


Evaluating the Impact of Tibial Tubercle Osteotomy in Adult Patients on Patellar Height and Patellar Tendon Length

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Background: Patellar height (PH) constitutes an important component of patellofemoral biomechanics. Iatrogenic decrease in PH after knee procedures has been demonstrated for arthroplasty and high tibial osteotomy, among others. However, alterations in PH resulting from tibial tubercle osteotomy (TTO) have yet to be described.

Purpose/Hypothesis: This study aimed to compare pre- and postoperative PH ratios and patellar tendon length (PL) in adult patients who have received an anteromedialization or medialization TTO. The authors hypothesized that TTO would result in PH alterations with trends toward patella baja.

Study Design: Case series; Level of evidence, 4.

Methods: This was a retrospective review of adult patients receiving primary TTO +/− medial patellofemoral ligament reconstruction from 2013 to 2020. All patients had a minimum 6-month radiographic follow-up. Pre- and postoperative PH measurements were assessed with the Blackburne-Peel Index (BPI), Caton-Deschamps Index (CDI), Insall-Salvati Ratio (ISR), and PL. Paired *t* tests were performed for each measurement index comparing pre- and postoperative radiographs.

Results: A total of 42 patients (64% women), with a mean age of 26.5 years (range, 18–51 years) and a mean radiographic follow-up of 19 months (6–110 months) met the inclusion criteria. The mean preoperative PH using the BPI, CDI, and ISR were 0.99 ± 0.239 , 1.20 ± 0.240 , and 1.29 ± 0.206 , respectively. The mean preoperative PL was 54.52 ± 7.23 mm. The mean postoperative PH using the BPI, CDI, and ISR were 0.95 ± 0.24 , 1.16 ± 0.21 , and 1.20 ± 0.19 , respectively. The mean postoperative PL was 52.79 ± 7.25 mm. The mean differences between the pre- and postoperative were as follows: BPI: 0.04; CDI: 0.04; ISR: 0.08; and PL: 1.73 mm, none of which were statistically significant.

Conclusion: While changes were observed in approximately 50% of patients, there were no statistically significant, nor predictable, alterations in PH after TTO using the BPI, CDI, ISR, or PL measurements at a minimum 6-month follow-up. Further large-scale studies are needed to determine the reliability of these PH findings and whether the changes are clinically impactful on surgeon decision-making and patient outcomes.

Keywords: anteriomedialization tibial tubercle osteotomy; medialization tibial tubercle osteotomy; patellar height; patellar tendon length

Tibial tubercle osteotomy (TTO) can be an effective treatment for patellar instability or select patients with patellofemoral joint cartilage pathology.^{4,10,20,21} The effectiveness of TTO has been demonstrated in both biomechanical and clinical studies.¹ By adjusting the relative position of the tibial tubercle, the goal of a TTO is to improve both the

magnitude and direction of forces exerted on the patella.^{3,6,19} Various osteotomy techniques can be performed on the tibial tubercle to address patient-specific pathology and alignment. In these patients, anteromedialization and medialization osteotomies of the tibial tubercle are most commonly performed. Medialization decreases laterally directed forces on the patella within the trochlear groove, while the addition of anteriorization of the tibial tubercle improves patellofemoral dynamics by increasing the moment arm from the center of rotation of the tibia.^{5,16,18}

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The patellar location within the sagittal plane of the joint, which we refer to as the patellar height (PH), is also important in dictating stability and motion at the knee joint. The PH can be calculated through a variety of measurement modalities. Three of the most widely utilized PH assessment techniques include the Blackburne-Peel Index (BPI), Caton-Deschamps Index (CDI), and Insall-Salvati Ratio (ISR).^{1,2,9} These measurements are associated with acceptable intra- and interrater reliability and reproducibility on lateral radiographs and magnetic resonance imaging.²² A superiorly deviated patella, patella alta, decreases bony engagement with the trochlea, potentially increasing the risk for instability.¹⁷ Conversely, inferior aberration of the patella, patella baja, increases frictional coefficients within the joint and can be a cause of knee pain, restricted range of motion, and premature osteoarthritis.

PH measurements have been previously reported on patients with patellar instability procedures; however, the studies have come with limitations.^{7,14,15} A study by Kreulen et al¹² demonstrated changes with a 2-bundle medial patellofemoral ligament reconstruction (MPFLR) technique but not a 1-bundle MPFLR technique; however, their radiographic follow-up was only 2 weeks. Hiemstra et al⁷ suggested that some patients with preexisting patella alta can achieve a PH decrease after isolated MPFLR at a 6-month radiographic follow-up. Luceri et al¹⁴ demonstrated similar findings in their study of isolated MPFLR. This study aimed to report on PH changes after combining MPFLR with medialization/anteromedialization TTO after the patients achieved radiographic healing of their TTO. We hypothesized that PH and patellar tendon length (PL) would decrease as healing progresses.

METHODS

This study was performed at a single academic institution. After obtaining institutional review board approval, a retrospective review was performed on patients who underwent medialization/anteromedialization TTO between 2013 and 2020. Patients were identified using Current Procedural Terminology (CPT) codes. Patients were included if they underwent anteromedialization or direct medialization TTO, with or without concomitant MPFLR, had available preoperative and 6-month postoperative lateral radiographs, and were at least 18 years old at the time of surgery. Patients were excluded for distalization TTO, revision TTO, concomitant surgeries performed at the injured knee (other than MPFLR), inadequate or missing radiographs, or no radiographic follow-up.

Plain film radiographs were accessed with the use of the institution's picture archiving and communication system (Intellispace; Philips). For each patient, PH measurements were conducted on pre- and postoperative lateral radiographs with the knee in 30° to 70° of flexion. BPI, CDI, and ISR measurements were performed by 2 independent reviewers (N.E.M., R.M.R.) for each radiograph (Figure 1). The PL was also recorded as an individual metric, defined as the length from the inferior pole of the patella to the insertion point on the tibial tubercle.

Statistical Analysis

All calculations and statistical analyses were performed using Microsoft Excel Version 16.54 (Microsoft) and R Version 2023 (R Core Team). Descriptive data were collected from the institution's electronic medical record software (Epic). The intraclass correlation coefficient (ICC) was used to determine interrater reliability between the 2 reviewers. Based on the 95% CI of the ICC estimate, values <0.5, between 0.5 and 0.75, between 0.75 and 0.9, and >0.90 were considered to have poor, moderate, good, and excellent reliability, respectively.¹¹ The single-score ICC was classified as excellent (0.97). Normality was determined using a Shapiro-Wilk test.

Preoperative PH was compared with postoperative PH using a paired-samples *t* test for normally distributed data. Comparisons were made separately for each measurement method. Pre- and postoperative PL were also compared using paired-samples *t* tests. Categorical data were similarly analyzed using the Fisher exact test.

PH changes were defined using 3 parameters to control for both the direction and magnitude of change. Changes that trended toward baja were those in which the BPI, CDI, or ISR changed by a magnitude of ≥ 0.1 , as it pertains to decreased PH or decreased PL. "No change" was defined as a change in the BPI, CDI, or ISR that was a difference of <0.1 in the direction of the baja or alta. Last, changes that trended toward alta were those in which the BPI, CDI, or ISR changed by a magnitude of ≥ 0.1 , as it pertains to an increased PH or increased PL.

Subgroup Analysis

Patients were then analyzed by the direction of the TTO, either anteromedialization or medialization TTO. The vector of the osteotomy was determined through the operative report of the attending surgeon. The mean preoperative PH was compared with the mean postoperative PH using

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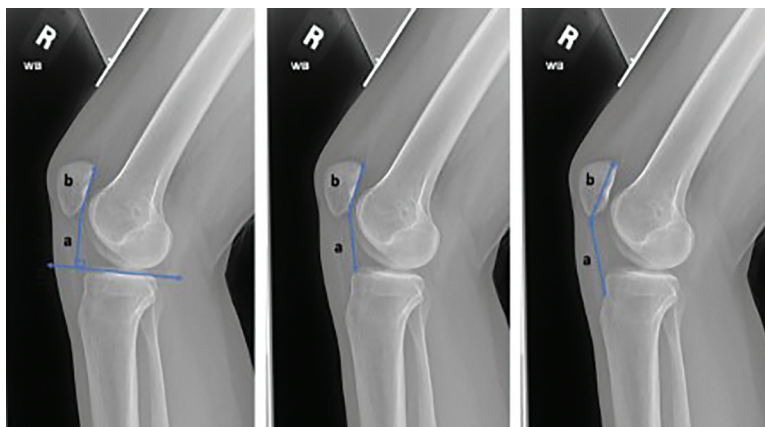


Figure 1. Diagram of PH assessments: The BPI, CDI, and ISR. The BPI (left panel) was defined by a/b , where a represents the perpendicular distance from a line projected anteriorly off the tibial plateau slope to the inferior patellar articular surface and b is the length of the patellar articular surface. The CDI (center) was defined by a/b , where a is the distance measured from the inferior-most point of the patellar articular surface to the anterior angle of the tibial plateau and b is the length of the patellar articular surface. The ISR (right panel) was defined by a/b , where a is the PL from the inferior pole of the patella to the insertion point on the tibial tubercle and b is the greatest pole-to-pole length of the patella. BPI, Blackburn-Peel Index; CDI, Caton-Deschamps Index; ISR, Insall-Salvati Ratio; PH, patellar height; PL, patellar tendon length.

the BPI, CDI, and ISR, separately for each group with a paired-samples t test.

RESULTS

A total of 129 patients were identified from CPT codes, with a minimum 6-month follow-up. A total of 49 patients were excluded for being aged <18 years, 23 patients for incorrect coding, and 15 patients for inadequate radiographs. A total of 42 knees from 38 patients met the inclusion criteria. The mean age of patients was 26.5 years (18–51 years). There were 27 (64%) female and 15 (36%) male knees. The mean radiographic follow-up was 19 months (6–110 months) (Table 1).

The mean preoperative PH measurements were 0.99 ± 0.239 , 1.20 ± 0.240 , and 1.29 ± 0.206 for the BPI, CDI, and ISR, respectively. Postoperative PH measurement means were 0.95 ± 0.243 , 1.16 ± 0.213 , and 1.20 ± 0.194 for the BPI, CDI, and ISR, respectively (Figure 2). The difference in means between the pre- and postoperative BPI, CDI, and ISR measurements were 0.04 ($P = .3623$), 0.04 ($P = .1391$), and 0.08 ($P = .0835$), respectively (Table 2). The mean pre- and postoperative PL were 54.5 ± 7.23 mm and 52.8 ± 7.29 mm, respectively. The difference in means for the pre- and postoperative PL was 1.73 mm ($P = .1550$).

The direction of change was not universal among patients (Table 3.) With regard to the BPI, 13 of 42 (31%) of patients trended toward *baja* with a BPI change of >0.1 , 21 of 42 (50%) demonstrated “no change” (<0.1 change in the direction of the *baja* or *alta*), and 8 of 42 patients trended toward *alta* postoperatively (19%). With the CDI, 12 of 42 (29%) patients trended in the direction of the *baja*, 24 of 42 (57%) patients showed “no change,” and 6 of 42 (14%) patients trended in the direction of the *alta*. Last, with the ISR, 16 of 42 (38%) patients changed

TABLE 1
Adult TTO Patient Characteristics^a

N	42
Age, y	26.5 (1)
Follow-up, months	24.8 (19.4)
Sex	
Female	27
Male	15
Laterality	
Right	22
Left	20

^aA demographic table of patients who underwent anteromedialization or direct medialization tibial TTO. Data are presented as mean (SD) or n. TTO, tibial tubercle osteotomy.

in the direction of *baja*, 24 of 42 (57%) patients showed “no change,” and 2 of 42 (5%) patients trended in the direction of the *alta*. There were no significant differences in means between pre- and postoperative PH measurements for male and female patients using the BPI, CDI, or ISR ($P = .56$, $P = .62$, $P \geq .999$), nor any differences between pre- and postoperative PL based on sex ($P \geq .999$).

Subgroup Analysis

Four patients underwent anteromedialization TTO, and 36 patients underwent medialization TTO. The anteromedialization group had a mean preoperative PH of 0.80, 1.05, and 1.31 using the BPI, CDI, and ISR, respectively. The mean postoperative PHs were 0.77, 0.97, and 1.20 for the BPI, CDI, and ISR, respectively. The difference in means for the anteromedialization group was 0.03 ($P = .7715$),



Figure 2. Pre- (top row) and postoperative (bottom row) radiographs with PH assessments: The BPI, CDI, and ISR from left to right, demonstrating no change in PH after TTO. Top left panel, BPI = 0.95. Bottom left panel, BPI = 1.04. Top middle panel, CDI = 1.02. Bottom middle panel, CDI = 1.15. Top right panel, ISR = 1.11. Bottom right panel, ISR = 1.15. BPI, Blackburn-Peel Index; CDI, Caton-Deschamps Index; ISR, Insall-Salvati Ratio; PH, patellar height; PL, patellar tendon length; TTO, tibial tubercle osteotomy.

TABLE 2
Adult Pre- and Postop PH Using BPI, CDI, ISR, and PL^a

PH Measurement	BPI	CDI	ISR	PL, mm
Preop	0.99 (0.239)	1.20 (0.240)	1.29 (0.206)	54.52 (7.23)
Postop	0.95 (0.243)	1.16 (0.213)	1.20 (0.194)	52.79 (7.25)
Difference in means (P)	0.04 (.3623)	0.042 (.1391)	0.084 (.0835)	1.73 (.1550)

^aData are presented as mean (SD). BPI, Blackburn-Peel Index; CDI, Caton-Deschamps Index; ISR, Insall-Salvati Ratio; PH, patellar height; PL, patellar tendon length; Postop, postoperative; Preop, preoperative.

TABLE 3
Direction of PH Change Using the BPI, CDI, and ISR Grouped by Magnitude of Difference Pre- to Postoperatively^a

Difference in Means	BPI	CDI	ISR	P (Chi-square)
Direction of patella baja, magnitude of change >0.1	13	12	16	.361
No change, magnitude of change between -0.1 and 0.1	21	24	24	
Direction of patella alta, magnitude of change <-0.1	8	6	2	

^aData are presented as n. Changes that trended toward alta were those in which the BPI, CDI, or ISR changed by a magnitude of ≥ 0.1 , as it pertains to an increased PH (difference in pre- to postop PH ratios of < -0.1). Changes that trended toward baja were those in which the BPI, CDI, or ISR changed by a magnitude of ≥ 0.1 , as it pertains to decreased PH (difference in pre to postop PH ratios of > 0.1). "No change" was defined as a change in the BPI, CDI, or ISR that was < 0.1 difference in the direction of the baja or alta. BPI, Blackburn-Peel Index; CDI, Caton-Deschamps Index; ISR, Insall-Salvati Ratio; PH, patellar height; Postop, postoperative; Preop, preoperative.

0.09 ($P = .6857$), and 0.10 ($P = .3429$) for the BPI, CDI, and ISR, respectively. The medialization group had a mean preoperative PH of 1.01, 1.21, and 1.28 using the BPI, CDI, and ISR, respectively. The mean postoperative PHs were 0.96, 1.19, and 1.21 for this group using the BPI, CDI, and ISR, respectively. Finally, the differences in means for the medialization group were 0.07 ($P = .272$), 0.03 ($P = .7555$), and 0.07 ($P = .2643$) for the BPI, CDI, and ISR, respectively.

DISCUSSION

The findings of the present study suggest that nondistalizing (anteromedialization and medialization) TTO is not associated with significant changes in PH or PL. Not only were the changes statistically insignificant when examining the mean PH change from pre- to postoperatively, but they were also unpredictable, as approximately 50% of patients had <0.1 unit change in CDI/BPI/ISR, and even a small percentage demonstrated a PH increase postoperatively. Thus, our hypothesis that TTO would result in a PH decrease was rejected.

While our hypothesis was rejected, our results still add novel considerations to patellar instability and chondromalacia procedures, with potential implications in surgical decision-making. First, these data suggest that medialization and anteromedialization TTO do not increase the risk of iatrogenic patella baja in adult patients. Similarly, this study suggests that medialization and anteromedialization TTOs do not improve PH in patients with patella alta. This finding is pertinent for patients with patella alta undergoing TTO for patellar instability. Consequently, surgeons may need to consider performing multipplanar TTO with a distalization component to adequately treat patellar instability in these patients.

The concept of PH changes after patellar stabilization procedures has been previously investigated. PH measurements have been previously reported on patients with patellar instability procedures; however, the studies have come with limitations. A study by Kreulen et al¹² demonstrated changes with a 2-bundle MPFLR technique but not a 1-bundle MPFLR technique; however, their radiographic follow-up was only 2 weeks. In addition, their cohort was somewhat heterogeneous in that they were comparing different MPFLR techniques and patients with and without TTO. Despite this, it is significant in that it is a larger cohort than our present study. Hiemstra et al⁷ suggested that some patients with preexisting patella alta can achieve a PH decrease after isolated MPFLR, which strengthens their findings; however, their study did not include patients with TTO. Luceri et al¹⁴ demonstrated similar findings in their study of isolated MPFLR. They concluded that the effect is more significant in patients with preexisting alta and recommended that distalization TTO not be performed in patients with a CDI of 1.2 to 1.4 because of this effect.

Last, there is significant variation in the clinical utilization of the PH assessments given the practical implementation of the measurements: knee flexion angle

requirements, the tediousness of some calculations, and the lack of consensus on the clinical significance of PH measurements and cutoffs.⁸ Addressing the variability in PH measurement techniques and clinical significance is outside the scope of this investigation. It is notable that while all 3 measurements did not detect a PH decrease after TTO, there was some variation in the difference in means observed between the measurements. Given this variation and the lack of consensus within the community, this study uniquely applies all 3 PH measurements and provides insight into how differences between BPI, CDI, and ISR may influence both study interpretation and clinical decision-making.

Limitations

There are several limitations to this study. First, we were unable to evaluate the effect of MPFLR in this analysis. Previous literature has described decreases in PH after isolated MPFLR; however, MPFLR was employed throughout this study population, and our analyses did not demonstrate a decrease in PH. In addition, MPFLR and TTO are commonly performed in concert, and reporting these observations together adds clinical utility. Although this study was appropriately powered to test our primary hypothesis, a larger sample size would provide additional generalizability and potentially detect differences in secondary outcomes such as trends in age and patient sex. In addition, the subgroup analysis of the anteromedialization and medialization cohorts was not adequately powered. The mean follow-up for this study was 19 months, which is relatively short-term in orthopaedics outcomes research. However, previous studies have demonstrated that changes in postoperative PH plateau at 3 months.¹³ Thus, we believe that our follow-up is sufficient to describe the radiographic findings in this study.


Patellofemoral biomechanics are complex. We did not account for other relevant variables such as tibial slope, Q-angle, the effect of MPFLR, and tibial tuberosity-trochlear groove distance, but differences in these variables among patients may affect the risk of developing PH changes postoperatively. Likewise, there is certainly variation in the surgical technique for shifting the tibial tubercle intraoperatively. Because our study was retrospective, we could not account for differences in intraoperative techniques. Future studies could seek to examine these variables as risk factors for developing iatrogenic PH changes.

CONCLUSION

The findings of the present study suggest that nondistalizing (anteromedialization and medialization) TTO is not associated with a significant decrease in PH or PL. Not only were the mean PH changes statistically insignificant from pre- to postoperatively, but there were wide variations in the direction and magnitude of PH changes, as approximately 50% of patients had <0.1 unit change in CDI/BPI/ISR, and even a small percentage demonstrated

a PH increase after TTO. Further large-scale studies are needed to determine the reliability of these PH findings and whether the changes are clinically impactful on surgeon choices and patient outcomes.

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