial resection in OUKA are preoperative body surface markers or intraoperative localisation of the femoral head, as demonstrated by the assistant using a rod or electrocautery device cable after touching the ASIS. However, these methods have evident shortcomings in the rotational alignment of the tibial component, mainly because of the noticeable displacement of the preoperative body surface markers after disinfection, towel laying, and anti-bacterial film sticking [5]. Moreover, identifying the AP axis and implanting components in the correct rotational position in a narrow operating field during UKA is difficult, especially when employing the tibia first-cut technique [1]. Therefore, we invented a novel tibial sighting device and explored whether combining it with intramedullary femoral localisation could be feasible for the rotational alignment of the tibial component for the OUKA.

Materials And Methods

Participants

From June 2019 to December 2019, 20 consecutive knees were treated with UKA using a novel tibial sighting device combined with intramedullary femoral localisation. To compare the radiographic assessments, an equal number of knees that underwent UKA performed with the conventional technique during the same period were selected and matched with controls. This study was approved by the institutional review board. The patient population was composed of 33 women and 7 men (mean age 69.13 ± 7.64 years and average body mass index 25.10 ± 2.96 kg/m^2), and informed consent was obtained for this study.

The indications for UKA were severe knee pain involving the medial compartment and difficulty in walking. Radiographs demonstrated medial loss of articular cartilage, as evidenced by a narrow medial joint width. The other indications were an intact anterior cruciate ligament, varus deformity of < 15°, flexion contracture of < 15°, and an intact lateral compartment.

Surgical procedure

The test group

All operations were performed in a single institution by a senior surgeon. The knee was suspended on a thigh support with a pneumatic tourniquet around the proximal thigh. A minimally invasive approach without release of the superficial medial collateral ligament and adjacent tendinous structures was utilised. Following removal of the medial osteophytes, tibial resection was initiated. First, proper ligament tension of the medial compartment was checked using a femoral sizing spoon. The femoral sizing spoon was connected to the extramedullary tibial guide using a G-clamp instrument. Aligning the extramedullary tibial guide parallel to the tibial long axis, the G-clamp was locked. During this procedure, a proximal tibial saw guide was pinned to the proximal tibia. The level and alignment of the tibial resection were checked under direct visualisation. The femoral sizing spoon and G-clamp were removed. The sagittal tibial resection was performed first.

With the knee in approximately 45° flexion, a hole was made in the intramedullary canal of the femur with a 4-mm drill. This was completed with a 5-mm awl. The hole was situated 1 cm anterior to the anterior edge and precisely medial to the medial wall of the intercondylar notch. It was aimed for the centre of the hip. By connecting the intramedullary rod and the dismantled femoral drilling guide (Fig. 1a and b) with the Oxford intramedullary (IM) link (Fig. 1c), the angle between the IM rod and the holes of the dismantled femoral drill guide (4-mm and 6-mm holes) was inherently 7° valgus (Fig. 2a and b), and the long prongs of the bovie were connected to the tibial sighting device (Fig. 3a and b). Therefore, the femur IM rod also had a relationship of 7° valgus with the long prongs of the bovie in the hole of the tibial sighting device (Fig. 4). The long prongs of the bovie should be approximately medial to the apex of the medial tibial spine and used to mark the longitudinal line. The line will pass through the edge of the anterior cruciate ligament tibial footprint, and the sagittal saw cut based on this mark line, which was directed towards the centre of the hip. The tibia was controlled by the assistant, so that the patient's toes were facing forward to avoid tibial rotation when the sagittal tibial resection was performed.

After the sagittal tibial resection, a horizontal resection was performed. The resection of the proximal tibia was aimed to be perpendicular to the mechanical axis of the tibia in the coronal plane. The remaining steps of the operation, including the femoral milling, flexion–extension gap equalising, and cementing technique, were performed as recommended by the manufacturer. Full weight-bearing, manual patellar mobilisation, quadricep strengthening programme, and range of motion exercises were initiated on the first postoperative day.

The control group

Using the OUKA operation manual, the hole in the intramedullary canal of the femur was not made in advance, and the assistant touched the ASIS. The saw pointed towards the centre of the femoral head, which was in the two transverse fingers of the ASIS, and the position of the tibia was controlled by the assistant when the sagittal tibial resection was performed, so that the patient's toes were directed forward, and tibial rotation was avoided. The other steps were not different from the test group.

All operations were performed with the Oxford phase 3 unicompartmental knee system, which was a mobile-bearing medial UKA (Zimmer Biomet, Warsaw, IN, USA) by the same senior surgeon.

Radiographic assessments

Scans of 1.25-mm slices were performed from the hip joint to the ankle joint with the patient in the knee-extended position with the patella facing upward. The obtained DICOM datasets were imported into the

Syngo postprocessing workstation. The highest point of the external epicondyle of the femur in the 3D reconstruction image was identified, then the scanned image was selected until the medial epicondyle sulcus appears. This level was taken as the measurement image, and the medial epicondyle's highest point and medial epicondyle medial sulcus were connected to draw the TEA (Fig. 5a). The TEA was then projected to the TEA' in the tibial CT transverse sections. The tibial component line (TCL) was defined by a line tangential to the lateral wall of the tibial component. The anteroposterior line(APL) was the vertical line of TEA'. The α angles were measured between the TCL and APL (Fig. 5b). All measured data were completed by two doctors and measured three times separately, and the average data were statistically analysed.

Statistical analyses

Results are presented as mean ± standard deviation, and the statistical analysis was performed using SPSS version 13.0 (Chicago, IL). The normality of data distribution was screened using the Shapiro-Wilk test. The independent sample t-test was used to compare measurements of the angle of the tibial component between the test group and control group. The chi-square test was used to compare the ratio of deviation between the TCL and target axis APL. Statistical significance was set at $P < 0.05$.

Results

There were no significant differences in age, sex, BMI, and preoperative femoral valgus angle between both groups (Table 1). The absolute value of the α angle between the TCL and APL of the test group had significantly smaller values than those of the control group (3.25 ± 1.37 vs 4.68 ± 1.71, $P = 0.006$). The ratio of △α > 3° of the test group was also significantly smaller than that of the control group (45.0% vs 80.0, $P = 0.006$) (Table 2).

Table 1
Comparison of clinical factors between test group and control group

	Test group	**Control group**	***t*/χ^2 value**	***P* value**
Number(knees)	20	20		
Age(years)	68.10 ± 7.46	70.15 ± 7.88	-0.845	0.403
BMI(kg/m^2)	25.84 ± 2.41	24.36 ± 3.32	1.612	0.115
Femoral valgus angle(degrees)	5.73 ± 0.84	5.84 ± 0.67	-0.479	0.635
Sex(male/female)	2/18	5/15	1.519	0.407

Table 2
Comparison of the angle of the tibial component between the test group and control group

	Number	Δα(degrees)	> 3 ° (%)
Test group	20	3.25 ± 1.37	45.0(9/20)
Control group	20	4.68 ± 1.71	80.0(16/20)
t/χ^2 value		-2.912	5.096
P value		0.006	0.048

Δα = Absolute value of angle α between TCL and APL. > 3 ° (%) = The ratio of Δα greater than 3 degrees.

Discussion

The failure of the long-term follow-up of UKA was mainly because of the poor force line, especially on the tibial component. To obtain a satisfactory lower limb force line, accurate osteotomy and implantation of the components in UKA are necessary. Although there is no consensus on how to determine the rotational alignment of the tibia, obtaining the correct AP orientation of the tibia is one of the key steps in UKA. Akagi et al. suggested that the line between the mid-point of the posterior cruciate ligament (PCL) and the medial edge of the patellar tendon could be used as APL for total knee arthroplasty[8–10]. The rotational alignment of the tibial component during UKA may also refer to APL used by total knee arthroplasty [1]. However, it can be difficult to identify the tibial APL in a modern mini-incision UKA because the PCL is barely visible or accessible in the small operating field.

Tsukamoto et al. have shown that the sagittal cut referencing the substitute AP line provides better AP rotation and fitting of the tibia in UKA than referencing the medial intercondylar [11]. Because the substitute AP was more similar to the tibial APL and when the substitute AP was used as the reference axis of osteotomy, the ratio of transverse diameter and longitudinal diameter of the tibial osteotomy is closer to the current model of the prosthesis, which is a good reference mark for sagittal tibial osteotomy. However, the study population was limited to Japanese patients undergoing UKA, and further studies with different and larger populations are needed. Kerens et al. have shown that patient-specific instrumentation in Oxford UKA is reliable and accurately translates the preoperative plan into the in vivo situation, except for the tibial rotational position [12]. Kawahara et al. have reported that the medial wall of the intercondylar notch is one of the recommended useful tibial AP rotational landmarks for UKA as it was almost parallel to the tibial AP line in their magnetic resonance imaging study using normal healthy knees [1]. However, degeneration and osteophytes of the intercondylar wall may change the positional relationship of these landmarks and reduce accuracy in osteoarthritic knees. Thus, there remains room for argument on the ideal landmarks for tibial component rotation in medial UKA.

The Oxford MP instrumentation simplifies the operation technology and significantly improves the positioning of the femoral component. However, MP instrumentation still uses the traditional method of

Oxford III in the tibial component's rotation and positioning, and it depends more on the operator's surgical experience. Therefore, the repeatability of the tibial component's rotation and positioning is low, and there remain many uncertainties in its rotation and alignment. According to the classic osteotomy method recommended by Oxford, 2–40% of the tibial components have poor alignment [11]. In UKA, the rotation alignment of sagittal tibial resection is always difficult. For tibial medial platform osteotomy, the knee joint should be bent 90° during sagittal tibial resection, and the reciprocating saw was aimed towards the femoral head centre. The purpose is to improve the accuracy of rotation alignment of the tibial component, so that the polyethylene bearing cannot easily impact the tibial component when the knee joint moves back and forth to avoid mobile-bearing dislocation. Additionally, the ASIS is covered by several layers of sterile towels during the operation; it is intrinsically difficult for assistants to precisely identify the pelvic landmark, so the ASIS is not an authentic and reproducible landmark for guidance of tibial component rotation. However, there has been no better way to solve the problem of rotation and positioning during sagittal tibial osteotomy in a UKA to date, thus limiting the application of the operation in primary hospitals.

The method of IM positioning can be used to indirectly guide sagittal tibial osteotomy as the tibial component can be placed accurately. In particular, the accuracy of rotation alignment of the tibial component can be improved to promote good matching of the mechanics and trajectory between the tibial and femoral components during knee motion for achieving physiologic bearing gliding on a flat tibial surface and reducing the risk of mobile-bearing impaction and dislocation, which is beneficial to improve patient comfort and satisfaction. The novel tibial sighting device combined with IM femoral localisation improved the accuracy of the tibial implant alignment in UKA and decreased the outliers of tibial sagittal alignment.

This method makes the vertical osteotomy of the tibial platform simpler, more precise and highly repeatable. Especially for beginners who have just performed this type of operation, it can improve the accuracy of the rotation and positioning of the tibial prosthesis and shorten the learning curve, which is beneficial to promote the UKA further in primary hospitals.

Limitation

There were several limitations in our study. First, this study was only carried out in a single medical unit on a relatively short period; therefore, there are certain limitations. Multi-centre studies with a large number of cases with more medical units are needed in the future to confirm the efficacy of this method in different medical conditions. Moreover, when the femoral IM rod, dismantled femoral drill guide, and Oxford IM link are connected, there is an inherent 7° valgus angle relationship between the vertical direction of the IM rod and the two holes of the femoral drill guide (4-mm and 6-mm holes), which is not adjustable, although the valgus angle of the femur is generally between 5° and 7°, which results in a small error. Because OUKA is mobile-bearing medial UKA, these errors may have little effect on clinical efficacy. It is hoped that in the future, the tools will be improved continuously, and there will be more choices of the femoral valgus angle to truly achieve personalisation.

Conclusions

The novel tibial sighting device combined with intramedullary femoral localisation provided the surgeon a better surgical view in sagittal tibial osteotomy and improved the accuracy of tibial implant alignment in UKA. This method makes the vertical osteotomy of the tibial platform simpler, more precise and highly repeatable.

Abbreviations

UKA: unicompartmental knee arthroplasty; TEA: the trans-epicondylar axis; TEA': which was projected to the TEA; OUKA: Oxford unicompartmental knee arthroplasty; AP: anteroposterior; ASIS: anterior superior iliac spine; IM: intramedullary; TCL: tibial component line; PCL: posterior cruciate ligament.

Declarations

Acknowledgements

None.

Authors' contributions

LC and XL invented the novel tibial sighting device and XL was a major contributor in writing the manuscript. All operations were performed by LC, CL, ZL and QC. ZL and QC fulfilled the radiographic assessments. All authors read and approved the final manuscript.

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Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

This study was approved by the ethics committee of Chancheng District Central Hospital(No. IRB-ATT-001-24). Written informed consent was obtained from all patients.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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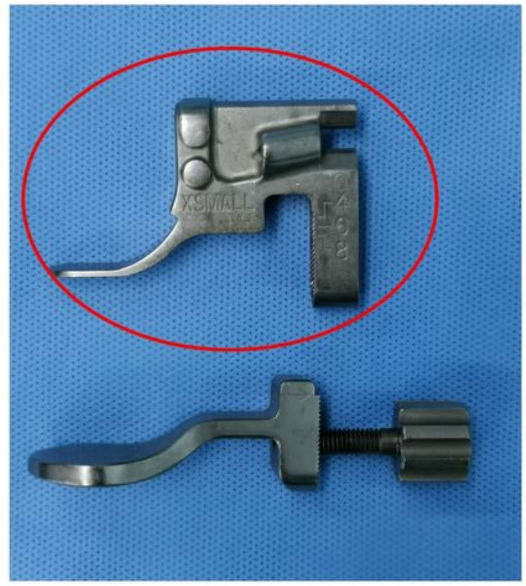
Figures

1A



1B

1C

Figure 1

(a) The Oxford femoral drill guide. (b) The dismantled Oxford femoral drill guide (the red circle). (c) The hole in the intramedullary canal of the femur was made in advance. Then, we inserted the cannulated intramedullary rod, installed the dismantled Oxford femoral drill guide, and inserted Oxford IM link

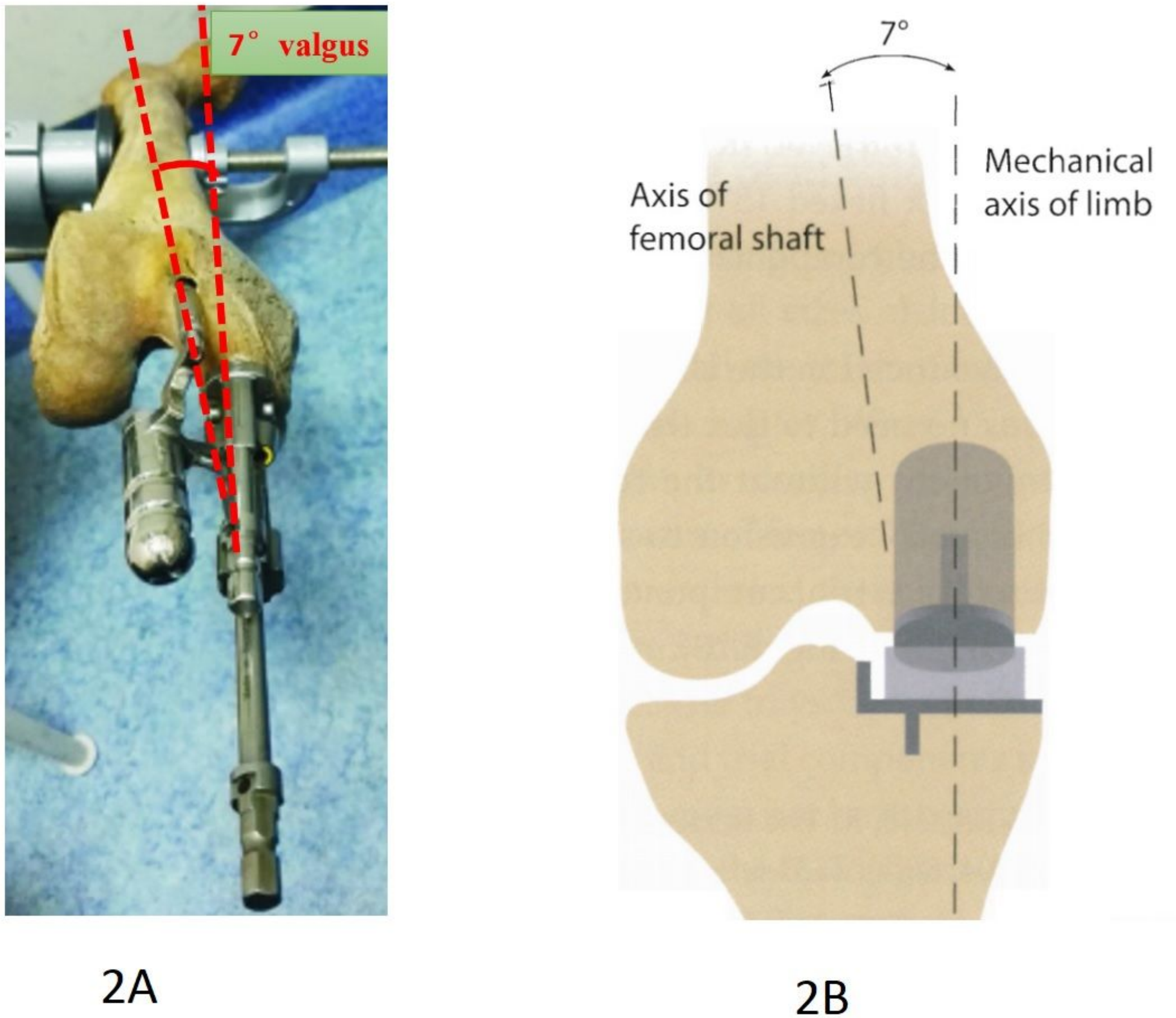
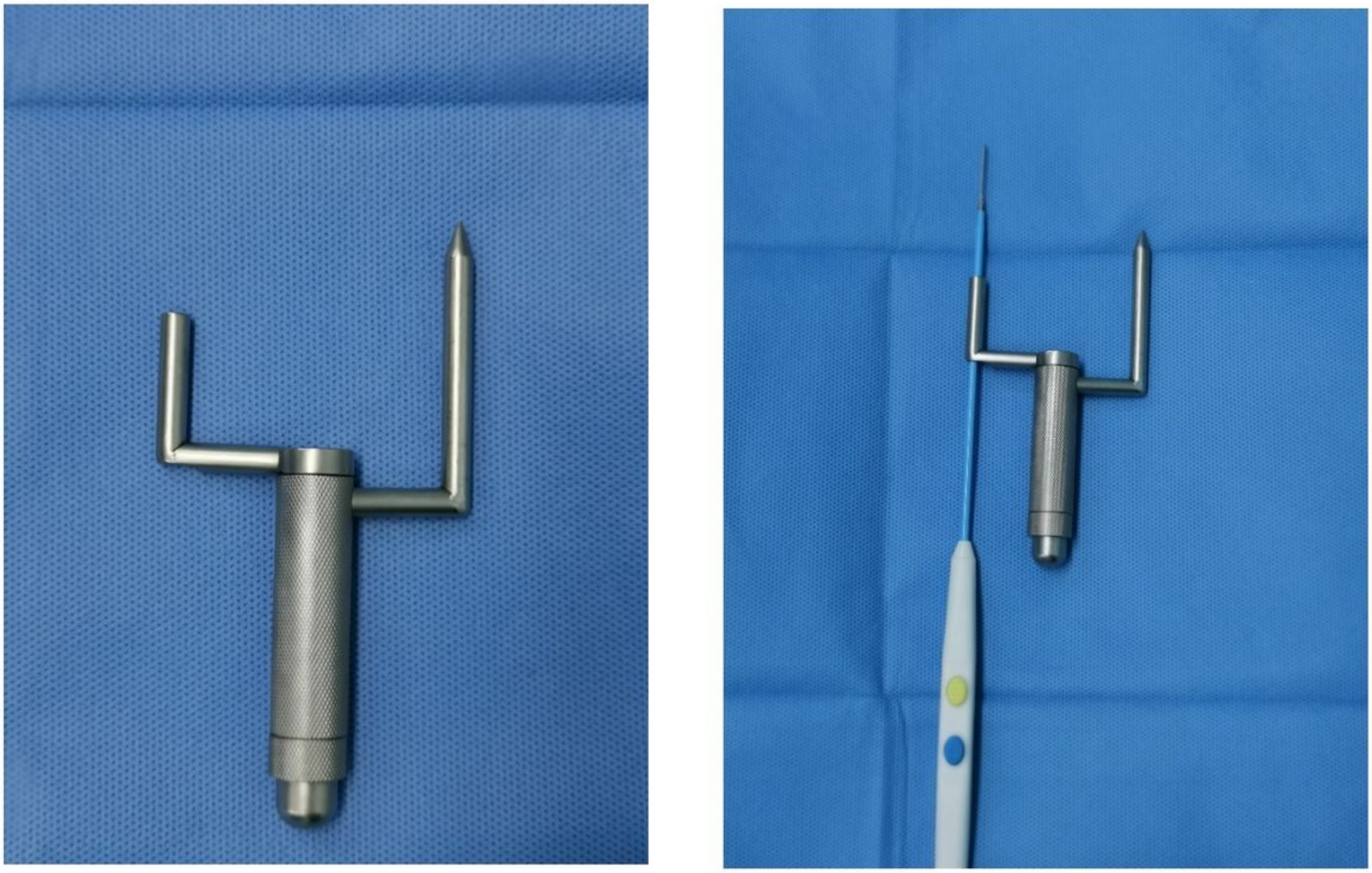


Figure 2

(a) The angle between the intramedullary(IM) rod and the holes of the femoral drill guide (4-mm and 6-mm holes) was inherently 7° valgus. (b) The diaphyseal axis was at 7° valgus relative to femoral component. Its peg was approximately parallel to the mechanical axis



3A 3B

Figure 3

(a) The tibial sighting device. (b) The long prongs of the bovie were connected with the tibial sighting device

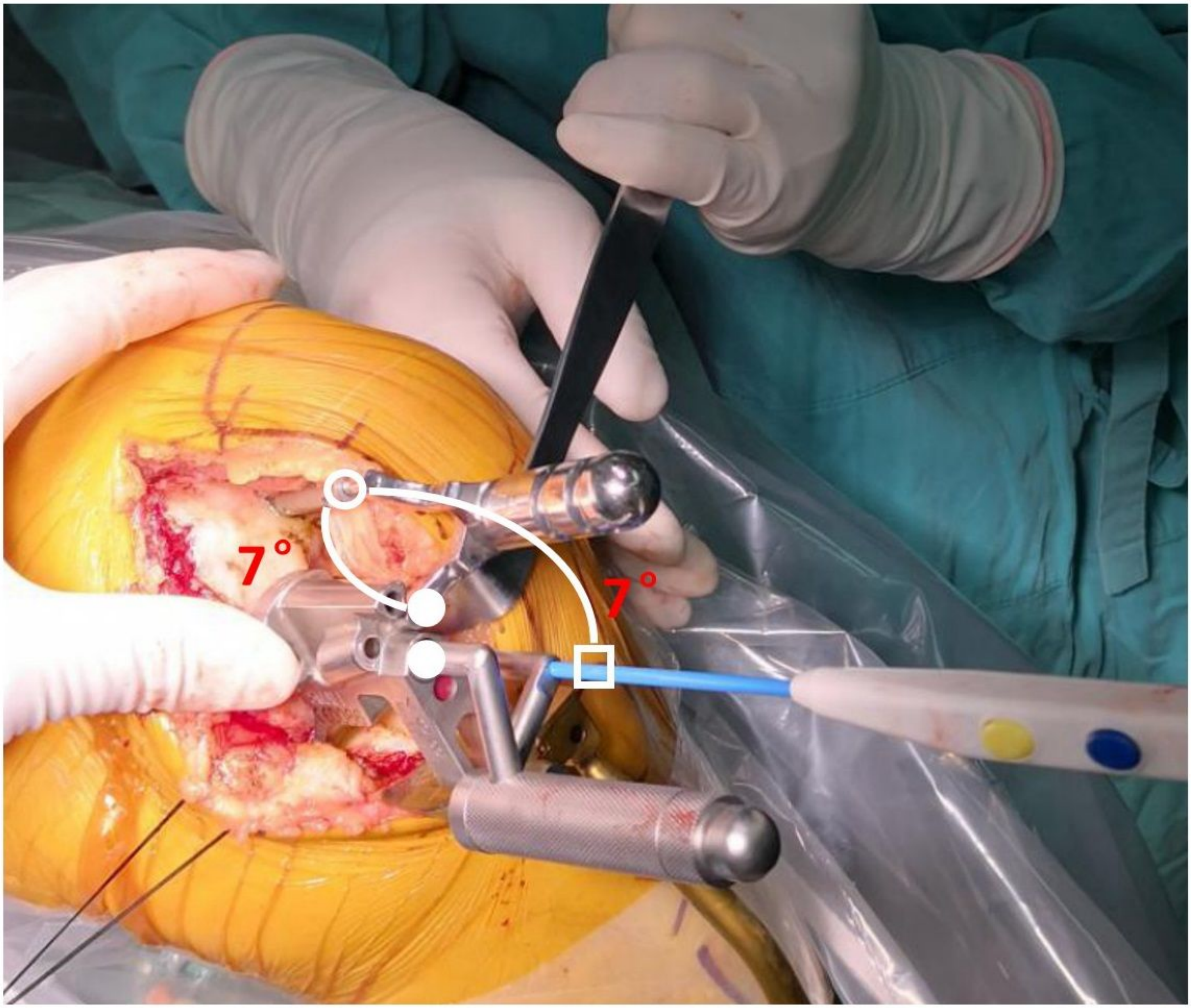
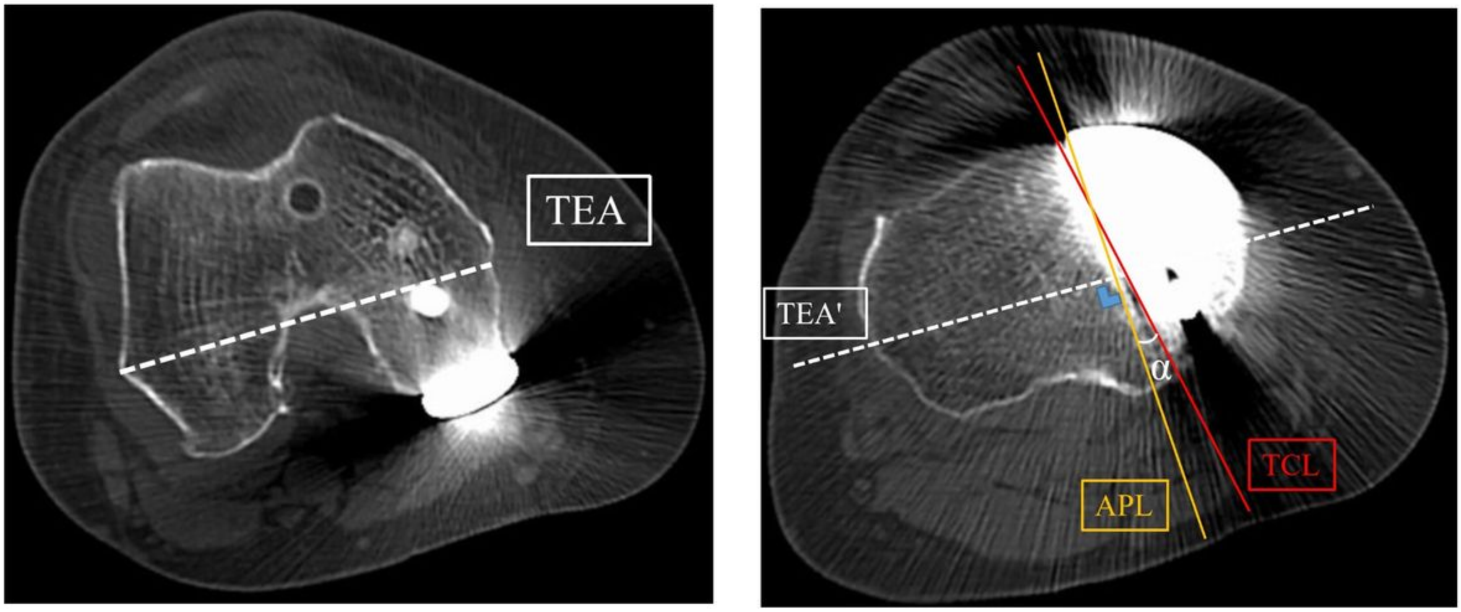


Figure 4

The angle between the intramedullary(IM) rod (hollow circle ●) and the holes of the femoral drill guide (4-mm and 6-mm holes) (white solid circle ●) was inherently 7° valgus, and the long prongs of the bovie (hollow □) were connected with the tibial sighting device so that the femur intramedullary rod (hollow circle ●) also had the relationship of 7° valgus with the long prongs of the bovie (hollow □) in the hole of the tibial sighting device



5A 5B

Figure 5

(a) The TEA was identified in the femoral CT transverse sections. (b) The TEA was projected to TEA' in the tibial CT transverse sections. Tibial component line (TCL) and the vertical line of TEA'(APL) were identified in the tibial transverse sections. The angles were measured between the TCL and APL