A New Technique for Distalization of the Tibial Tubercle That Allows Preservation of the Proximal Buttress

Luiz Felipe Ambra,*[†‡] MD, PhD, Amy Phan,[‡] BS, and Andreas H. Gomoll,[‡§] MD

This study was performed at Brigham and Women's Hospital, Boston, Massachusetts, USA

Background: Tibial tubercle osteotomy (TTO) is a treatment option for patients with patellofemoral instability and chondrosis. Occasionally, these patients also present with patella alta, and distalization of the tibial tubercle is desirable. Free distal transfer of the tubercle, however, can compromise mechanical stability of the osteotomy construct, leading to loss of fixation.

Purpose: To evaluate alternative TTO proximal cut geometries to investigate whether these can result in tubercle distalization while preserving the proximal buttress.

Study Design: Descriptive laboratory study.

Methods: Three variants of TTO cut geometry were evaluated on Sawbones as well as cadaveric knees. The proximal cut of the osteotomy was modified in 2 axes: anterior-posterior (AP) and medial-lateral (ML). Three variations were used: ML neutral/AP neutral, ML 30° proximal/AP neutral, and ML neutral/AP 30° proximal. The medial cut plane was 45° for all specimens. Tibial tubercle position was evaluated before and after osteotomy to calculate anteriorization, medialization, and distalization.

Results: Distalization was achieved with all variants. Increasing the inclination angle of the proximal cut in the AP and ML axes resulted in maximum distalization. A proximally directed cut yielded significantly more distalization when performed in the AP axis than in the ML axis ($P < .05$). Even the standard, neutral cut resulted in 5 mm of distalization.

Conclusion: Fulkerson osteotomy allows 3-dimensional repositioning of the tibial tubercle and has historically been utilized to achieve anteriorization and medialization. Even the neutral cut of a standard TTO resulted in distalization, which is relevant for patients with preexisting patella baja. Modification of the proximal cut increased distalization of the tubercle while preserving the proximal buttress, a potential benefit for construct stability.

Clinical Relevance: These results provide a guideline for adjusting the proximal cut geometry in Fulkerson TTO to meet specific patient needs.

Keywords: patellofemoral joint; osteotomy; patellofemoral syndrome; knee injury

Patella alta is a known risk factor for patellar dislocation and instability, as well as patellofemoral osteoarthritis.[1,3] Patella alta is usually not an isolated finding but is rather a single component of patellofemoral dysplasia with other major instability factors, such as trochlear dysplasia, excessive tibial tubercle–trochlear groove (TT-TG) distance, and patellar tilt.[2] Tibial tubercle osteotomy (TTO) is a common surgical procedure to treat patients with patellar instability and/or patellofemoral chondrosis.[5,11] Variations of the osteotomy can address patellar maltracking by correcting suboptimal alignment and patellar height abnormalities. Distalization of the tibial tubercle is an effective technique for correction of patellar height, thus reducing the risk of recurrent patellar dislocations.[7] However, there are concerns around the reduced mechanical stability of the osteotomy construct owing to the lack of a proximal buttress for the distalized tubercle fragment to abut, as well as concerns of increased joint reactive forces associated with isolated distalization.[7,10] Complications of distalization TTO

*Address correspondence to Luiz Felipe Ambra, MD, PhD, Departamento de Ortopedia e Traumatologia, Escola Paulista de Medicina, Universidade Federal de São Paulo, Rua Borges Lagoa 783, 5° Andar, São Paulo, Brazil (email: felipeambra71@gmail.com).

[†]Departamento de Ortopedia e Traumatologia, Escola Paulista de Medicina, Universidade Federal de São Paulo, São Paulo, Brazil.

[‡]Center for Regenerative Medicine and Cartilage Repair Center, Brigham and Women's Hospital, Boston, Massachusetts, USA.

[§]Harvard Medical School, Boston, Massachusetts, USA.

The authors declared that they have no conflicts of interest in the authorship and publication of this contribution. AOSSM checks author disclosures against the Open Payments Database (OPD). AOSSM has not conducted an independent investigation on the OPD and disclaims any liability or responsibility relating thereto.

Ethical approval for this study was obtained from Brigham and Women's Hospital.

The Orthopaedic Journal of Sports Medicine, 6(9), 2325967118798621
DOI: 10.1177/2325967118798621

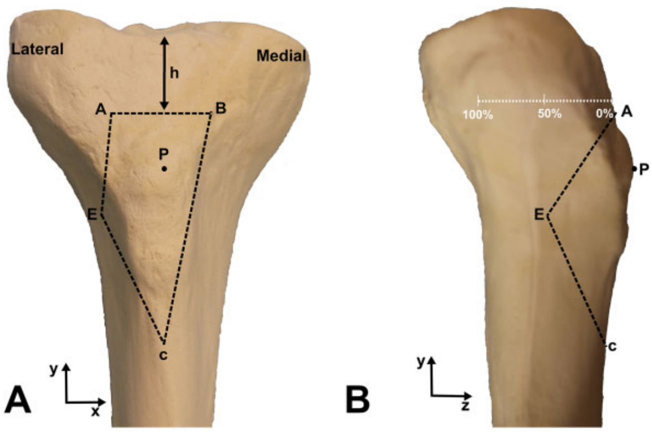

Figure 1. (A) The starting points are represented by dashed lines: *AB*, proximal cut (3 cm); *BC*, medial cut (7 cm). The double-arrow line (*h*) defines the distance of the proximal cut from the tibial plateau (2.5 cm). The most prominent point of the tibial tubercle (*P*) was used as a reference point to determine changes in position. (B) The most posterior lateral exit point (*E*) is where the lateral countercut starts; it is halfway between the anterior and posterior aspects of the lateral tibial wall.

include loss of fixation, delayed union or nonunion, and tibial fracture.[10] Furthermore, many patients with patellofemoral instability and patella alta have increased TT-TG distance, which would benefit from medialization osteotomy to normalize the TT-TG distance and decrease patellofemoral loading. While isolated distalization TTO can be performed in a comparatively stable fashion (V-cut) by transferring cortical bone stock from the distal aspect of the fragment to fill the resultant proximal void, (antero)medialization results in a mechanically weak sliver of distal bone that does not provide significant stability when transferred proximally.

The objective of this study was therefore to investigate whether the proximal cut of a Fulkerson-type anteromedialization osteotomy can be modified to provide not only medialization and anteriorization but also distalization of the tibial tubercle while preserving the proximal buttress. We hypothesized that by using an alternative proximal cut, we may achieve distalization while preserving the proximal buttress, leading to a mechanically more stable osteotomy without leaving a proximal empty gap.

METHODS

This study was designed in 2 phases. First, the study protocol and modifications on the proximal cut were tested with Sawbones tibiae (No. 1116-2, medium right; Pacific Research Laboratories Inc). Utilizing artificial samples is advantageous to precisely reproduce identical anatomic conditions without interspecimen variability. Afterward, the hypothesis and protocol underwent confirmatory testing with human cadaveric knees.

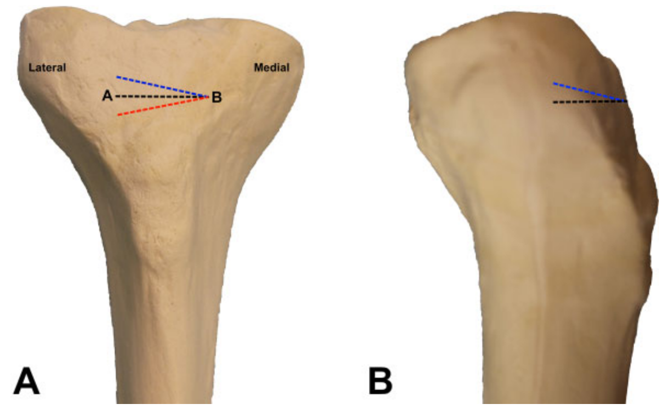

Figure 2. Proximal cut planes. (A) The dashed lines show the 2 variations for the medial-to-lateral proximal cut: the black line shows a neutral position; the red line, a distally directed cut; and the blue line, a proximally directed cut. (B) The dashed lines demonstrate the planes used for the anterior-to-posterior proximal cut: the black line shows a neutral position and the blue line, a proximally directed cut.

Sawbones Specimen Test

To enhance reproducibility, a standard template (Figure 1) was designed to determine the proximal-medial starting point of the osteotomy (Figure 1, point *B*) as described by Fulkerson.[4] This template was used as the standard, and all modifications were based on this. To ensure consistency with Sawbones specimens, a positioning stand was molded to match the posterior tibial contour. This stand was used to reproduce the same tibial rotation (posterior condylar axis parallel to the floor) during specimen preparation. Then, the specimen was fitted on the stand and the most prominent point on the tibial tubercle (Figure 1, point *P*) was marked. The template was now drawn on the specimen. Once the entry points and reference points were defined and marked on the specimen, the plane of osteotomy was prepared.

The inclination angle of the osteotomy was chosen as a standard 45° for all specimens. Three guide pins were inserted along the medial origin of the osteotomy (Figure 1, line *BC*), aiming 45° posterolaterally. With these pins as reference, the osteotomy was performed with an oscillating saw, exiting the lateral cortex at approximately the halfway mark (Figure 1, line *EC*). Proximally, the medial cut was stopped short of the lateral cortex, and a proximal lateral countercut was performed (Figure 1, line *AE*).

The proximal cut of the osteotomy (Figure 1, line *AB*) was modified in 2 planes: medial-lateral (ML) (Figure 2A) and anterior-posterior (AP) (Figure 2B). By combining these modifications, the proximal cut was performed in 5 geometries as described in Table 1. This cut resulted in a proximal bone shelf acting as a buttress to restrain the osteotomy fragment from sliding proximally.

After completing the osteotomy, the fragment was mobilized, transferring the tibial tubercle medially and anteriorly along the osteotomy plane. The fragment was transferred to

TABLE 1
Proximal Cut Geometry Variants

No.	Proximal Cut, deg	
	Medial-Lateral	Anterior-Posterior
1	Neutral	Neutral
2	20° proximal	Neutral
3	Neutral	30° proximal
4	20° distal	30° proximal
5	20° proximal	30° proximal

achieve 1 cm of medialization and anteriorization, respectively. The fragment was then secured with a pin in the most proximal position so that it was abutting the proximal buttress.

All measurements were performed with a 3-dimensional MicroScribe Digitizer (accuracy, 0.022 mm; Immersion Corp) to accurately measure the position of the tibial tubercle fragment before and after osteotomy. First, the coordinate axes were established with the following references: y, parallel to the tibial shaft axis (sagittal plane); z, perpendicular to the tibial shaft axis (axial plane); x, perpendicular to the tibial shaft axis (coronal plane). Then, with a reference point on the fragment (Figure 1, point *P*), the fragment position was recorded before (*P*x, *P*y, *P*z) and after (*P′*x, *P′*y, *P′*z) the transfer in 3 dimensions. The difference between the coordinates (*P′*x-*P*x, *P′*y-*P*y, *P′*z-*P*z) was the displacement in each plane where the positive values for the x, y, and z axes represented medialization, distalization, and anteriorization, respectively.

For the first phase of the study, 5 Sawbones specimens were used to refine the protocol and technique. The protocol was then tested in 3 additional Sawbones specimens to evaluate reproducibility. The test-retest mean ± SD difference for distalization among these 3 samples was 0.8 ± 0.5 mm.

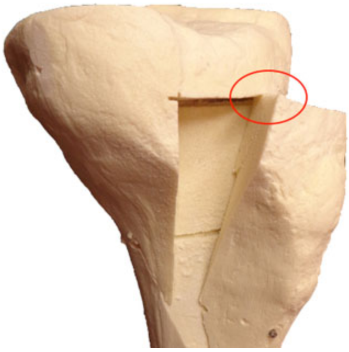

Figure 3. Contact point between the posterolateral aspect of the tubercle fragment and the medial proximal shelf/buttress (red circle), providing resistance to proximal migration.

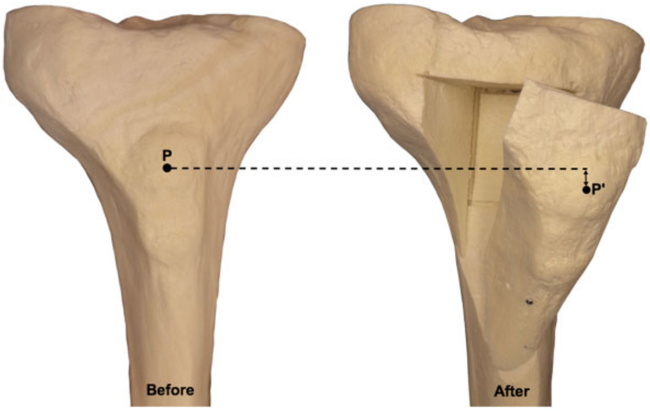

Figure 4. Anterior views of a right tibia Sawbones specimen after tibial tubercle osteotomy: proximal cut medial-lateral neutral/anterior-posterior neutral. The image compares tibial tubercle position (*P*) before and (*P′*) after transfer. The double-arrow line represents the amount of distalization.

Cadaveric Specimen Test

Based on the results of the Sawbones specimen tests, the 5 proximal cut variations were now evaluated in cadaveric knee specimens and reduced to 3 variants: ML neutral/AP neutral, ML 30° proximal/AP neutral, and ML neutral/AP 30° proximal. Variant 4 was discarded because it led to only a modest amount of distalization. Variant 5 was discarded given the risk of possible complications presented by this modification: first, the osteotomy extends proximally very close to the tibial plateau, increasing the risk of intra-articular extension and/or fracture. In addition, the required orientation of the sawblade for this osteotomy presented a risk for damage to the patellar tendon.

Nine fresh-frozen cadaveric knees with no history of bone disease or knee surgery were obtained from an accredited tissue bank (4 female, 5 male; mean age, 46.8 years; range, 42-50 years) and were equally distributed in the 3 groups: ML neutral/AP neural, ML 30° proximal/AP neutral, and ML neutral/AP 30° proximal. The cadavers were stored at –20°C and thawed before use. Skin and subcutaneous fat were removed, preserving the extensor mechanism. The specimens were secured with the posterior femoral condyle axis parallel to the floor. Following clinical practice, the medial and lateral aspects of the patellar tendon as well as the lateral cortex were exposed. The osteotomy was marked out and performed as described in the Sawbones protocol. All measurements were performed with the MicroScribe device as described.

Statistical Analysis

Results were compared with the Kruskal-Wallis test and Dunn multiple-comparison post hoc test if any observed differences were significant ($P < .05$). A power calculation was performed per results from the Sawbones study, demonstrating a required sample size of 3 per group to detect a significant change in distal translation (2 ± 1 mm) with 80% power and 95% CI. Stata (v 14.1; StataCorp) was used to perform all statistical analysis. A P value <.05 was considered significant.

TABLE 2
Results of Sawbones and Cadaveric Specimen Test

No.	Proximal Cut, deg: Medial-Lateral	Proximal Cut, deg: Anterior-Posterior	Distalization, mm: Sawbones	Distalization, mm: Cadavers[a]
1	Neutral	Neutral	5.09	4.83 ± 2.07
2	20° proximal	Neutral	6.8	7.89 ± 0.91
3	Neutral	30° proximal	11.52	10.29 ± 1.3
4	20° distal	30° proximal	3.71	—[b]
5	20° proximal	30° proximal	12.23	—[b]

[a]Mean ± SD.
[b]Discarded.

RESULTS

Anteromedial displacement of the fragment brought the proximal posterolateral aspect of the fragment in contact with the medial aspect of the proximal buttress for all tested configurations (Figure 3, circle). Depending on the specific geometry of the proximal cut, this resulted in various amounts of distalization of the fragment (Figure 4). All 5 variants of proximal cut angle geometries tested with Sawbones specimens resulted in various amounts of distalization (Table 2). Similarly, all 3 proximal cut variants tested in cadaveric specimens distalized the tibial tubercle. The modification of the proximal cut in the medial-lateral direction (increasing the angle by aiming more proximally; group 2) resulted in significantly greater distalization than that of the standard geometry (group 1) ($P = .02$). The modification in the anterior-to-posterior direction (group 3) yielded significantly more distalization than that of the other 2 alternatives ($P < .0001$ vs group 1, $P = .069$ vs group 2).

DISCUSSION

Our study demonstrated that a modified anteromedialization TTO can achieve >10-mm distalization of the tibial tubercle by varying the angle of the proximal cut. Importantly, this distalization can be achieved while preserving contact of the tibial tubercle fragment with the proximal bone buttress, thus avoiding the decreased mechanical stability seen with free distal transfer of the fragment. Of note, even with a standard technique with neutral cuts, a mean distalization of 4.83 mm was achieved.

In 1983, Fulkerson[4] described an oblique TTO that permits tibial tubercle displacement along a smooth osteotomy plane simultaneously in the anterior and medial directions. TTO can also be utilized to move the tibial tubercle fragment distally to address patella alta. One of the most concerning complications after TTO is loss of fixation and nonunion of the osteotomy site, a rare but potentially devastating complication. The overall rate of nonunion in a TTO procedure is as low as 1% but can triple with distalization.[6] Payne et al[10] reviewed 787 TTOs, reporting that the major factor associated with nonunion was the complete detachment of the tibial tubercle, a necessity for distalization. An additional reason for the seemingly increased vulnerability of distalization TTO could be the increased stress on the osteotomy fixation: without a proximal buttress to act as a restraint against proximal migration, fragment stability relies solely on interfragmentary compression from the screws to resist shear. Straight distalization of the tubercle can utilize a V-shaped osteotomy, removing a solid cortical segment of bone distally and placing this segment proximal to the tubercle fragment to fill the gap resulting from the distalization and to re-create a stable buttress. However, this technique cannot be utilized when distalization is combined with anteromedialization, since here the osteotomy cut feathers out distally. The distal tip of the resultant osteotomy fragment is too thin to be used in any meaningful way to restore a proximal buttress. Cortical allograft could be utilized instead, although this increases the cost. Although no biomechanical study has demonstrated the potential benefit of the proximal buttress increasing stability, some authors have recommended filling the gap to increase the strength of the osteotomy.[8]

Our study investigated distalization of the tibial tubercle fragment with 3 proximal cut geometries during anteromedialization TTO, altering the osteotomy plane in 2 axes: anterior to posterior and medial to lateral. Our study showed that distalization increases in relation to the proximal inclination of the osteotomy cut, the major impact being achieved through changes in the AP axis. By directing the angle of the cut 30° proximally, the tubercle fragment was moved distally by 10 mm. Variations in the inclination of the ML axis presented smaller but significant amounts of distalization.

This study evaluated distalization of the tibial tubercle in just 1 inclination of the medial osteotomy with a fixed amount of anteromedialization. The amount of distalization should be expected to vary with different osteotomy angles (steeper or shallower than 45°), as well as with different amounts of anteromedialization. We recommend planning the cut to achieve more distalization than required, because distalization can be easily decreased by removing some of the proximal bone of the tibial tubercle fragment. However, if additional distalization were required beyond that achieved by the angle variation, an empty gap would result, similar to standard distalization. Similarly, as we demonstrated in this study, a small amount of distalization occurs with a neutral cut. Thus, when distalization is not desired, the proximal aspect of the fragment can be removed to prevent unintentional distalization and, consequently, patella baja.

Patella alta is caused by a long patellar tendon rather than a proximalized tibial tubercle. Neyret et al[9] demonstrated that the distance from the tibial plateau to the tibial tubercle varied only minimally among individuals: 29 ± 4 mm in a patellar instability group, which did not differ significantly from a control group (28 ± 5 mm). The distance from the tibial plateau to the tibial tubercle therefore does not significantly contribute to patellar height. We established the starting point for the proximal cut 2.5 cm below the tibial plateau, and this distance was shown to be safe for all combinations of proximal cut geometry. The osteotomy always remained >1 cm from the tibial plateau, even with the most aggressive geometry. However, the combination of proximal modification in both the AP and the ML planes extended the closest to the tibial plateau and is therefore not recommend.

One potential limitation of this study was the limited number of specimens tested for each condition. However, test-retest variation in identical Sawbones specimens remained <1 mm, demonstrating reproducibility and proof of concept. This study aimed to establish anatomic reference points and evaluate the reproducibility and feasibility of adding distalization to anteromedialization osteotomy by modifying proximal cut geometry. Future biomechanical and clinical studies are desirable to investigate the construct strength and clinical benefits on this novel technique.

In conclusion, TTO allows 3-dimensional repositioning of the tibial tubercle medially, anteriorly, and distally. Based on our data, a proximal cut modification can be used to obtain additional distalization if so desired while preserving a proximal buttress as a restraint to displacement. All variations of the proximal cut described in this study resulted in distalization. These results provide a guideline for selecting a proximal cut geometry during anteromedialization osteotomy to meet the specific needs of the patient. Also, surgeons should be aware that even a standard proximal cut geometry results in a small amount of distalization, a potential concern for patients with preexisting patella baja.

REFERENCES

1. Balcarek P, Oberthür S, Hopfensitz S, et al. Which patellae are likely to redislocate? *Knee Surg Sports Traumatol Arthrosc*. 2013;22(10): 2308-2314.
2. Caton JH, Dejour D. Tibial tubercle osteotomy in patello-femoral instability and in patellar height abnormality. *Int Orthop*. 2010;34(2): 305-309.
3. Dejour H, Walch G, Nove-Josserand L, Guier C. Factors of patellar instability: an anatomic radiographic study. *Knee Surg Sports Traumatol Arthrosc*. 1994;2(1):19-26.
4. Fulkerson JP. Anteromedialization of the tibial tuberosity for patellofemoral malalignment. *Clin Orthop Relat Res*. 1983;(177): 176-181.
5. Hall MJ, Mandalia VI. Tibial tubercle osteotomy for patello-femoral joint disorders. *Knee Surg Sports Traumatol Arthrosc*. 2016;24(3): 855-861.
6. Longo UG, Rizzello G, Ciuffreda M, et al. Elmslie-Trillat, Maquet, Fulkerson, Roux Goldthwait, and other distal realignment procedures for the management of patellar dislocation: systematic review and quantitative synthesis of the literature. *Arthroscopy*. 2016;32(5):929-943.
7. Magnussen RA, De Simone V, Lustig S, Neyret P, Flanigan DC. Treatment of patella alta in patients with episodic patellar dislocation: a systematic review. *Knee Surg Sports Traumatol Arthrosc*. 2013; 22(10):2545-2550.
8. Mayer C, Magnussen RA, Servien E, et al. Patellar tendon tenodesis in association with tibial tubercle distalization for the treatment of episodic patellar dislocation with patella alta. *Am J Sports Med*. 2012; 40(2):346-351.
9. Neyret P, Robinson A, Le Coultre B, Lapra C. Patellar tendon length—the factor in patellar instability? *Knee*. 2002;9(1):3-6.
10. Payne J, Rimmke N, Schmitt LC, Flanigan DC, Magnussen RA. The incidence of complications of tibial tubercle osteotomy: a systematic review. *Arthroscopy*. 2015;31(9):1819-1825.
11. Sherman SL, Erickson BJ, Cvetanovich GL, et al. Tibial tuberosity osteotomy: indications, techniques, and outcomes. *Am J Sports Med*. 2013;42(8):2006-2017.