OPERATIVE TECHNIQUE

Precise Patellar Tendon Insertion Protection and Osteotomy Surface Advantage of Transtibial Tuberosity–High Tibial Osteotomy

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Objective: Medial opening wedge high tibial osteotomy (HTO) is successful in the treatment of knee osteoarthritis with medial compartment stenosis and tibial varus deformity, but patella infera is the main complication. This study aims to design a new medial tibial open osteotomy scheme, transtibial tuberosity-high tibial osteotomy (TT-HTO), which can fully protect the patellar tendon insertion. In addition, the area of the osteotomy surface and wedge volume were evaluated in TT-HTO, biplanar distal tibial tuberosity osteotomy (biplanar-DTO), and uniplanar-DTO to evaluate the potential advantages of this technology in bone healing.

Methods: The tibial tubercle was divided into four equal sections from proximal to distal, which were defined as zones A, B, C, and D. From September to December 2020, the imaging examinations of 200 patients (95 males and 105 females) with a mean age of 40.6 years (range 19–60 years) were evaluated to observe the zonation of the tibial tubercle where the insertion of the patellar tendon is located. Then, 59 patients (23 males and 36 females) with a mean age 59.6 years (range 43–77 years), for a total of 69 knees (32 right and 37 left), who underwent routine knee surgery were observed and verified. According to the position of the patellar tendon insertion, TT-HTO was designed. Fifteen tibial sawbones were divided equally into three groups: TT-HTO; biplanar-DTO; and uniplanar-DTO. The total area of the osteotomy surface was compared using the graph paper method. The wedge volume at wedge heights of 10 mm was compared among osteotomy types using the plasticine Archimedes principle. One-way repeated-measures analysis of variance was used to compare the total area of the osteotomy surface and the wedge volume.

Results: The osteotomy line of TT-HTO passes through the boundary point of zones B and C of the tibial tubercle to fully protect the insertion point of the patellar tendon. The total area of the osteotomy surface in TT-HTO and biplanar-DTO was significantly larger than that in uniplanar-DTO ($P < 0.05$). The wedge volume in uniplanar-DTO was significantly smaller than that in TT-HTO and biplanar-DTO ($P < 0.05$). No significant differences in the osteotomy surface and the wedge volume were identified between TT-HTO and biplanar-DTO.

Conclusion: TT-HTO can protect the patellar tendon insertion and avoid postoperative patella infera. The osteotomy surface is large and located in an area of cancellous bone, which ensures its good healing characteristics.

Key words: High tibial osteotomy; Osteotomy surface; Patellar infera; Wedge volume

Introduction

High tibial osteotomy (HTO) is a well-accepted treatment for medial compartment stenosis osteoarthritis.[1,2] Correction of the force line can reduce the pressure on the overloaded medial compartment of the knee joint to decrease the level of inflammation,[3] thereby reducing pain as much as

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possible and preparing for cartilage repair.[4] Although the current valgus correction technique is clinically successful, patellar infera is a common postoperative complication of this technique, with a reported incidence as high as 89%.[5] In medial opening wedge HTO, patellar infera occurs because the osteotomy line is located above the patellar tendon insertion. When the osteotomy space is opened to correct the force line, the patellar tendon insertion moves distally relative to the tibial plateau, resulting in a reduction in patellar height.[6] Changes in the height of the patellofemoral joint can result in increased pressure on the patellofemoral joint surface, dislocation of the patellofemoral joint,[7] and progression of patellofemoral arthritis,[8,9] which manifest as pain in the anterior knee joint, patellofemoral joint locking, bone crepitus, and limited flexion function,[10] which not only affects a patient's motor function but also accelerates degeneration of the patella joint. Moreover, these conditions can increase the difficulty of total knee arthroplasty.[11]

The fundamental method to avoid postoperative patella infera is to cut the bone below the patellar tendon insertion and maintain the relative position between the patellar tendon insertion and the tibial plateau. One solution is uniplanar distal tibial tuberosity osteotomy (uniplanar-DTO).[12] The disadvantages of this approach are that the osteotomy plane is too distal, and the osteotomy surface is cortical bone, which increases the risk of nonunion and hinge fracture.[13] The second is biplanar distal tibial tuberosity osteotomy (biplanar-DTO), which involves a complicated operative process and increases the risk of fracture of the tibial tubercle bone.[14] Therefore, additional anteroposterior screw insertion from the flange to the distal tibial fragment is generally needed in biplanar DTO, which is sometimes difficult, especially in cases with an increased opening width.[15]

At present, no osteotomy method simultaneously satisfies the three conditions: below the insertion point of the patellar tendon, located in the cancellous bone region, and in a single plane. The purpose of this study was to: (i) design a transtibial tuberosity–high tibial osteotomy (TT-HTO) technique that includes the above three elements based on observation of the patellar tendon insertion; and (ii) demonstrate the advantages of this method for postoperative bone healing based on evaluation of the area of the osteotomy surface and wedge volume.

Methods

Assessment of the Patellar Tendon Insertion

We included the adult patients who presented to the Orthopedic Outpatient Department of the Affiliated Hospital of Guizhou Medical University for knee pain from September to December 2020 and underwent lateral radiographs and magnetic resonance (MR) examinations of the knee. All of the imaging data with disorders that may affect the anatomy of the patellar tendon insertion were excluded (tibial tuberosity deformity, patellar tendon injury, history of surgery around the knee; rheumatoid arthritis, gout, tumors around the knee). Two hundred patients (95 males and 105 females) with a mean age of 40.6 years (range 19–60 years) were included in this study. A total of 234 knees, including 113 left knees and 121 right knees, were studied.

The tibial tuberosity is a bony projection observed in the proximal tibia. The initial cortical elevation of the

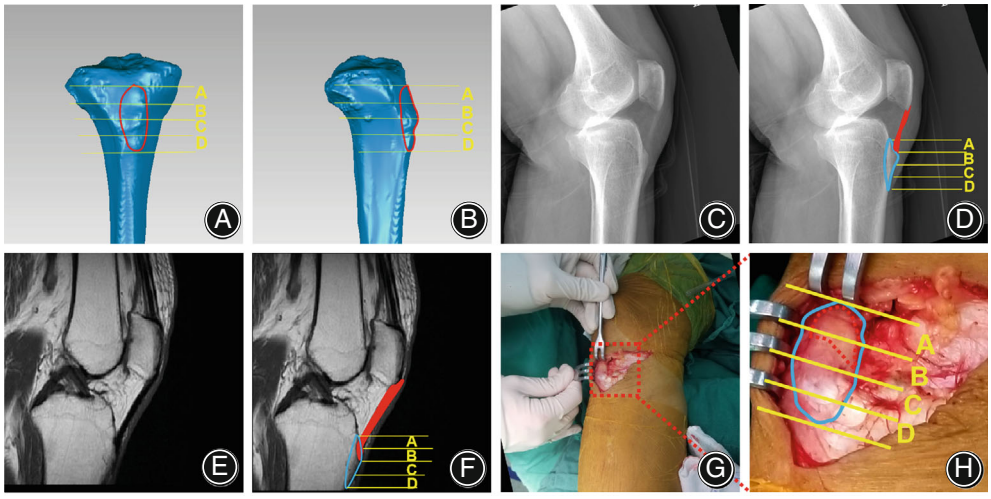

Fig. 1 The division of the tibial tubercle and observation of the patellar tendon insertion. (A, B) The region between the proximal and distal boundaries of the tibial tubercle was divided into four equal portions, which were defined as zones A, B, C, and D. (C–F) On the lateral radiographs and MR examinations of the knee joints, the relationship of the lower edge of the patellar tendon insertion and the tibial tubercle were observed. (G) The tibial tubercle and patellar tendon were exposed during the operation. (H) The lower edge of the patellar tendon insertion was at zone B of the tibial tubercle, and most of the patellar tendon fibers were attached to zone A

proximal tibia was defined as the upper boundary of the tibial tuberosity, and the end point of cortical descent and migration to the anterior tibial shaft was defined as the lower boundary.[16] The area between the upper and lower boundaries of the tibial tuberosity is divided into four equal parts, defined as zones A, B, C, and D from the proximal end to the distal end (Fig. 1A,B).

Based on standard knee lateral radiographs (Fig. 1C) and sagittal T1-weighted images (Fig. 1E), three senior orthopedic surgeons were asked to mark the upper and lower boundaries of the tibial tubercle and patellar tendon insertion. The three images marked by the three surgeons were merged with the middle position as the final boundary line. Then, we studied the relationship between the lowest edge of the patellar tendon insertion and the tibial trochanter area (Fig. 1D,F).

Verification of the Patellar Tendon Insertion in Surgical Patients

From December 2020 to February 2021, we continuously observed 59 patients who underwent routine knee arthroplasty and HTO in the Department of Orthopedics of the Affiliated Hospital of Guizhou Medical University to determine the relative position of the patellar tendon at the tibial tubercle. The inclusion criteria were patients who underwent routine knee arthroplasty or HTO due to knee osteoarthritis. Patients with a history of knee surgery and limb fracture were excluded. After obtaining approval from the University Ethics Committee (2021055K), 59 patients (23 males and 36 females) with a mean age 59.6 years (range 43–77 years), for a total of 69 knees (32 right and 37 left), who underwent surgical treatment with exposure of the patellar tendon insertions and the tibial tubercles (30 patients underwent knee replacement, 29 patients underwent routine HTO) were selected for intraoperative observation.

Under successful anesthesia, the patient was placed in the supine position. The operative field was routinely disinfected and draped. A routine surgical incision was made to separate the skin and subcutaneous tissue.[17,18] The relationship between the lower edge of the patellar tendon insertion and the tibial tubercle zones was observed (Fig. 1G). The upper and lower boundaries of the tibial tuberosity are evaluated consistently in humans and radiographically. Three senior orthopedic surgeons simultaneously identified the region of the patient's patellar tendon insertion, and a consensus among two or more of the surgeons was considered valid. The three doctors did not hold different views in any case.

Tibial Sawbone

Based on imaging and intraoperative observations of the insertion of the patellar tendon, a new osteotomy was designed based on the following principles. First, the osteotomy line should be as close to the patellar tendon insertion as possible. Second, the osteotomy surface needs to be located within the cancellous bone region. Third, the osteotomy was uniplanar to simplify the operative procedures. The tibial sawbone (model FZ001, left tibia, ENOVO, Shanghai, China) was selected for the test osteotomy to verify the osteotomy plan (Fig. 2).

The wedge volume after osteotomy was compared using the plasticine Archimedes principle. The tibial sawbones were divided into three groups: TT-HTO (Fig. 3A–E), biplanar-DTO[19] (Fig. 3G–K), and uniplanar-DTO[20] (Fig. 3M–Q). The osteotomy site was expanded at the medial opening to 10 mm in height. After routine internal fixation, plasticine was packed (Fig. 3A–E,G–K,M–Q) into the bone defect after expansion. Then, the displacement method was used to measure the volume of the osteotomy site.

The graph paper method was used to compare the osteotomy surface area. The three groups of artificial bones undergoing TT-HTO (Fig. 3E), biplanar-DTO (Fig. 3K), and uniplanar-DTO (Fig. 3Q) were cut at the hinge point to form isolated osteotomy fragments. The horizontal part of the osteotomy fragments was marked with a (distal tibial end) and b (proximal tibial end). If dorsal and ventral osteotomy surfaces were available, they were marked as c and d, respectively. The shape of each osteotomy surface was printed on the graph paper. The size of each osteotomy surface was calculated by counting the small cells (1 mm^2) (Fig. 3F,L,R).

Statistical Analysis

All the variables had a normal distribution and SPSS 26.0 (SPSS, Chicago, IL, USA) was used for statistical analysis. Cohen's kappa coefficient (k) was used to analyze consistency between different radiological evaluations. A k value <0.00 represents poor agreement, 0.00–0.20 represents slight agreement, 0.21–0.40 represents fair agreement, 0.41–0.60 represents moderate agreement, 0.61–0.80 represents substantial agreement, and 0.81–1.00 represents almost perfect agreement.[21] One-way repeated-measures analysis of variance (ANOVA) was used to compare the surface in square millimeters (mm^2) and calculated wedge volumes (mL) between groups. Differences were considered significant at $P < 0.05$. When the surface area and the wedge volume were compared, the sample size of each group ($n = 5$) was determined according to previous studies.[15]

Results

Imaging Examination of the Patellar Tendon Insertion

In the standard knee lateral radiographs, the lowest edge of the patellar tendon insertion was located in tibial tubercle zone A in 168 (71.79%) knees and in tibial tubercle zone B in 66 (28.21%) knees. Meanwhile, the standard knee MR examination showed that the lowest edge of the patellar tendon insertion was located in tibial tubercle zone A in 141 (60.26%) knees and in tibial tubercle zone B in 93 (39.74%) knees, and we clearly observed that most of the patellar tendon fibers were still attached to zone A; only a small portion of the fibers were attached to zone B (Fig. 1D,F). Substantial agreement was noted between the X-ray and MR examinations ($k = 0.71 \pm 0.05$, $P < 0.05$).

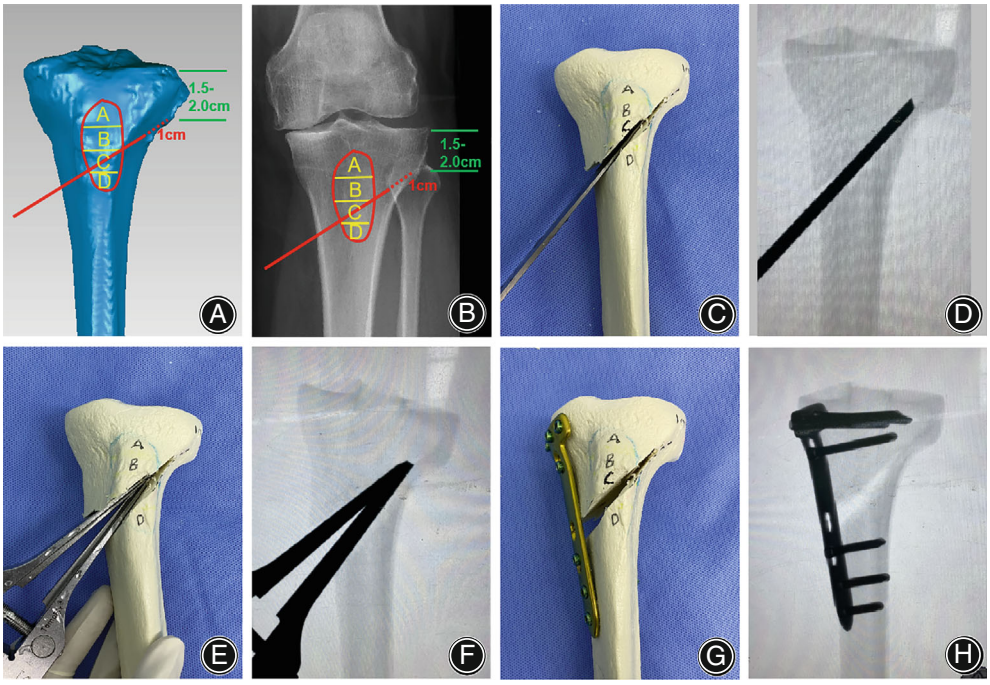

Fig. 2 Design of the osteotomy line and surgical procedure on the tibial sawbones. (A, B) The K-wire exit point was 1.5–2.0 cm away from the tibial plateau. These locations ensured that the osteotomy line passed through the intersection of the dividing line of tibial tubercle zones B and C and the lateral edge of the tibial tubercle. The lateral cortex (1 cm in thickness) should be preserved as a hinge (red line). (C, D) The osteotomy was performed, and the lateral cortex (1 cm in thickness) was preserved as a hinge point. (E, F) The medial tibial osteotomy site was dilated to the desired height. (G, H) A T-shaped locking plate was placed

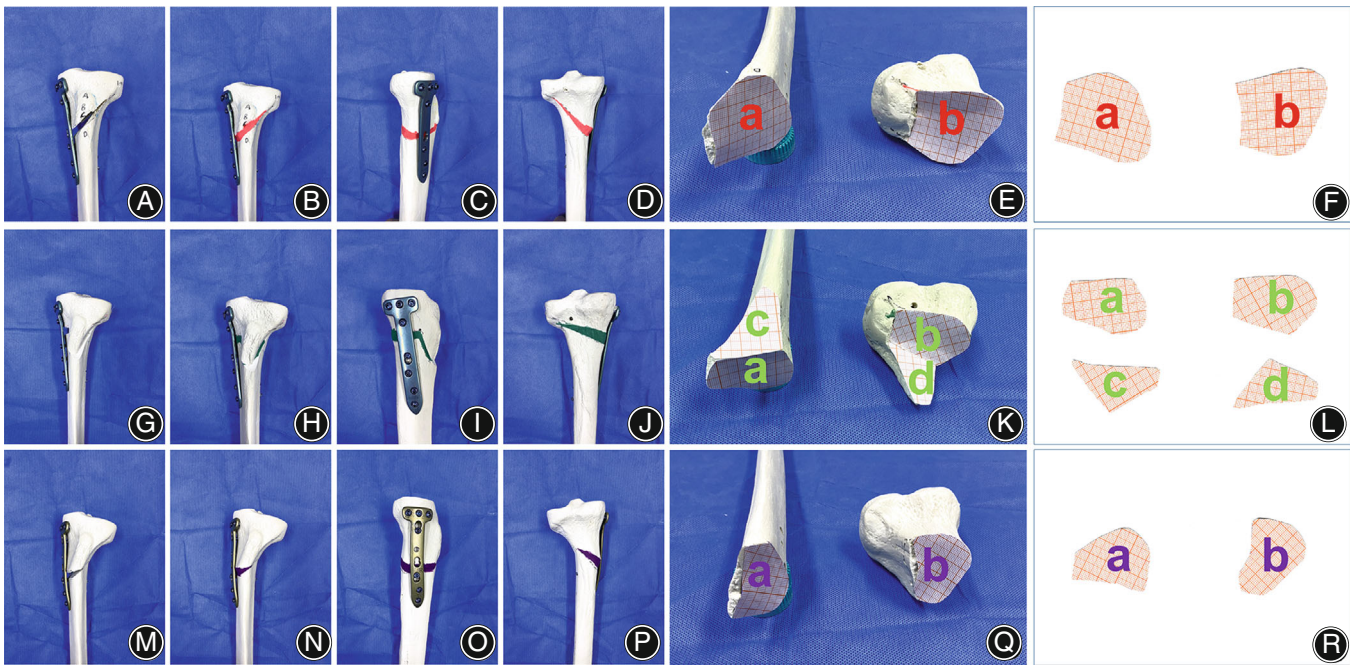

Fig. 3 Measurements of the wedge volume and osteotomy area with the three osteotomy methods. (A-F) In the TT-HTO group, (G-L) biplanar-DTO group, (M-R) and uniplanar-DTO group, after internal fixation, the wedge-shaped region was filled with colored plasticine, and the osteotomy surface was marked on graph paper for counting. Osteotomy surfaces of the transverse cut are labeled a (distal tibial end) and b (proximal tibial end); the coronal cuts are labeled c (dorsal osteotomy surface) and d (ventral osteotomy surface)

Observation of the Patellar Tendon Insertion during the Operation

In the 59 patients (69 knees) undergoing knee arthroplasty and HTO, the lowest edge of the patellar tendon insertion was located in tibial tubercle zone A in 43 (62.32%) knees and in tibial tubercle zone B in 26 (37.68%) knees (Table 1). No patellar tendon insertion was attached to zone C or D (Fig. 1H).

TT-HTO Design and Comparison of Wedge Volume and Osteotomy Surface Area

The osteotomy line was drawn from the medial side of the proximal tibia, obliquely to the upper tibiofibular syndesmosis on the lateral side of the tibia, and the Kirschner (K)-wire exit point was 1.5–2.0 cm away from the tibial plateau. The osteotomy line passed through the intersection of the dividing line of tibial tubercle zones B and C and the lateral edge of the tibial tubercle. The lateral cortex (1.0 cm in thickness) should be preserved as a hinge to ensure the continuity of the lateral bone cortex (Fig. 2A,B). The osteotomy was performed close to the distal ends of the K-wires (Fig. 2C,D). The medial tibial osteotomy site was dilated to the desired height (Fig. 2E,F), and a T-shaped locking plate was placed on the medial proximal tibia (Fig. 2G,H).

The wedge-shaped volume formed by the three osteotomy methods was measured. No significant difference in volume was found between the TT-HTO group and the biplanar-DTO group (7.2 ± 0.3 *vs* 7.4 ± 0.4 ml) ($P > 0.05$), but the volume in uniplanar-DTO was the smallest at 5.4 ± 0.4 ml ($P < 0.05$) (Fig. 4A).

Since a 1.0-mm-thick saw blade was used in all osteotomies, the corresponding tibial planes after osteotomy were not completely anastomosed. Therefore, the proximal osteotomy surface was slightly larger than the distal osteotomy surface (TT-HTO plane a:1891.3 ± 94.0 mm^2; plane b: 1968.0 ± 53.0 mm^2). Similarly, the dorsal osteotomy surface was slightly larger than the ventral surface (plane c: 783.0 ± 12.8 mm^2; plane d: 763.0 ± 6.6 mm^2). The comparison of osteotomy areas between the three osteotomy methods showed that the area in the TT-HTO group was the largest, but no significant difference was found between the TT-HTO group and the biplanar-DTO group (3859.3 ± 143.4 *vs* 3834.0 ± 137.5 mm^2) ($P > 0.05$). However, it was significantly larger than that in the uniplanar-DTO group (2143.0 ± 31.0 mm^2, $P < 0.05$) (Table 2) (Fig. 4B).

Typical Case

A 46-year-old woman was diagnosed with osteoarthritis of the right knee joint with varus deformity (Fig. 5A). She signed an informed consent form after the study was approved by Guizhou Medical University Ethics Committee. She underwent TT-HTO under general anesthesia. The osteotomy was performed as described above. The correction angle was 8.1°, and the intraoperative extension height was 7.8 mm. The force line in the patient's lower limb was completely corrected after the operation (Fig. 5B). During the operation, the patellar tendon insertion was confirmed again (Fig. 5C), and the osteotomy was performed along the K-wire with a bone knife (Fig. 5D). After expansion to the desired height, it can be seen that the osteotomy surface is completely located in the cancellous bone area (Fig. 5E). No

TABLE 1 Distribution of the patellar tendon insertion in the tibial tubercle

	X-ray examination	MR examination	Intraoperative verification
A	168 (71.79%)	141 (60.26%)	43 (62.32%)
B	66 (28.21%)	93 (39.74%)	26 (37.68%)
C	0	0	0
D	0	0	0

Notes: Data are expressed as the total number of cases and the percentage. Based on X-ray examination, MR examination, and intraoperative findings, the lowest edge of the patellar tendon insertion was located in tibial tubercle zone A in most patients, and a few were in tibial tubercle zone B. No patellar tendon insertion was attached to tibial tubercle zone C or D; Abbreviation: MR, magnetic resonance.

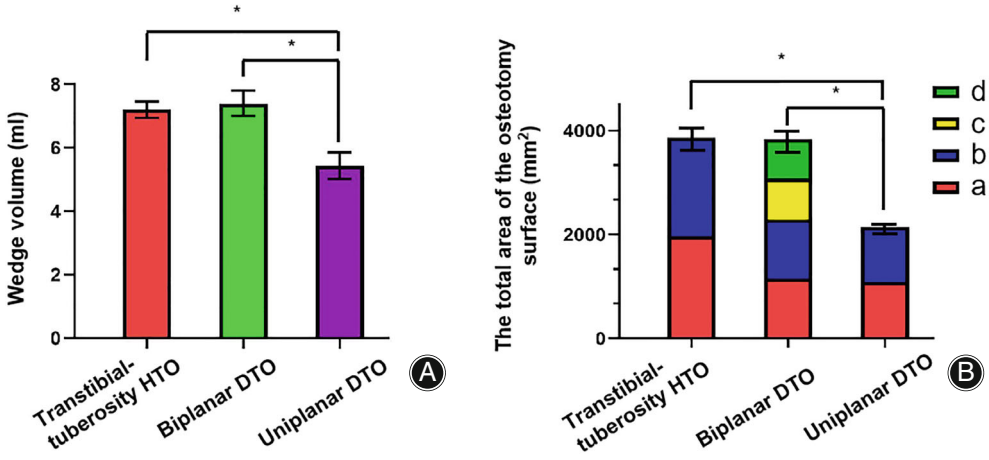

Fig. 4 The wedge volume and the total area of the osteotomy surface with the three osteotomy methods. (A) The mean wedge volume in uniplanar-DTO was smaller than those in TT-HTO and biplanar-DTO. No significant difference was found between TT-HTO and biplanar-DTO. (B) The mean area of the osteotomy surface in uniplanar-DTO was smaller than those in TT-HTO and biplanar-DTO. No significant difference was noted between TT-HTO and biplanar-DTO. *$P < 0.05$

TABLE 2 The total area of the osteotomy surface with TT-HTO, biplanar-DTO, and uniplanar-DTO (mm^2)

	TT-HTO	Biplanar-DTO	Uniplanar-DTO
a	1891.3 ± 94.0 (1799.0–1987.0)	1132.0 ± 57.6 (1082.0–1195.0)	1059.3 ± 14.6 (1044.0–1073.0)
b	1968.0 ± 53.0 (1907.0–2003.0)	1156.0 ± 66.2 (1096.0–1227.0)	1083.7 ± 16.8 (1069.0–1102.0)
c	0	783.0 ± 12.8 (769.0–794.0)	0
d	0	763.0 ± 6.6 (757.0–770.0)	0
Total area of the osteotomy surface	3859.3 ± 143.4 (3706.0–3990.0)	3834.0 ± 137.5 (3704.0–3978.0)	2143.0 ± 31.0 (2113.0–2175.0)

Notes: Data are expressed as the means ± standard deviations, with the range in parentheses. The osteotomy surfaces of the transverse cut were labeled a (distal tibial end) and b (proximal tibial end), and the coronal cut surfaces were labeled c (dorsal osteotomy surfaces) and d (ventral osteotomy surfaces), respectively; Abbreviations: biplanar-DTO, biplanar distal tibial tuberosity osteotomy; TT-HTO, transtibial tuberosity–high tibial osteotomy; uniplanar-DTO, uniplanar distal tibial tuberosity osteotomy.

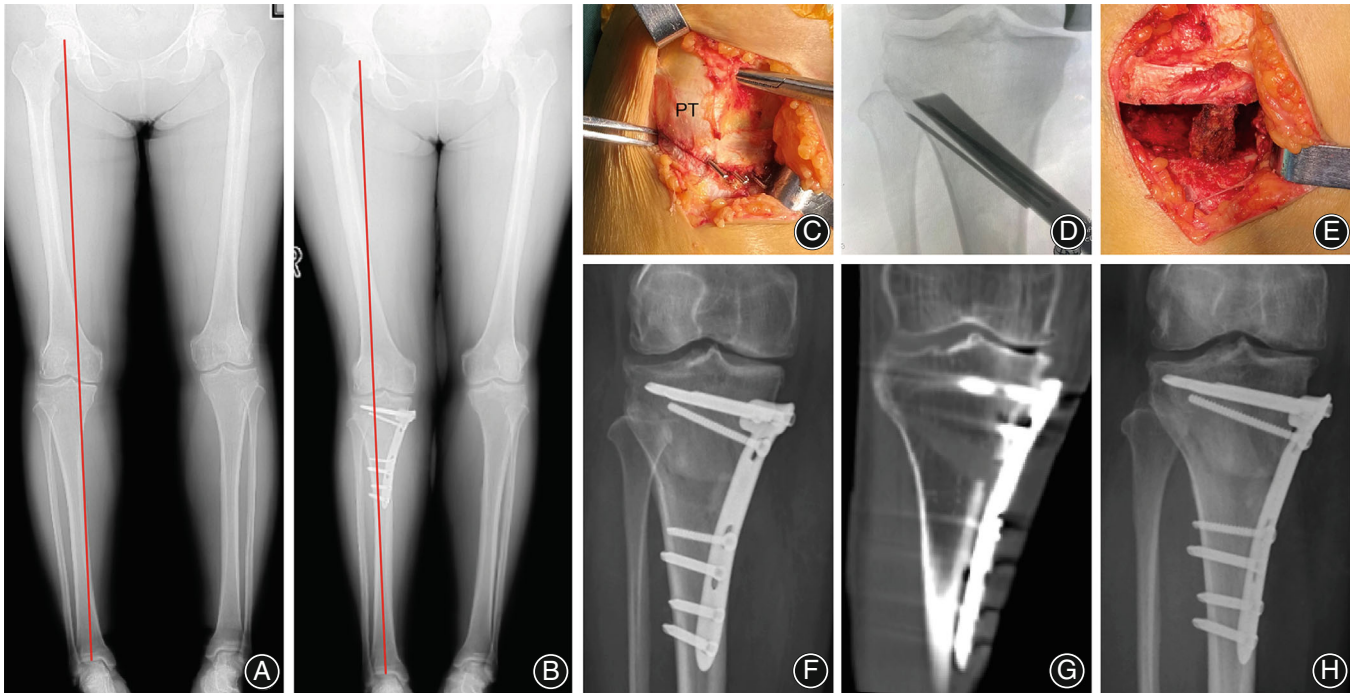

Fig. 5 Presentation of a typical case. (A, B) Preoperative and postoperative full-length radiographs of the lower limbs. (C, D) During the operation: the patellar tendon insertion was reconfirmed, and osteotomy was performed in the K-wire direction with a bone knife. (E) Observation of the osteotomy surface shows that it was completely located in the cancellous bone area. (F, G) Postoperative anteroposterior radiograph and coronal computed tomography (CT) scan of the knee joint. (H) The osteotomy area had completely healed 6 months after the operation. PT: patellar tendon

postoperative complications such as lateral hinge fracture occurred (Fig. 5F,G). The modified Insall–Salvati index was 1.12, which was not significantly different from that before surgery. Radiography (anteroposterior view) of the knee joint was repeated 6 months after the operation and showed that the osteotomy expansion area had completely healed (Fig. 5H).

Discussion

This study proposes the innovative concept of TT-HTO, which can solve the problem of medial opening wedge HTO easily leading to postoperative patellar infera. According to accurate observations of the patellar tendon insertion and adjustment of the hinge point position, the osteotomy line was designed. Based on the area of the osteotomy surface and wedge volume evaluated, TT-HTO has better potential advantages for bone healing.

Existing Modified Techniques for Avoiding Patella Infera

HTO becomes increasingly important in the treatment of cartilage damage or osteoarthritis of the medial compartment

with concurrent varus deformity.[22] In addition, HTO also has important application value for posttraumatic arthritis caused by proximal tibial and tibial plateau fractures with insufficient axial reduction.[23,24] In response to the problem of patella infera after conventional HTO, many teams have adopted improved osteotomy methods to preserve the relative anatomical position of the patellar tendon insertion, alter the patellofemoral joint relationship as little as possible, and avoid patella infera.[11,25,26]

A well-recognized procedure is biplanar-DTO, which involves the descending osteotomy surface in the coronal plane.[27] This technique may generate a tibial tubercle bone fragment. To correct the force line, the wedge region is stretched along the osteotomy line for correction. It moves medially and loses cortical bone support. A greater correction angle can result in a more obvious effect and smaller contact area between the tibial tubercle bone fragment and the cancellous bone, which will increase the risk of nonunion of the tibial tubercle.[12] If the thickness of the bone fragment is less than 1 cm or the position of the bone fragment fixation screw is not accurate, the bone fragment may break, which increases the risk of fracture and the difficulty of the operation.[28]

Another procedure is uniplanar-DTO. This osteotomy method moves the osteotomy line down to avoid the tibial tubercle. However, this will cause the following problems. First, the osteotomy surface is composed of cortical bone. Expansion of the wedge region can easily cause contralateral cortical fractures;[20] therefore, a K-wire is necessary to weaken the rigidness of the contralateral cortex at multiple points to reduce the risk of cortical fractures,[13] which undoubtedly increases the difficulty of the operation. Second, the osteotomy surface of cortical–cortical bone also poses challenges for postoperative bone healing.[15] Third, the reduced area of the osteotomy surface requires a greater anti-rotation ability of the tibia. Thus, the probability of internal fixation failure after osteotomy is high.[29,30]

Kentaro Igarashi's team adopted the focal dome condylar osteotomy procedure. This surgical technique minimally disturbs patellar tendon insertion and can maintain the length of the limbs. However, the operation is difficult, the risk of neurovascular injury is high, and the rotation correction angles cannot match.[31] Takenori Akiyama's team also developed a technique called open-wedge distal tibial tuberosity osteotomy. However, the surgical technique is three-plane osteotomy.[28] Accurately setting the ideal osteotomy line during the operation is difficult and cannot be carried out at primary-level hospitals.

Precise Location of the Patellar Tendon Insertion and the Osteotomy Line in TT-HTO

Based on the many problems with the existing osteotomy techniques, we first proposed tibial tubercle zoning, and we studied the X-ray and MR examinations of 200 patients. X-ray and MR examinations showed that no patellar tendon insertion was located in zone C or D of the tibial tubercle. Although a few patients had the lower edge of the patellar tendon insertion located in zone B of the tibial tubercle, most of the patellar tendon fibers were still attached to zone A. Intraoperative findings for the patellar tendon insertion were consistent with this result. These results provide a theoretical basis for transtibial tuberosity osteotomy.

According to the zoning of the tibial tubercle, under the premise of fully protecting the patellar tendon insertion, the osteotomy line should be as close to the cancellous bone area as possible to ensure healing of the osteotomy surface.[32] Therefore, we designed the osteotomy line to pass through, but not higher than, the lowest point of the patellar tendon insertion, that is, the intersection of the BC dividing line and the lateral edge of the tibial tubercle.

Compared with that in the traditional method, the hinge point of the new method is moved down by approximately 5 mm (1.5–2.0 cm away from the tibial plateau) to appropriately increase the thickness of the proximal osteotomy, and the hinge point is located in zone WL (within the proximal tibiofibular joint, lateral to the medical margin of the proximal tibiofibular joint). Accordingly, the risk of type II and type III fractures can be reduced at the same time.[33,34] The angle of the osteotomy line is increased because the osteotomy line is moved down to avoid the insertion point of the patellar tendon. An increase in the osteotomy line angle can also reduce the risk of type II fracture.[35] Although the distance between the tibial plateau and the crown of the fibula was 9.4 ± 2.8 mm,[36] because neither the bone knife nor the K-wire penetrated the lateral cortex, the superior tibiofibular syndesmosis was not damaged by the surgical procedure.

Potential Bone Healing Advantages of TT-HTO

The healing process of the osteotomy wedge region extends from lateral to medial.[37,38] In addition to the osteotomy surface located in the cancellous bone region, the area of the osteotomy surface and the volume of the bone defect are also important factors affecting the healing time.[39] This study compared TT-HTO with the two currently more recognized osteotomy methods that do not change the height of the patella to observe the osteotomy surface and the volume of the bone defect at a 1-cm height. No significant difference in the osteotomy area was identified between the TT-HTO group and the biplanar-DTO group; in both groups, it was significantly larger than that in the uniplanar-DTO group, indicating that TT-HTO and biplanar-DTO can provide greater bone support at the osteotomy site.[15] The volume of the bone defect was similar between TT-HTO and biplanar-DTO, but these volumes were slightly larger than that with uniplanar-DTO, possibly because the osteotomy line in the uniplanar-DTO was more distal than those in the above two methods, and since the tibia becomes thinner, this results in a reduction in the wedge-shaped volume. Although uniplanar-DTO seems more advantageous in terms of the absolute volume, we cannot conclude that uniplanar-DTO is associated with a better healing ability because it involves a

cortical bone area, which has a much lower healing ability than cancellous bone.[40] Thus, TT-HTO has an advantage in terms of the osteotomy area; the osteotomy area and volume are similar to those in classic biplanar-DTO.

Strengths and Limitations

This study showed a new high tibial osteotomy method that can accurately locate and protect the insertion point of patellar tendon. It not only demonstrated the design process of TT-HTO, but also confirmed its advantage in osteotomy surface.

In this study, the patellar tendon insertion was observed in a small sample because only the trend needs to be observed to demonstrate the research value of TT-HTO. When performing surgery for patients with this method, the position of the insertion of the patellar tendon must be reconfirmed for protection. A study with a larger sample size is needed to summarize the general rule for the relative position of the patellar tendon insertion and tibial tuberosity. The disadvantage of this osteotomy method lies in the large slope of the osteotomy line; although it can increase the elasticity of the hinge and reduce the risk of hinge breakage, it also reduces postoperative stability and increases the risk of internal fixation failure. Therefore, stronger internal fixation is required to provide reliable mechanical support. This will be our next research focus. At the same time, multicenter clinical trials and long-term follow-ups must be performed to verify the clinical feasibility.

Conclusion

According to the tibial tuberosity zoning, we achieved the precise localization of the patellar tendon insertion. Based on this, TT-HTO was designed, and its osteotomy line was close to the lower edge of the patellar tendon insertion. While avoiding postoperative patella infera, the osteotomy line is located in the cancellous bone area as much as possible. And the large osteotomy surface of TT-HTO ensures postoperative bone healing potential.

Acknowledgments

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Author Contributions

ZhanYu Wu, DaiZhu Yuan, DaWei Hua and Long Yang completed the data measurement. Qiang Zou completed the statistical analysis. ZhanYu Wu completed the article writing. At last Chuan Ye and XiaoBin Tian directed research design and paper revision. All authors read and approved the final manuscript.

Ethical Approval

The study was reviewed and approved by Guizhou Medical University Ethics Committee (2021055K). This study was registered in the Chinese Clinical Trial Registry (ChiCTR2100044254).

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