Patellar Height and Tibial Slope After Opening-Wedge Proximal Tibial Osteotomy

A Prospective Study

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Background: Further knee surgery after proximal tibial osteotomies has been reported to have a more difficult surgical exposure due to decreased patellar height after the osteotomy. Although a decrease in patellar height has been reported for closing-wedge proximal tibial osteotomies, it has not been widely verified among opening-wedge procedures.

Hypothesis: A significant decrease in patellar height would result after opening-wedge proximal tibial osteotomies and a postoperative change in tibial slope would also result, depending on the medial tibial plate position, which would affect patellar height.

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

Methods: Patients (n = 129) who underwent opening-wedge proximal tibial osteotomies (n = 130) were prospectively followed. Patellar height was calculated for preoperative lateral knee radiographs, and postoperatively at 2 weeks and 3 and 6 months. The Insall-Salvati, Blackburne-Peel, and Caton-Deschamps indices and a modified Miura and Kawamura index were used to calculate patellar height. Posterior tibial slope was also calculated for preoperative and 6-month postoperative knees.

Results: Coronal plane alignment changed significantly, from 24.6% to 55.2% of the tibial weightbearing axis. The overall decrease in patellar height for all patients was significant from preoperative assessment to the 2-week postoperative assessment and to both 3-month and 6-month follow-up with all 4 methods. The Insall-Salvati index decreased from 1.03 preoperatively to 0.99 at 2 weeks postoperatively, 0.97 at 3 months, and 0.95 at 6 months postoperatively. The Blackburne-Peel index decreased from 0.90 preoperatively to 0.75, 0.77, and 0.76, respectively, at each postoperative interval. The Caton-Deschamps index decreased from 0.98 preoperatively to 0.87, 0.86, and 0.84 at each postoperative measurement. The Miura-Kawamura index changed from 0.76 preoperatively to 0.61, 0.63, and 0.60 for each postoperative assessment. The average tibial slope significantly increased from 9.0° to 11.9° overall for all patients. In comparing the plate position, the tibial slope significantly increased from 8.8° preoperatively to 13.1° at 6 months postoperatively for anteromedially positioned plates and from 9.3° to 10.3° for posteromedially positioned plates.

Conclusion: Opening-wedge proximal tibial osteotomies decrease patellar height within the first 3 postoperative months. Shortening of the patellar tendon may affect future surgeries and needs to be evaluated in preoperative assessment. Moreover, a significant increase in tibial slope occurred, which may affect patellar height and future ligament reconstructions.

Keywords: proximal tibial opening wedge osteotomy; patellar height; patella baja; posterior tibial slope

Proximal tibial osteotomies are primarily performed to treat patients with medial compartment osteoarthritis or chronic ligament deficiencies with concurrent genu varus alignment.[3,11,15,26,32,34,35,41] Prior studies have reported that proximal tibial osteotomies often delay the need for knee arthroplasty by relieving pain and improving knee function,[1,6,9,21,26,27,37,42] as well as improving knee stability in patients with cruciate ligament and posterolateral knee injuries.[3,35]

Arthrotomy-related knee operations, such as total knee arthroplasties, have been reported to involve increased technical difficulties in surgical exposure after proximal tibial osteotomies.[6,18,24-26,41,47,48] One of the main causes of the difficulty in surgical exposure after closing-wedge proximal tibial osteotomies has been reported to be the development of patellar tendon shortening.[13,26,38,41,43-49]

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In the radiographic assessment of patellar height, a number of different measurement ratios have been devised. The majority of methods for patellar height assessment use a ratio to curtail problems associated with radiographic magnification, varying joint size, and other discrepancies.[4,8,22] Most popular among these are the Insall-Salvati, Blackburne-Peel, and Caton-Deschamps indices. While the Blackburne-Peel and the Caton-Deschamps indices directly assess patellar height, the Insall-Salvati index is a direct assessment of patellar tendon length and an indirect index of patellar height.[4,22,49] Another ratio used for patellar height assessment was developed by Miura et al.[31] This ratio is unlike the other 3 methods because it uses a femoral rather than tibial reference point to assess the location of the patella.

In addition to the postoperative effect on patellar position, closing-wedge and opening-wedge proximal tibial osteotomies have been reported to cause alteration in the sagittal plane tibial slope.[§] Both decreased[24,26] and increased[6] tibial slope after proximal tibial osteotomies have been reported to have a significant association with reduced patellar height.

Although a decrease in patellar height has been reported after closing-wedge proximal tibial osteotomies,[13,38,41,43,47,48] it has not been widely verified prospectively among opening-wedge osteotomy procedures. In addition, while tibial slope has been reported to increase after opening-wedge proximal tibial osteotomy,[2,3,5,29,30,32,40] it was our goal to verify these results depending upon anteromedial or posteromedial tibial fixation plate position and to determine the effect of these plate positions on patellar height. We hypothesized that a significant decrease in patellar height would result after opening-wedge proximal tibial osteotomy due to an increase in the distance between the patella and tibial tubercle and also that a change in sagittal tibial slope would occur from preoperative to postoperative assessments, which would affect patellar height. Therefore, our purpose was to quantify patellar height and tibial slope in patients who had undergone an opening-wedge proximal tibial osteotomy and to establish a stronger understanding of the time when patellar height changes occur postoperatively and to determine if changes in tibial slope correlate with patellar height changes.

MATERIALS AND METHODS

Patient Demographic Data

Between May 2000 and August 2007, all patients who underwent an opening-wedge proximal tibial osteotomy were prospectively followed. Institutional Review Board approval for this study was obtained though the University of Minnesota. Inclusion criteria were all patients who underwent an opening-wedge proximal tibial osteotomy performed by the same surgeon for any of the following conditions: genu varus alignment with concurrent medial compartment osteoarthritis, chronic posterolateral knee instability, genu recurvatum, or as a first-stage procedure for patients scheduled for a potential medial meniscus transplant who had concurrent genu varus alignment. Patients with medial compartment osteoarthritis and chronic anterior or posterior cruciate ligament (PCL) tears concurrent with any of the above pathologic lesions were included as well. Varus alignment was defined as occurring in patients whose mechanical axis, as drawn on the long-leg alignment radiographs, passed medial to the tip of the medial tibial eminence.[14]

Figure 1. Left long-leg alignment. The mechanical axis is drawn. The point where it crosses the joint is expresses as a percentage of tibial width.

Patients were excluded from the study if there was a history of extensor mechanism–related surgery, including autogenous patellar tendon cruciate ligament reconstructions. Patients were also excluded if any radiographs corresponding to the specified time frames indicated for this study were missing, if there was hardware failure at any point within 6 months after surgery, or if a subsequent surgery was performed within 6 months after the osteotomy.

Surgical Treatment

Preoperative radiographic assessment included single long-leg standing AP alignment radiographs, AP standing radiographs, and lateral radiographs with the knees flexed to 30º. In addition, varus[28] or valgus stress radiographs at 20º of knee flexion and posterior kneeling stress radiographs[23] were used in patients with suspected ligament injuries.

The same standard medial plate (Puddu plate, Arthrex, Naples, Florida) with 4 fixation screws was used to fix the osteotomy, and allograft bone grafting was performed in all cases (Opteform, Regeneration Technologies Inc, Alachua, Florida). During each operation, the correction of genu varus alignment was attempted such that the corrected mechanical axis passed through the midpoint of the lateral downslope of the lateral tibial eminence (Figure 1) as described previously.[3] The surgical technique consisted of a proximal anteromedial skin incision that split the distance between the tibial tubercle and the posteromedial border of the tibia,

§References 5, 11, 16, 19, 20, 26, 30, 32, 35, 36, 40.

Figure 2. Illustrative radiographs demonstrating the specified time frames when patellar height was measured.

extending approximately 6 to 8 cm. A subperiosteal dissection was performed under the patellar tendon and the deep infrapatellar bursa anteriorly and under the superficial medial collateral ligament and the popliteus musculature posteromedially. Two guide pins were placed parallel to the joint line under fluoroscopic guidance in the coronal plane and adjusted as necessary in the sagittal plane to follow the native sagittal plane slope of the tibia. The osteotomy was performed to within 1 cm of the lateral cortex. A spreader device was used to slowly open the osteotomy to the desired amount of opening. The osteotomy plate was then placed and secured with the fixation with the 4 screws. Bone graft was then inserted under fluoroscopic guidance. For prophylaxis against deep venous thrombosis, 325 mg daily of enteric coated aspirin was prescribed for 8 weeks postoperatively.

Postoperatively, patients were instructed to perform isometric quadriceps exercises and straight-leg raises while wearing a knee immobilizer a minimum of 4 times daily. Additionally, while patients were non-weightbearing for the first 8 weeks, they were instructed to remove the immobilizer 4 times daily and to work on full knee motion as tolerated. Starting at 6 weeks postoperatively, patients were allowed to pedal a stationary bike without resistance. Leg presses at one-quarter body weight were also permitted starting at 8 weeks postoperatively. Partial weightbearing on crutches was initiated 8 weeks postoperatively. Progressive increases in weightbearing by one-quarter body weight were performed each week until patients were fully weightbearing by 12 weeks after surgery. Beginning at 12 weeks postoperatively, patients were allowed to gradually wean from crutches once they could ambulate without a limp and radiographic evidence of healing of the lateral aspect of the osteotomy with no evidence of hardware failure or subsidence of the osteotomy site was apparent. Patients then began a progressive strengthening program using an elliptical machine, a stationary bicycle with increasing resistance, and progressive weight training. Patients were allowed to perform twisting and turning activities after 5 months if these exercises were tolerable.

Radiographic Measurement

Patellar height was measured using lateral radiographs with a digital image viewer (Imagecast, Burlington, Vermont). Preoperative, 2-week postoperative, 3-month, and 6-month lateral knee radiographs were measured for each patient (Figure 2). Because our clinic switched to the use of digital radiographs starting in July 2004, all available patient radiographs before this time were scanned into the digital imaging system. The Insall-Salvati,[22] Blackburne-Peel,[4] Caton-Deschamps[8] indices, and a modified version of the Miura-Kawamura index[31] were used as radiological measurements for determining patellar height (Figure 3).

The Insall-Salvati index was measured by dividing the length of the patellar tendon, measured from the inferior pole of the patella to the tibial tuberosity, by the longest diagonal length of the patella on the lateral radiograph (Figure 3). Ratio values between 0.80 and 1.20 have been reported to be within the normal range, while values less than 0.80 were reported to represent patella baja.[22] The Blackburne-Peel index was obtained by dividing the distance from the inferior tip of the distal patellar articular surface to a line tangent to the proximal tibial articular surface by the length of the patellar articular surface (Figure 3). The normal range for the Blackburne-Peel index has been reported to vary from 0.54 to 1.06, with patella baja reportedly present for ratios less than 0.54.[4] Determining the Caton-Deschamps index involved calculating the ratio between the distance from the inferior tip of the articular surface of the patella to the anterosuperior angle of the tibia and the patellar articular cartilage surface length (Figure 3). The normal ranges of this index have

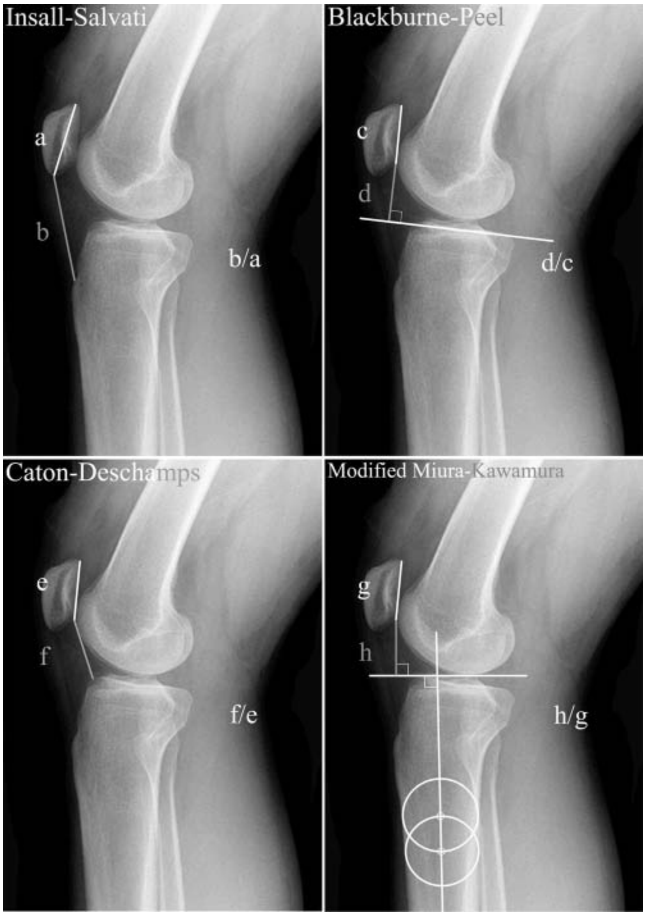

Figure 3. Radiographic diagrams showing the 4 measurement ratios used to assess patellar height. Insall-Salvati: a, diagonal length of the patella; b, length of the patellar tendon. Blackburne-Peel: c, length of the patellar articular surface; d, distance from the inferior tip of the distal patellar articular surface to a line tangent to the proximal tibial articular surface. Caton-Deschamps: e, length of the patellar articular surface; f, distance from the inferior tip of the articular surface of the patella to the anterosuperior angle of the tibia. Miura-Kawamura: g, length of the patellar articular surface; h, distance from the femoral condyle line to the inferiormost aspect of the patellar articular surface.

been reported to be 0.96 ± 0.134 in men and 0.99 ± 0.129 in women.[8] Patella baja has been reported to be present when the Caton-Deschamps index was below 0.6.[8] The method described by Miura et al[31] was a modification of the Blackburne-Peel method. However, it differs because the distal end of the femur is used as the reference point instead of the tibial plateau. A line perpendicular to the tibial diaphyseal line was drawn at the distal end of the femur (Figure 3). The distance from the femoral condyle line to the inferior-most aspect of the articular surface of the patella was then measured, and the ratio of that distance to the length of the articular surface of the patella was then calculated to arrive at the Miura-Kawamura index (Figure 3). Using the Miura-Kawamura index, a change of 10% in patellar height from preoperative to the 2-week postoperative assessment has been reported to be significant.[31]

Figure 4. Radiographic diagram showing the method used in determining tibial slope, which was the angle between the tibial plateau and the line perpendicular to the middiaphysis of the tibia on the lateral knee radiograph.

Tibial slope was defined as the angle between the tibial plateau and a line perpendicular to the middiaphysis of the tibia (Figure 4). The tibial diaphyseal line was centered through the tibial shaft using digitally generated circles. Two overlapping circles were digitally drawn on each radiograph with diameters equal to the width of the tibial shaft at the respective position of each circle on the tibia. Each circle was sized and positioned so that the anterior and posterior borders of the tibia were tangent to its circumference. A line parallel to the tibial axis was drawn through the centers of these two circles to ensure correct positioning within the center of the tibial shaft.[39] Tibial slope was measured on both preoperative and 6-month postoperative radiographs.

Coronal plane alignment was defined as the percentage of the tibial width (from medial to lateral) where the mechanical axis line, drawn between the center of the femoral head and the center of the ankle mortise, crossed the joint line.[3] Preoperative values were calculated and compared with the 6-month postoperative mechanical axis lines.

In addition to grouping tibial slope measurements into preoperative and 6-month follow-up, the data were further divided into 2 subgroups based on the location of the osteotomy plate on the tibia. Group I (anteromedial) consisted of a plate position primarily (>50%) anterior to the line bisecting the tibial diaphysis on the lateral view, and group II (posteromedial) represented an osteotomy plate position primarily posterior to this line. Anteromedial positioning of the plate during surgery was performed on patients with concurrent chronic PCL and/or posterolateral knee injuries to attempt to increase tibial slope. Posteromedial plate positioning was carried out on patients

TABLE 1
Overall Results With the 4 Methods of Patellar Height Measurement

Overall Results		Preoperative	2 Weeks Postoperative	3 Months Postoperative	6 Months Postoperative
Insall-Salvati (IS)	Average measurement	1.03	0.99[a]	0.97[a,b]	0.95[a,b]
	Range	0.71-1.34	0.58-1.42	0.62-1.39	0.58-1.39
	Knees with ratio decrease from preoperative	-	72 (70.6%)	75 (73.5%)	78 (76.5%)
	Number of knees with patella baja (IS <0.8)	8 (7.8%)	11 (10.8%)	13 (12.7%)	16 (15.7%)
Blackburne-Peel (BP)	Average measurement	0.90	0.75[a]	0.77[a]	0.76[a]
	Range	0.56-1.25	0.38-1.15	0.43-1.11	0.45-1.21
	Knees with ratio decrease from preoperative	-	91 (89.2%)	90 (88.2%)	90 (88.2%)
	Number of knees with patella baja (BP <0.54)	0 (0%)	8 (7.8%)	6 (5.9%)	8 (7.8%)
Caton-Deschamps (CD)	Average measurement	0.98	0.87[a]	0.85[a,b]	0.84[a,b]
	Range	0.58-1.53	0.44-1.31	0.49-1.24	0.54-1.41
	Knees with ratio decrease from preoperative	-	89 (87.3%)	92 (90.2%)	96 (94.1%)
	Number of knees with patella baja (CD <0.6)	1 (0.98%)	1 (0.98%)	10 (9.8%)	5 (4.9%)
Miura-Kawamura	Average measurement	0.92	0.82[a]	0.84[a,b]	0.84[a,b]
	Range	0.54-1.25	0.47-1.23	0.44-1.20	0.51-1.25
	Knees with ratio decrease from preoperative	-	84 (82.4%)	90 (88.2%)	76 (74.5%)
	Number of knees with patella baja (change >10%)	-	62 (60.8%)	51 (50.5%)	45 (44.1%)

[a]Significant change from preoperative measurement.
[b]Significant change from immediate postoperative measurement.

suffering from medial knee compartment osteoarthritis and in patients with chronic anterior cruciate ligament (ACL) tears to attempt to decrease the tibial slope. There was no other difference in surgical technique between groups.

Statistical analysis was performed to compare the data of each measurement technique between the obtained radiograph time frames with the use of SAS software (SAS Institute Inc, Cary, North Carolina). We compared the ratios using a 2-way analysis of variance with a post hoc Tukey test. Additionally, a paired *t* test was used to detect significant differences between the preoperative and 6-month postoperative sagittal and coronal plane tibial slope. Significant differences were assumed to be present for $P < .05$.

RESULTS

Clinical Evaluation

A total of 129 patients (103 men, 26 women; 130 knees), underwent an opening-wedge proximal tibial osteotomy. Twenty-eight patients were excluded from the study, leaving 101 patients (81 men, 20 women; 102 knees) who were prospectively followed. No significant differences were found between the inclusion group (102 knees) and the exclusion group (28 knees) regarding patient age, sex, weight, height, preoperative limb alignment, indications for surgery, or surgical technique. Indications for surgery included one or more of the following: medial knee osteoarthritis (54), chronic PCL and posterolateral knee injuries (16), chronic posterolateral instability (15), chronic ACL injuries (7), chronic ACL and posterolateral knee injuries (5), genu recurvatum (2), chronic PCL injury (1), malunion in the anterior medial tibial plateau with concurrent PCL injury (1), and medial collateral ligament tear with concurrent medial knee osteoarthritis and PCL injury (1). Among the excluded patients, 16 were dismissed due to unavailable radiographs (missing or not obtained within the specified time frame) from 1 or more of the specific time frames indicated for this study. Other exclusions included 2 patients who had hardware failure, 2 patients who had an intraoperative lateral cortex fracture that required extra fixation with a lateral cortex staple, and 8 patients who had previous autologous patellar tendon cruciate ligament grafts (7 ACL reconstructions and 1 PCL reconstruction). In the current study, there were 59 osteotomies (57.8%) with anteromedially positioned fixation plates and 43 osteotomies (42.2%) with posteromedially positioned fixation plates. No significant differences were found between the anteromedial or posteromedial fixation groups regarding patient sex, weight, height, preoperative limb alignment, indications for surgery, or surgical technique. The 101 patients included in the present study had a mean age of 35 years (range, 19-55) at the time of surgery.

Radiographic Analysis

The radiographic analysis was broken down into overall findings and also for comparisons between the effects of plate

TABLE 2
Results for the Patient Group With Anteromedial Plate Positioning Utilizing the 4 Measurement Methods of Patellar Height

		Preoperative	2 Weeks Postoperative	3 Months Postoperative	6 Months Postoperative
Insall-Salvati (IS)	Average measurement	1.01	0.97[a]	0.94[a,b]	0.92[a,b]
	Range	0.71-1.31	0.58-1.42	0.62-1.38	0.58-1.39
	Knees with ratio decrease from preoperative	-	42 (71.2%)	46 (78%)	47 (79.7%)
	Number of knees with patella baja (IS <0.8)	4 (6.8%)	8 (13.6%)	11 (18.6%)	12 (20.3%)
Blackburne-Peel (BP)	Average measurement	0.89	0.74[a]	0.76[a]	0.74[a]
	Range	0.56-1.25	0.38-1.15	0.43-1.11	0.45-1.11
	Knees with ratio decrease from preoperative	-	52 (88.1%)	51 (86.4%)	57 (96.6%)
	Number of knees with patella baja (BP <0.54)	0 (0%)	6 (10.2%)	4 (6.8%)	7 (11.9%)
Caton-Deschamps (CD)	Average measurement	0.98	0.85[a]	0.83[a]	0.83[a]
	Range	0.58-1.53	0.44-1.31	0.49-1.20	0.54-1.41
	Knees with ratio decrease from preoperative	-	53 (89.8%)	56 (94.9%)	56 (94.9%)
	Number of knees with patella baja (CD <0.6)	1 (1.7%)	1 (1.7%)	7 (11.9%)	4 (6.8%)
Miura-Kawamura	Average measurement	0.90	0.80[a]	0.84[a]	0.84[a]
	Range	0.54-1.25	0.48-1.23	0.44-1.20	0.51-1.22
	Knees with ratio decrease from preoperative	-	46 (78%)	39 (66.1%)	38 (64.4%)
	Number of knees with patella baja (change >10%)	-	28 (47.5%)	22 (37.3%)	20 (33.9%)

[a]Significant change from preoperative measurement.
[b]Significant change from immediate postoperative measurement.

position on each individual ratio assessment. Findings are reported in Tables 1, 2, and 3; values are reported for all knees, knees fixed with anteromedial plates, and knees fixed with posteromedial plates. Values reported include (1) average measurement ratio values, (2) range of measurement ratio values, (3) number of knees demonstrating a decrease in measurement ratio compared with preoperative measurements, and (4) number of knees defined by a given ratio as having patella baja. In addition to these table data, reported below are measurement ratios for all knees and comparisons between anteromedial and posteromedial plates, including the effects of these plate positions on patellar height ratios.

Patellar Height Ratio Measurements

Insall-Salvati Index. The mean preoperative, 2-week postoperative, 3-month postoperative, and 6-month postoperative ratios overall for the Insall-Salvati index were 1.03 (range, 0.71-1.34), 0.99 (range, 0.58-1.42), 0.97 (range, 0.62-1.39), and 0.95 (range, 0.58-1.39), respectively. The alteration in patellar height according to the Insall-Salvati index was significant from preoperative to the 2-week ($P < .001$), 3-month ($P < .001$), and 6-month ($P < .001$) assessments. The change in patellar height was also significant from 2 weeks postoperative to 3 months ($P < .02$) and 6 months ($P < .001$) of follow-up.

With regard to anteromedial plate position, the preoperative patellar height was significantly decreased at the 2-week ($P < .002$), 3-month ($P < .001$), and 6-month ($P < .001$) 2-week follow-ups. The 2-week patellar height was also significantly decreased at 3 months ($P < .02$) and 6 months ($P < .002$) of postoperative follow-up.

For the posteromedial plate position, the alteration in preoperative patellar height was significant at the 2-week ($P < .002$), 3-month ($P < .001$), and 6-month ($P < .001$) postoperative assessments. Patellar height after opening-wedge proximal tibial osteotomy among the posteromedial plate group was significantly higher than patellar height among the anteromedial plate group at 3 ($P < .05$) and 6 months ($P < .05$) of follow-up.

Blackburne-Peel Index. For the Blackburne-Peel index, mean preoperative, 2-week postoperative, 3-month postoperative, and 6-month postoperative ratios overall were calculated to be 0.90 (range, 0.56-1.25), 0.75 (range, 0.38-1.15), 0.77 (range, 0.43-1.11), and 0.76 (range, 0.45-1.21), respectively. The preoperative patellar height according to the Blackburne-Peel index significantly decreased at the 2-week ($P < .001$), 3-month ($P < 0.001$), and 6-month ($P < 0.001$) postoperative assessments. There was no significant difference in the Blackburne-Peel ratios between the anteromedial and posteromedial plate positions at any time period.

The alteration in preoperative patellar height among the anteromedial group was significant at the 2-week ($P < .001$), 3-month ($P < .001$), and 6-month ($P < .001$) postoperative assessments. There was no significant difference in patellar

TABLE 3
Results for the Patient Group With Posteromedial Plate Positioning Utilizing the 4 Measurement Methods of Patellar Height

		Preoperative	2 Weeks Postoperative	3 Months Postoperative	6 Months Postoperative
Insall-Salvati (IS)	Average measurement	1.06	1.01[a]	1.01[a]	0.99[a]
	Range	0.72-1.34	0.73-1.29	0.7-1.39	0.71-1.34
	Knees with ratio decrease from preoperative	-	31 (72.1%)	27 (62.8%)	31 (72.1%)
	Number of knees with patella baja (IS <0.8)	4 (9.3%)	3 (7.0%)	4 (9.3%)	5 (11.6%)
Blackburne-Peel (BP)	Average measurement	0.91	0.77[a]	0.78[a]	0.80[a]
	Range	0.68-1.16	0.47-1.14	0.43-1.09	0.48-1.21
	Knees with ratio decrease from preoperative	-	39 (90.7%)	38 (88.4%)	33 (76.7%)
	Number of knees with patella baja (BP <0.54)	0 (0%)	2 (4.7%)	1 (2.3%)	1 (2.3%)
Caton-Deschamps (CD)	Average measurement	0.99	0.90[a]	0.87[a]	0.87[a]
	Range	0.76-1.27	0.61-1.14	0.57-1.24	0.56-1.20
	Knees with ratio decrease from preoperative	-	37 (86.0%)	37 (86.0%)	39 (90.7%)
	Number of knees with patella baja (CD <0.6)	0 (0%)	0 (0%)	0 (0%)	3 (7.0%)
Miura-Kawamura	Average measurement	0.96	0.81[a]	0.83[a]	0.83[a]
	Range	0.57-1.25	0.47-1.13	0.55-1.08	0.57-1.25
	Knees with ratio decrease from preoperative	-	39 (90.7%)	41 (95.4%)	37 (86.0%)
	Number of knees with patella baja (change >10%)	-	34 (79.1%)	29 (67.4%)	25 (58.1%)

[a]Significant change from preoperative measurement.

height from the 2-week postoperative assessment to either 3 months or 6 months of follow-up. There was also no significant difference between 3 and 6 months of follow-up.

For the posteromedial group, the alteration in preoperative patellar height was significant at the 2-week ($P < .001$), 3-month ($P < .001$), and 6-month ($P < .001$) postoperative assessment. There was no significant difference in patellar height from the 2-week postoperative assessment to either 3 months or 6 months of follow-up. There was also no significant difference between 3 and 6 months of follow-up.

Caton-Deschamps Index. The mean preoperative, 2-week postoperative, 3-month postoperative, and 6-month postoperative ratios overall for the Caton-Deschamps index were 0.98 (range, 0.58-1.53), 0.87 (range, 0.44-1.31), 0.85 (range, 0.49-1.24), and 0.84 (range, 0.54-1.41), respectively. Alteration in preoperative patellar height according to the Caton-Deschamps index was significant at the 2-week ($P < .001$), 3-month ($P < .001$), and 6-month ($P < .001$) postoperative assessments. There was no significant difference in the Caton-Deschamps ratios between the anteromedial and posteromedial plate positions at any time period.

The alteration from preoperative patellar height for the anteromedial group was significant at the 2-week ($P < .001$), 3-month ($P < .001$), and 6-month ($P < .001$) postoperative assessments. There was no significant difference in patellar height from the 2-week postoperative assessment to either 3 months or 6 months of follow-up. There was also no significant difference between 3 and 6 months of postoperative follow-up.

Patellar height change for the posteromedial group was significant at the 2-week ($P < .001$), 3-month ($P < 0.001$), and 6-month ($P < 0.001$) postoperative follow-ups. There was no significant difference in patellar height from the 2-week postoperative assessment to either 3 months or 6 months of follow-up. There was also no significant difference between 3 and 6 months of follow-up.

Miura-Kawamura Index. For the Miura-Kawamura index, mean preoperative, 2-week postoperative, 3-month postoperative, and 6-month postoperative ratios for all patients overall were calculated to be 0.92 (range, 0.54-1.25), 0.82 (range, 0.47-1.23), 0.84 (range, 0.44-1.20), and 0.84 (range, 0.51-1.25), respectively. The alteration in patellar height according to the Miura-Kawamura index was significantly decreased from preoperative to the 2-week ($P < .001$), 3-month ($P < .001$), and 6-month ($P < .001$) postoperative assessments. There was also a significant difference in patellar height from the 2-week postoperative assessment to both 3 ($P < 0.01$) and 6 months ($P < .004$) of follow-up. There were no significant changes in the Miura-Kawamura ratios between the anteromedial and posteromedial plate positions at any time period.

The alteration in preoperative patellar height for the anteromedial group was significant at the 2-week ($P < .001$), 3-month ($P < .005$), and 6-month ($P < .001$) postoperative assessment. There was no significant difference in patellar height from the 2-week postoperative assessment to either 3 months or 6 months of follow-up. There was also no significant difference between 3 and 6 months of follow-up.

Patellar height changes for the posteromedial group were significant at the 2-week ($P < .001$), 3-month ($P < 0.001$), and 6-month ($P < 0.001$) postoperative assessments. There were no significant differences in patellar height between the 2-week postoperative assessment to either 3 months or 6 months of follow-up. There was also no significant difference between 3 and 6 months of postoperative follow-up.

Coronal Plane Correction

The average coronal plane alignment[3] changed significantly from 24.6% (±9.8%; range, 4.3%-41.2%) of the total tibial weightbearing axis to 55.2% (±5.6%; range, 36.3%-76.3%) ($P < .001$). The average coronal plane alignment changed significantly from 25.3% (±9.5%; range, 5%-41.1%) preoperatively to 54.4% (±5.1%; range, 36.3%-65.4%) at 6 months postoperatively ($P < .0001$) for anteromedial plate positioning and from 23.7% (±10.2%; range, 4.3%-41.2%) to 56.3% (± 5.9%; range, 47.9%-76.3%) for posteromedially positioned plates ($P < .0001$). There were no significant differences in coronal plane tibial alignment among plate positions.

Sagittal Plane Tibial Slope

The average tibial slope significantly increased from 9.0° to 11.9° overall for all patients ($P < .001$). The average tibial slope changed significantly from 8.8° (range, 2º-16º) preoperatively to 13.1º (range, 7º-22º) at 6 months of follow-up for anteromedially positioned plates ($P < .001$). For the posteromedial plate group, preoperative tibial slope changed significantly from 9.3° (range, 3º-15º) at preoperative assessment to 10.3° (range, 2º-19º) at 6 months of follow-up ($P < .05$) (Figure 5).

Complications

Four patients had complications related to the osteotomy. One patient had a deep venous thrombosis and a superficial cellulitis and later had hardware failure. Two patients had hardware failure and 1 other patient had a superficial cellulitis, which was treated with oral antibiotics.

DISCUSSION

In this study, we confirmed our hypothesis that a significant decrease in patellar height after opening-wedge proximal tibial osteotomies occurs. The decrease in patellar height observed was similar to the decrease in patellar height reported after closing-wedge proximal tibial osteotomy procedures.[13,26,38,41,43,47] We also found that this significant decrease in patellar height after opening-wedge proximal tibial osteotomies happens within the first 3 postoperative months. However, only when measuring the patellar height using the Insall-Salvati index was there a significant difference in patellar height ratio between the anteromedial and posteromedial plate positions. In addition, we found that there was also a significant increase in tibial slope with opening-wedge proximal tibial osteotomies, which confirmed prior findings.[2,3,5,29,30,40] In our study, a greater overall increase in tibial slope was observed among patients with an anteromedial plate position compared with those with a posteromedial plate position (Tables 2 and 3).

In this study, we used a modified version of the patellar height ratio described by Miura et al because it has been reported that measurement of patellar height was not affected by surgical procedures on the proximal tibia for this measurement ratio.[31] Our modification to the Miura-Kawamura technique involved the use of digitally generated overlapping circles in determining the tibial diaphyseal line.[39] This differs from the bisection of 2 lines perpendicular to the tibial shaft and spanning the diameter of the tibia as used by Miura et al. We chose to use a measurement method based on a femoral reference point[31] to measure patellar height because both the Blackburne-Peel and Caton-Deschamps indices have been reported to be potentially inaccurate to measure patellar height changes caused by proximal tibial osteotomies as both the tibial slope and anteroposterior translation of the proximal portion of the osteotomy may be affected and these ratios both rely on reference lines based on the proximal tibia.[17,26] These methods have been reported to have potential inconsistencies due to the fact that any change in tibial slope or proximal tibial shape will potentially alter the perpendicular distance between the inferior tip of the distal patellar surface and the line tangent to the tibial articular surface. Because the Insall-Salvati index is the quotient of patellar tendon length to the overall patellar length,[22] significant decreases in patellar height found with this ratio would indicate that patellar tendon shortening occurred. Patellar height has been reported to decrease by a greater length after proximal tibial opening-wedge osteotomy than with closing-wedge osteotomy.[44] This greater decrease in patellar height is reportedly due to distalization of the tibial tuberosity after proximal tibial opening-wedge osteotomy.[49] However, because the Miura-Kawamura index also found significant decreases in patellar height, and it also does not rely on tibial landmarks for patellar height measurements, we believe that the significant decrease in patellar height calculated by the Blackburne-Peel and Caton-Deschamps ratios is real and not solely due to changes in tibial slope from the opening-wedge osteotomy.

It has been previously reported that shortening of the patellar tendon was the primary issue causing difficulty during the arthrotomy exposure for total knee arthroplasty after failed proximal tibial osteotomy.[26,48] Patellar tendon shortening has been theorized to be caused by intratendinous fibrosis, interstitial scarring of the patellar tendon, ossification around the patellar tendon during healing causing tendon contracture, cast immobilization, adhesion of the tendon at the proximal part of the tibial tuberosity, adherence of the tendon to the deep infrapatellar bursa, and/or changes in sagittal plane tibial slope.[6,26,31,41,47]

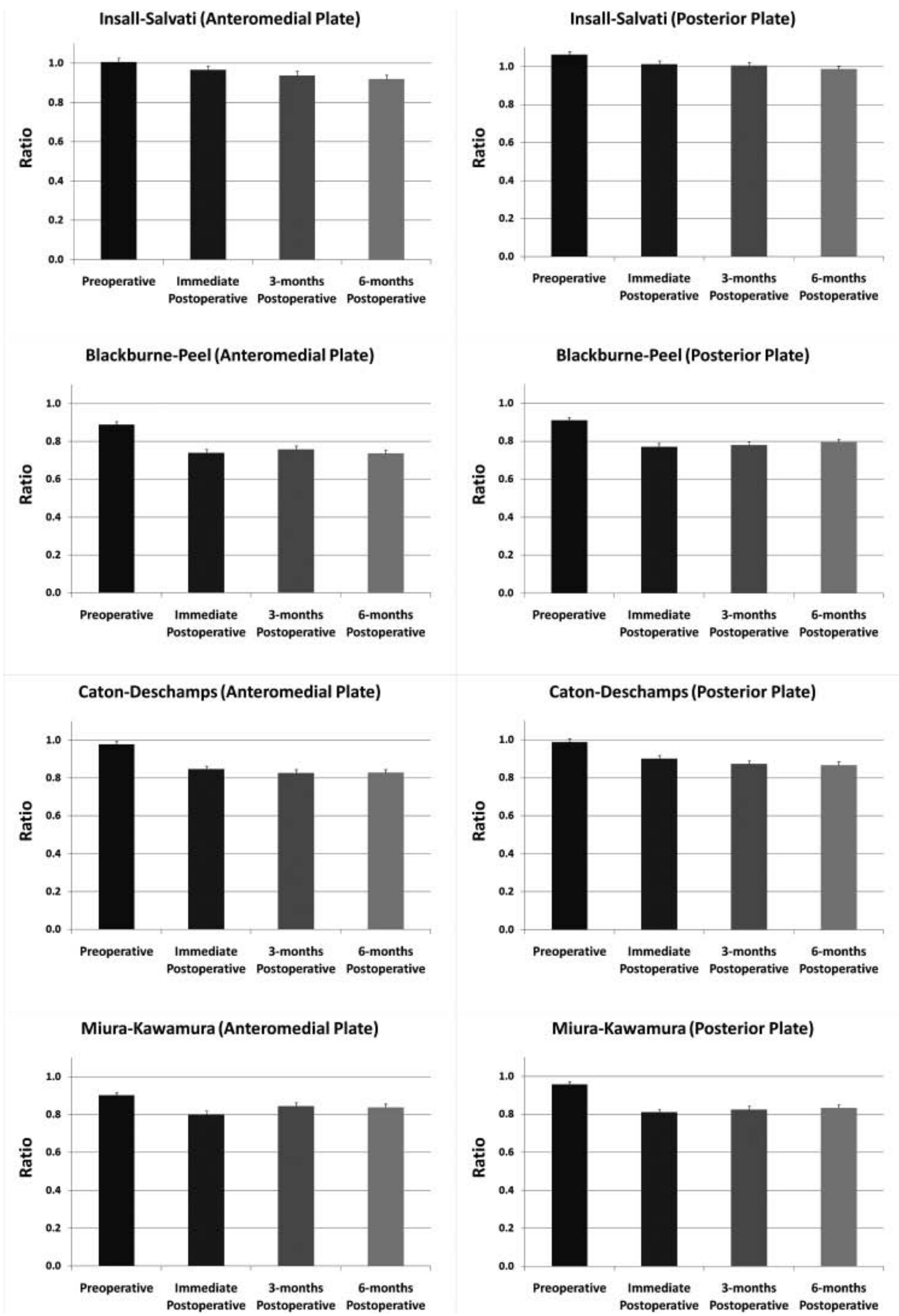

Figure 5. Preoperative and 6-month postoperative tibial slopes for patients with anteromedial and posteromedial tibial fixation plates.

Therefore, with the link between measured patellar descent and shortening of the patellar tendon verified by this study for opening-wedge proximal tibial osteotomies, we recommend that patellar height be evaluated for patients undergoing surgery after opening wedge proximal tibial osteotomy because the potential for decreased patellar height may affect future autogenous patellar tendon ACL reconstructions or open knee operations.

Decreased patellar height after closing-wedge proximal tibial osteotomies, which reduce the distance between the tibial tubercle and the joint line, has been reported to be as high as 89% in 2 separate studies using the Insall-Salvati index.[26,41] Similarly, high percentages of decreased patellar height after closing-wedge proximal tibial osteotomies using the Blackburne-Peel index have also been reported.[26,41] In these previous studies, patellar descent was significant even though slight elevation of the patella relative to the femur was theoretically expected with a closing-wedge proximal tibial osteotomy due to shortening of the segment between the joint line and the tibial tuberosity.[26] These previous results support the concept that the change in patellar height was not a direct result of the osteotomy but instead dependent on the patellar tendon because the length of the patella and patellar tendon length were not surgically altered.

In our study, both anteromedial and posteromedial plate positioning resulted in a significant increase in sagittal plane tibial slope. Anteromedial plate positioning was implemented in patients with concurrent chronic PCL and/or posterolateral knee injuries to attempt to increase tibial slope.[16,32] For patients suffering from medial knee compartment osteoarthritis and in patients with chronic ACL tears, posteromedial plate positioning was used in attempt to decrease the tibial slope. Other than anatomical placement of the plate, there was no difference in surgical technique between groups. Decreasing tibial slope in patients with anterior instability has been theorized to minimize the anteroposterior component of the joint contact forces and decrease anterior subluxation of the tibia relative to the femur, thereby decreasing anterior instability and related symptoms.[10] The same report also theorized that increasing sagittal plane posterior tibial slope increases the anteroposterior component of the joint contact forces while decreasing posterior subluxation of the tibia relative to the femur, thereby relieving posterior instability and related symptoms.[10] Although we did observe a significant increase in sagittal plane tibial slope among patients with posteromedial plate positioning after surgery, the greater overall increase in posterior tibial slope observed among patients with anteromedial plate positioning was expected. We theorize that the reason the tibial slope increased after an opening-wedge proximal tibial osteotomy was because either the current plate design does not allow for sufficient posteromedial plate positioning to decrease tibial slope or that our lack of fixation along the anteromedial portion of the osteotomy resulted in an increase in gapping between the osteotomy segments in the early postoperative period. Increased tibial slope in patients who have undergone opening-wedge proximal tibial osteotomy has been previously reported.[2,3,5,29,30,32,40] Although studies have suggested a decrease in tibial slope after lateral closing-wedge osteotomy and furthermore suggested that the lateral closing-wedge procedure be used for patients with chronic ACL tears,[11,12,29,33,35] we have found successful results among patients undergoing opening-wedge proximal tibial osteotomy for ACL deficiency. We acknowledge that thorough consideration of sagittal plane tibial slope must be observed in patients with chronic ACL or PCL deficiencies.[7,12]

It would be anticipated that anteromedial tibial plate positioning should result in decreased patellar height compared with a posteromedial tibial plate position due to the increased distances between the patella and the tibial tubercle with the expected changes in the sagittal tibial slope. However, we did not find that in our series. We theorize this was because the overall measured differences were small and that there were not enough patients to detect a difference between these 2 conditions.

One of the limitations of our study was that these patients were a heterogeneous group of patients with treatment designed for both ligament instability and medial compartment arthritis. However, the rehabilitation protocol and surgical approach and fixation methods were no different between the 2 groups. In addition, we only measured the patellar height ratios for these patients to 6 months postoperatively. We did this because many of the patients went on to subsequent second-stage surgeries at 6 months after the osteotomy had healed. Because we found no significant difference in patellar height between the 3- and 6-month postoperative radiographs for any measurement index, we believe that this was not a major limitation of our study.

In conclusion, we found that opening-wedge proximal tibial osteotomies decrease patellar height and this effect happens within the first 3 postoperative months. The decreased patellar height appears to be due to patellar tendon shortening. The shortening of the patellar tendon may affect future surgeries, including total knee arthroplasty, and needs to be evaluated as part of the preoperative assessment in these patients. We also validated that significant alterations in sagittal plane tibial slope occur after opening-wedge proximal tibial osteotomies, which are dependent upon anteromedial or posteromedial fixation plate position and need to be closely assessed in these patients.

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