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Surgical Correction of Limb Malalignment for Instability of the Patella

A Comparison of 2 Techniques

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Background: Although patients considered "successful" at longer-term follow-up no longer exhibited patellar instability, those with more severe malalignment issues had other, gradually worsening symptoms such as activity-related pain, crepitation, swelling with activities, and pain with weather changes.

Hypothesis: Improvement of patellar tracking by correction of the tubercle-sulcus angle and related ligament deficiencies will result in good to excellent results, regardless of the technique employed.

Study Design: Cohort study; Level of evidence, 3.

Methods: Twenty-five patients with dislocating patellae and significant lower leg deformity were treated; 12 patients (group 1) underwent a derotational high tibial osteotomy and 13 patients (group 2) underwent an Elmslie-Trillat-Fulkerson proximal-distal realignment. All were prospectively evaluated a minimum of 24 months postoperatively with a physical examination, validated outcome questionnaires, radiographs, and computerized axial tomography scans. Postoperative 3-dimensional bilateral gait analyses were performed on all subjects walking on a 3-dimensional force treadmill to measure stance kinematics, foot progression angle, knee flexion, knee valgus-varus, hip flexion, and patella angle. Contralateral limbs with similar preoperative alignment were used as controls.

Results: Group 1 patients significantly improved over their preoperative status in all primary subjective and functional outcome parameters, and were significantly better than group 2 patients. Group 2 patients improved, but not to the degree of group 1 patients. Gait analysis revealed group 1 patients had more symmetrical gait patterns, with less variability and less compensatory gait changes, than group 2 patients.

Conclusion: The original hypothesis proved to be incorrect. The simultaneous correction of ligament imbalance, excessive tubercle-sulcus angle, and lower limb torsional deformity produced significantly better results than conventional proximal-distal realignment.

Keywords: patellar instability; torsional malalignment; proximal-distal realignment

Over 100 surgical procedures for realignment and/or stabilization of the patellofemoral articulation have been described in the English-language literature.[17,43] Few authors have provided comparative patient information, and even more perplexing is the failure of many authors to accurately describe and categorize the patients selected for their particular surgical procedure. Patients selected for nonsurgical or surgical treatment are frequently intermixed, without careful consideration of presenting symptoms, previous conservative care, anatomic variables, or lifestyle demands.

In an effort to better understand the important features that a surgeon must consider before patellofemoral surgery, the senior author (L.P.) in 1990 began a retrospective comparison of patients who had a "successful" lateral retinaculum release and a group of patients who had a failed lateral release.[21] The surgical algorithm that was developed as a result of correcting the failed cases has been successfully employed by the senior author for the past 19 years.[21]

Over time and with careful observation, it was noted that some patients who underwent patellar realignment

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Figure 1. Significant (thigh-foot angle, 43°) torsional deformity of the right lower extremity allows the foot to point backward. The left extremity has undergone a derotational high tibial osteotomy. Note the surgical scar lateral to the tibial tubercle.

and were initially satisfied with their result began to develop arthritic complaints. In other instances, patients were seen with such severe tubercle-sulcus (T/S) angles (Figure 1) and/or patellofemoral dysplasia that it was impossible to completely correct their malalignment with conventional techniques. It appeared that the patients most likely to develop late symptoms were those with the most severe malalignment, which could only be partially corrected. To better understand this group of patients, and enlightened by conversations with Dr Peter Stevens as well as a publication by Bruce and Stevens,[7] the senior author developed a new surgical procedure. This approach was subsequently used for patellar instability requiring a distal realignment in patients who also had increased T/S angles and the rotational deformities that invariably accompany them.

The purpose of this investigation is to elucidate and compare the results of patients with unstable patellae who underwent proximal-distal patellar realignment by 1 of 2 procedures. Both groups had significant torsional deformity (thigh-foot angle of 30° or more) and increased T/S angles (>10°). A group of patients who underwent a novel, supratubercle, derotational high tibial osteotomy (D-HTO) were compared with a historical group of patients who underwent an Elmslie-Trillat-Fulkerson (ETF)[6,16,51] proximal-distal patellar realignment procedure. The hypothesis was that improvement of patellar tracking by correction of the T/S angle and related ligament deficiencies will result in good to excellent results, regardless of torsional correction of the limb.

METHODS

Patient Selection

All patients in this study signed an approved Institutional Review Board informed consent. They all had a diagnosis of dislocating and/or subluxating patella(e), a T/S angle >10°, and a thigh-foot angle of >30°. All had failed nonoperative treatment, which included formal physical therapy, activity modification, attempted weight reduction, orthotics, and restraining braces for a mean of 18.2 months (range, 12-34 months) before surgery. The patients were candidates for a proximal-distal realignment according to the senior author's published algorithm.[21]

Exclusionary criteria included moderate to severe radiographic arthrosis of any of the 3 compartments of the knee; a history or presence of ligament instability, infection, rheumatic diseases, or severe trauma to the involved limb; a thigh-foot angle <30°; and a T/S angle <10°.

There were 12 patients (12 knees) in group 1 who underwent the combined D-HTO and proximal realignment procedure between 2002 and 2005. There were 13 patients in group 2, who underwent an ETF proximal-distal patellar realignment between 1988 and 2002. All patients were available for preoperative and postoperative physical examination, radiographs, computerized axial tomography, gait studies, and interview by an independent reviewer. The same postoperative rehabilitation protocol was used for both groups.

Historical data collected included history of each injury, family history, subluxation and dislocation, provocative activities, previous surgery, medication usage, and details of physical therapy programs. The physical examination of both knees included standing alignment, foot alignment, T/S angle measurement, patellar glides and tilts at 0° and 30° of flexion, apprehension signs, passive and active range of motion, crepitation assessment, manual strength testing, prone measurement of hip rotation, and thigh-foot angle (Figure 2). In addition, standard knee ligament and meniscus tests were performed.

Radiographs included preoperative and postoperative anteroposterior and 45° lateral, 60-inch anteroposterior (AP) long-standing, 45° posteroanterior (PA) weightbearing, and 30° sunrise (Merchant) views.[25,29,42] The sulcus depth, determined from the lateral radiograph, was rated as either normal, shallow, flat, or convex (D. DeJour, unpublished data, 2007). All patients underwent a "gun-sight" computerized axial tomography and independent reading to confirm and measure torsional limb alignment by using limited views at the hip, knee, and ankle to reduce radiation exposure (Figure 3).[23,50]

Operative Procedures

A complete diagnostic (anterior and posterior) arthroscopy of the knee was first performed, with any intra-articular lesion noted and treated as required.

If a negative passive patellar tilt was present, a lateral release was performed by incising the lateral retinaculum and synovium from the tibial tubercle to, but not including, the vastus lateralis muscle.

Figure 2. A, with the patient sitting, the knee flexed to 90°, and the foot hanging free, the tubercle-sulcus (T/S) angle can be estimated. This is the angle formed by drawing a line from the midpatella to the midtubercle and a line drawn perpendicular to the transcondylar axis.[21] Except in severe trochlear dysplasia, the patella will reduce into the sulcus as the knee is flexed. Thus, the center of the sulcus and the center of the patella in relation to each other and the transcondylar axis can be measured. The normal angle is from 0° to 10° of valgus. B and C, with the patient prone, passive and active internal and external rotation of the hip can be measured. The loss of active rotation compared with passive rotation reflects weak, inflexible periarticular hip and knee muscle groups that will respond to directed physical therapy. D, with the patient prone, the knee flexed to 90°, and the foot supported in the neutral position, the thigh-foot angle can be measured. The normal range is 0° to 15° of external rotation.

The D-HTO was performed through a 4-cm vertical inferior lateral incision, midway between the tibial tubercle and proximal fibular head (Figure 1). The patellar tendon and proximal tibiofibular joint were exposed. The area of the peroneal nerve at the neck of the proximal fibula was identified and the peroneal nerve was released anteriorly, along its periarticular course. The anterior tibiofibular joint was exposed and the articular portion (3 mm) of the fibular head resected using a small osteotome. The capsule of the fibular head was released so that it moved freely from the tibia. This step was critical to allow rotation of the proximal tibia and reduce peroneal nerve tension.

The area posterior to the patellar tendon was exposed and the superior portion of the tibial tubercle identified.

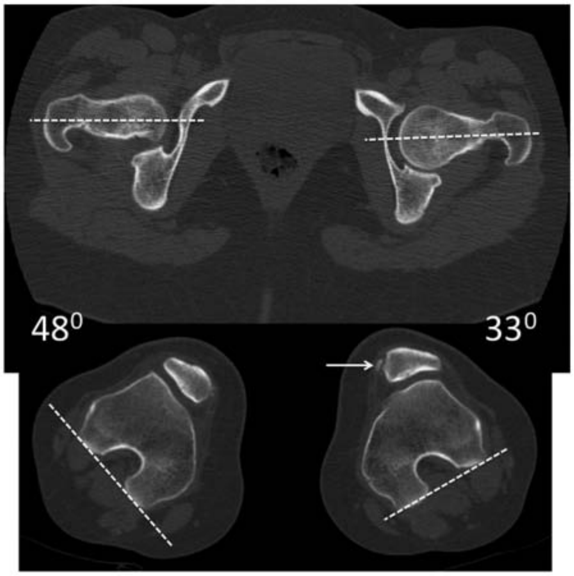

Figure 3. Gun-sight tomography reveals 48° of external tibial torsion and 33° of internal femoral rotation. When comparing the thigh-foot angle to computerized axial tomography scan measurements, 15° of external tibial rotation (normal) should be added to the computerized axial tomography value.

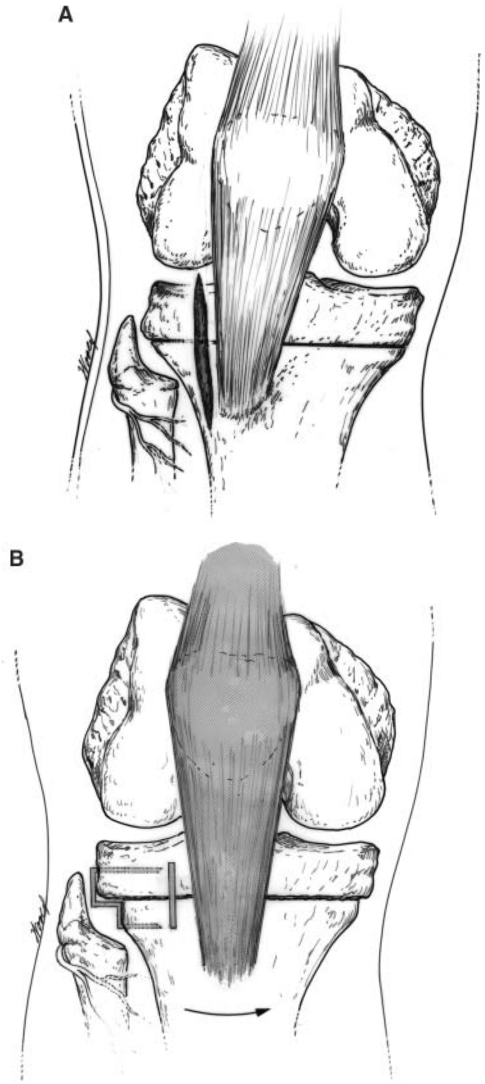

Figure 4. A, the tibial bone cut is superior to the tibial tubercle, perpendicular to the tibia, and parallel to the tibial plateau. B, the proximal tibia is reduced without posterior or medial subluxation, and fixed using 2 or 3 step staples. One staple is placed perpendicular to the other to prevent loss of rotation.

A guidewire was passed, lateral to medial, perpendicular to the tibial shaft and superior to the tibial tubercle. Proper pin placement was confirmed with fluoroscopy. A second pin was passed 2 cm posterior and parallel to the first pin and verified with fluoroscopy. A thin, oscillating saw blade was used to cut the lateral and anterior tibial cortex while protecting the patellar tendon. The posterior and medial cortices were not cut with the saw. They were fractured with a specially designed wedge osteotome and then separated by twisting the osteotome to spread the osteotomy site (Figure 4A). Before separation and rotation of the distal tibia, and using an electrocautery or marking pen, a perpendicular mark was made from superior to inferior, crossing the osteotomy cut. The distal tibia was then internally rotated a predetermined amount based on physical examination and CT scan (usually 10-15 mm). Internal rotation of the tibia should reduce the thigh-foot angle to 5° to 10°. (If a computerized axial tomography scan is used to determine the amount of tibial torsion present, it is necessary to normalize the value to the thigh-foot angle by adding 15° to the normal thigh-foot angle). The tibial tubercle should not proceed past the midpoint of the femoral sulcus (0° T/S angle) (Figure 4B). If it was necessary to rotate the tibia so that the tibial tubercle rotates into a negative T/S angle (usually required after a previous distal realignment), then the tubercle was cut and elevated free from the anterior tibial cortex and reattached with a 0° T/S angle after rotation and fixation of the distal tibia was completed. This was necessary for 1 patient in group 1.

Once proper tibial position was verified using fluoroscopy, the proximal and distal tibial sections were fixed using 1 or 2 lateral compression staples (BioMedical Enterprises Inc [BME], San Antonio, Texas) placed perpendicular to the tibial shaft and osteotomy cut. A third staple was placed from anterior to posterior and perpendicular to the lateral staples. (The use of Nitinol heat compression staples (BME) aids in fixation, expedites healing, and helps prevent medial translation of the proximal tibia as staple impaction is unnecessary.)

The medial tubercle transfer (ETF) procedure was accomplished through a 4- to 6-cm incision in line with the lateral arthroscopic portal and lateral to the tibial tubercle. After the tubercle and patellar tendon were exposed, a 15-mm deep and 2-cm wide supratubercle cortical cut was made perpendicular to the tibial shaft. With the patient's foot internally rotated, a 15-mm posterior cortical

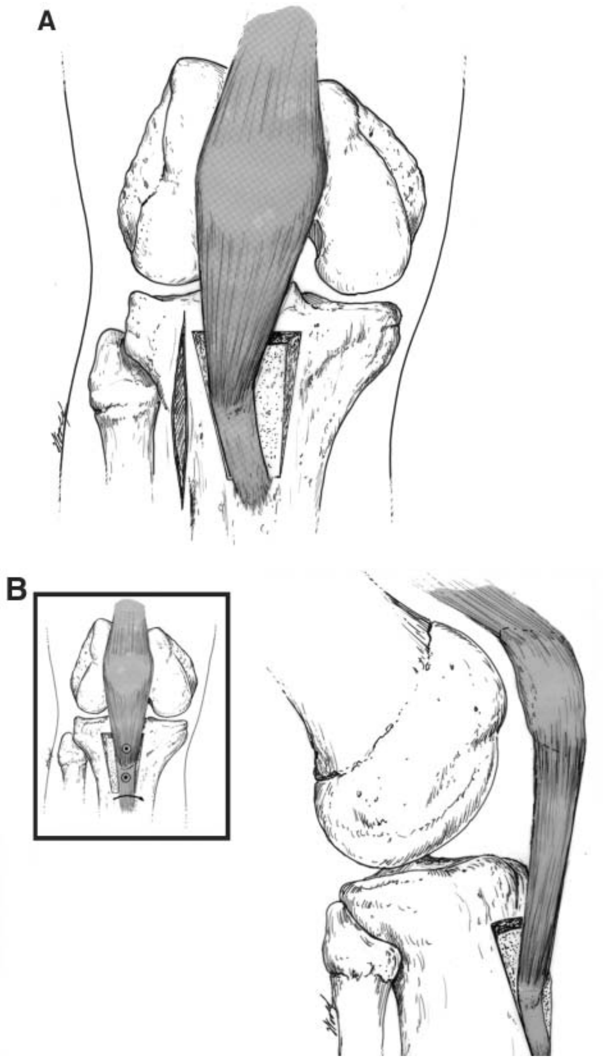

Figure 5. A and B, the incision is 6 to 8 cm lateral to the tibial tubercle. Note that the bone cuts produce large bone fragments to aid in fixation and prevent posterior placement. B inset, with the knee flexed and a proceeding lateral retinacular release (when indicated), the patella reduces into the femoral sulcus and the patellar tendon and tibial tubercle rotate into the desired position (T/S angle of 0° to 5°) before fixation.

cut was made from lateral to medial. The cut angled from posterior-superior to anterior-distal (Figure 5A). If anteriorization was indicated (Fulkerson), then the cut proceeded more anteriorly as it proceeded medially. Internally rotating the foot helped accomplish this goal and prevented posterior relocation of the tubercle. The medial cortex was fractured and the overlying periosteum left intact. As the knee was flexed, the tubercle found its ideal location secondary to the patella centering in the femoral sulcus. This maneuver resulted in a 0° T/S angle. The tibial tubercle was then fixed in this position using 2 low-profile cancellous or cortical screws (Figure 5B).

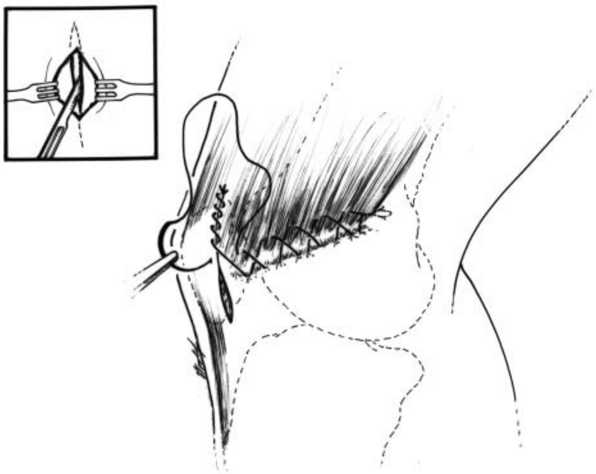

Figure 6. Note the bone anchor at the adductor tubercle and progression of imbricating sutures toward the proximal-superior patella. Total retinacular volume and laxity are reduced simultaneously with reformation and augmentation of the medial patellofemoral ligament.

Lateral retinacular release and medialization of the tibial tubercle can loosen the medial restraints and a medial tightening procedure may be required. All patients in this study underwent a minimally invasive medial reconstruction in the following manner. The proximal realignment was performed through a 2- to 3-cm incision medial to the patella (Figure 6). The patellar attachment of the medial patellofemoral ligament (MPFL) and medial retinaculum were incised from the patella and tissue planes were developed posterior and anterior to the retinaculum. The MPFL and its associated retinaculum were mobilized posterior to the level of the medial femoral epicondyle. A small stab wound was made through the skin over the adductor tubercle and a bone-suture anchor was embedded into the bone at the adductor tubercle. The sutures were retrieved subcutaneously and used to imbricate the medial retinaculum, while the MPFL was simultaneously reinforced with crossing sutures that proceeded from posterior to anterior. Once the patella was reached, the sutures were passed through the superior patellar retinaculum and tied. The repair was further reinforced with a “vest-over-pants” technique. By taking the knee through a range of motion before tying the sutures, we adjusted the suture tension to avoid tilting the patella and overtightening the medial restraints. The patella tracked centrally and did not shift from medial to lateral. The sutures were tied with the knee flexed at 30°, which helped prevent overtightening.

Postoperative Protocol

All incisions were closed using absorbable suture and the knees dressed and locked in a postoperative hinged brace at 20° of flexion. Straight-leg raises, isometrics, and neuromuscular stimulation were begun as soon as possible. Patients remained on crutches (toe-touch weightbearing) for 4 to 6 weeks or until swelling subsided.[9] Passive range of motion exercises were initiated in the second postoperative week and active extension was begun in the fourth week. Flexion was increased slowly each week as tolerated. Aquatic exercises were initiated in the third week and cycling exercises as soon as the knee achieved 110° of flexion. Unrestricted closed kinetic chain exercises were begun by 12 weeks and running and return to full activities, by 6 months. A soft, lateral buttress brace was recommended on return to sports for the first year of activity.

Gait Evaluation

After 5 to 10 minutes of acclimatization to treadmill walking, all subjects walked on a single-bed instrumented treadmill at their preferred walking speed for 4 to 5 minutes. During this time, the 3-dimensional trajectories of 51 retroreflective markers attached to the trunk, pelvis, and both lower extremities were recorded at 200 Hz with 8 digital Motion Analysis cameras (Motion Analysis Corp, Santa Rosa, California). The analog output from four 3-dimensional force transducers (MC3, Advanced Mechanical Technology Inc, Watertown, Massachusetts) supporting the instrumented treadmill (Athletic Republic, Park City, Utah) were recorded synchronously at 1600 Hz using a 12-bit analog/digital converter. For each subject, 50 seconds of data were collected (5 × 10 seconds) at regular intervals during the 5 minutes the subjects walked at their preferred speed.

The 3-dimensional trajectories of each marker were low-pass filtered using a fourth order, recursive Butterworth digital filter with cutoff of 20 Hz. The analog data from the 4 force transducers were summed to calculate the treadmill reaction forces in the vertical, anterior-posterior, and medial-lateral directions. The force data were low-pass filtered using the same filter as the kinematic data proposed by Bisseling and Hof.[3] Kinematic and kinetic analyses based on a linked segment model were calculated using Visual 3D RealTime Software (C-Motion, Bethesda, Maryland). Lower extremity joint moment data were only calculated for periods of single stance due to the single-bed design of the treadmill. Kinematic and kinetic variables of interest for each extremity were exported for statistical analysis. All data from nonoperated limbs with similar limb alignment were also compared with postoperative data from operated limbs.

Subjective/Functional Analysis

All patients were evaluated preoperatively and postoperatively using the Kujala scoring sheet, the Knee injury and Osteoarthritis Outcome Score (KOOS) questionnaire, and the RAND Short-Form 36-Item Health Survey (SF-36). An independent observer familiar with all questionnaires was available to answer patient questions and provide clarification. The KOOS questionnaire is a valid and reliable tool to measure patient-based outcomes after total knee arthroplasty and knee osteoarthritis. The Kujala scoring sheet is a specific and easily understood system, first published in 1993 and validated in 2003. Reliability (0.86), internal consistency (0.82), and ceiling (19%) and floor effects (0%) are all acceptable. This scoring system is specific to the patellofemoral articulation. The RAND 36-Item Health Survey (Version 1.0) taps 8 health concepts: physical functioning, bodily pain, role limitations due to physical health problems, role limitations due to personal or emotional problems, emotional well-being, social functioning, energy/fatigue, and general health perceptions. All patients entering the senior author's clinic for the first time and as part of research protocols repeatedly complete these forms.[22,34,40,41]

Statistical Methods

Appropriate statistical methods were selected for univariable, multivariable, and covariant determinations. The statistical methods are described in Appendix 1 (see online Appendix for this article at http://ajs.sagepub.com/supplemental/).[13,18,47,55]

RESULTS

Preoperative Findings

The 12 patients (12 knees) in group 1 who underwent the combined D-HTO and proximal realignment procedure all suffered from recurrent patellar subluxation and dislocation; the average number of episodes was 8.6 (range, 3 to >100). According to physical examination, all but 1 patient had an increased T/S angle of >20° (range, –8° to 40°, compared with a normal range of 0° to 10°). One patient who had undergone a previous proximal-distal procedure demonstrated a negative (varus) angle of 8°. All patients had increased femoral anteversion (>15°) and all but 2 had <60° difference between passive internal and external hip rotation (range, 55°-0°). Two patients demonstrated 80° and 85° of internal hip rotation with 15° of external rotation. Ten patients (83%) demonstrated moderate to severe flexible pes planus. The mean lateral patellar tilt was –8° (range, 0° to –15°) and all patients demonstrated medial-lateral patellar glides of >3 quadrants (compared with a normal glide of 2 quadrants). Apprehension was present in 10 patients and palpable patellar crepitation was present in 9 patients.

Preoperative 45° PA weightbearing radiographs demonstrated no loss of medial tibiofemoral joint space in any patient in group 1. One patient had narrowing of the lateral tibiofemoral joint space of 2 mm. Patella alta (>1 cm, Blackburne and Peel[4]) was present in 6 patients and patella infera (<1 cm) in 1 patient. The patella congruence angle on the Merchant view ranged from 10° to 30° (mean, 23.4°). The sulcus depth was normal in 2 knees, shallow in 7, flat in 2, and convex in 1. The standing mechanical axis (patella forward) revealed all patients to be in a neutral or valgus alignment (mean, 3.7° valgus; range, 0°-6°).

Patients were randomly screened and selected for group 2 from a historical cohort of 256 patients who had undergone an ETF proximal-distal patellar realignment. In an attempt to study patients with a similar follow-up time to group 1, those who had undergone the most recent operations were contacted first. The 13 patients in group 2 were women who had recurrent patellar subluxation and dislocation (mean, 6.3; range, 2 to >100). There were no significant differences compared with group 1 for body mass index; physical examination of the knee, hip, and feet; and apprehension to patellar subluxation. Preoperative radiographs demonstrated no significant differences from group 1 when comparing joint-space narrowing, patellar subluxation, standing alignment, or patellar height.

Intraoperative and Postoperative Findings

Group 1. All patients in group 1 returned for evaluation between 24 and 36 months postoperatively (Table 1). Repeat subjective and functional telephone interviews were conducted between 36 and 48 months postoperatively. No patient suffered a subluxation or dislocation event postoperatively. Three patients (25%) had occasional aching with changes in weather. Five (43%) patients used a soft knee brace for sports.

At surgery, grade II and III chondromalacia (Outerbridge) of the patella was noted on the median ridge and lateral facet in 6 patients (50%).[1] Two patients had a grade IV osteochondral lesion (15 × 20 mm and 10 × 15 mm in size) of the median ridge and medial facet. One patient demonstrated a grade IV lesion of the lateral femoral condyle that extended onto the lateral femoral weightbearing surface. Grade I to II changes on the femoral sulcus were noted in 5 patients extending from the sulcus terminalis, inferior to the intercondylar notch. Two patients had lateral compartment chondromalacia of the femur; 1 had grade II damage over an area of 1.5 × 2 cm, and the other patient had grade III damage over an area of 2.5 × 2 cm.

There were no operative or postoperative complications. Only 2 patients required a second surgery—1 for an arthroscopic debridement and closed manipulation for a flexion deficit at 4 months postoperative, and the second for a plate removal 18 months postoperatively. A normal range of knee motion was restored in all patients.

Eleven patients (92%) stated that they were happy with the results of their surgery and would undergo the procedure again. One patient was happy with the result, but would not repeat the surgery because of the length of recovery.

No patient complained of or demonstrated tenderness to palpation of the proximal tibiofibular joint. Passive patellar tilt was positive in all patients, averaging 10.6° (range, 5°-15°). Patellar glides demonstrated 2 to 3 quadrants. Apprehension was present in 4 patients (33.3%) and palpable crepitation in 3. Hip motion was unchanged and no patient complained of hip discomfort.

Postoperative radiographs revealed all osteotomies healed without loss of correction or delayed union. No change in patellar height, sulcus depth, or articular space loss (any compartment) was noted. Merchant views demonstrated a mean patella congruence angle of 4.2° (range, 0°-10°). Standing mechanical alignment demonstrated a significant shift (P = .05) toward a more neutral alignment, with a mean of 2.2° valgus (range, 2° of varus to 3° of valgus). No change in femoral head coverage was detected by radiography.

Group 2. All patients in group 2 returned for follow-up evaluation a mean of 4.8 years (range, 3-8 years) postoperatively. Three patients (23%) had recurrent subluxation and/or dislocation. Six (46%) demonstrated a positive apprehension sign, and 8 patients (62%) used a stabilizing brace for sports.

TABLE 1
Patient Characteristics[a]

	Group 1 Derotational High Tibial Osteotomy (N = 12)	Group 2 Proximal-Distal (N = 13)	*P* Value
Number of females	9	13	.10
Age (years)			
Median (IQR)	20 (16.5, 23.5)	23 (17, 33)	.14
Minimum-maximum	15-30	13-70	
Body habitus (number)			
Thin	4	3	.26
Medium	4	4	
Heavy	4	2	
Extra large	0	4	
Number of prior operations			
Median (IQR)	0 (0, 2)	0 (0, 1)	1.00
Minimum-maximum	0-7	0-7	
Number of subsequent operations			
Median (IQR)	0 (0, 0.5)	1 (0, 1)	.16
Minimum-maximum	0-1	0-3	
Time from surgery, months			
Median (IQR)	30.5 (29, 34)	60 (36, 120)	< .001
Minimum-maximum	24-36	30-168	
Repeat subjective, functional interview	36-48		
Time of return of symptoms (months)			
8	0	1	< .001
20	0	3	
24	1	4	
36	0	3	
48	1	1	
Never	10	1	
Preop T/S angle (deg)			NA
Median	27.5	25	
Minimum-maximum	–8 to 40	20-35	
Preop thigh-foot angle (deg)			
Median	35	38	
Minimum-maximum	30-57	30-43	
Postop T/S angle (deg)			
Median	5	5	
Minimum-maximum	0-8	0-10	
Postop thigh-foot angle			
Median	12	38	
Minimum-maximum	8-17	30-43	

[a] IQR, interquartile range (25th, 75th percentiles); T/S, tubercle-sulcus; NA, not applicable.

At surgery, 3 patients had significant grade III chondromalacia of the median ridge and lateral facet of the patella. One patient had a grade IV lesion of the medial facet that extended 1 cm past the median ridge. Six patients had diffuse grade II chondromalacia extending throughout the

TABLE 2
Kujala and KOOS Scores Preoperatively and at the Most Recent Follow-up Evaluation[a]

	Group 1 (Derotational High Tibial Osteotomy)			Group 2 (Proximal-Distal)			
	Preoperative	Follow-up	*P* Value	Preoperative	Follow-up	*P* Value	*P* Value Group 1 vs Group 2 Follow-up
Kujala score	50 ± 23	80 ± 10	< .001	55 ± 22	65 ± 16	NS	.01
KOOS scores							
Pain	54 ± 26	85 ± 12	< .001	57 ± 22	67 ± 18	NS	.005
Symptoms	48 ± 21	81 ± 16	< .001	49 ± 18	62 ± 17	.02	.008
Activities of daily living	67 ± 22	85 ± 15	< .001	62 ± 25	73 ± 19	.03	NS
Sports and recreation	24 ± 24	58 ± 28	.002	31 ± 29	44 ± 30	NS	NS
Quality of life	17 ± 19	62 ± 24	< .001	31 ± 22	35 ± 25	NS	.005

[a] All values are mean ± standard deviation. KOOS, Knee injury and Osteoarthritis Outcome Score; NS, not significant. There were no significant differences at the preoperative evaluation between group 1 and group 2. The between-group comparisons were done using a multivariable linear regression comparing the group follow-up scores, controlling for both the preoperative scores and time to follow-up evaluation, with *P* values adjusted for 6 multiple comparisons using Hochberg's procedure.

entire surface of the patella. Four patients had grade I and II changes in the central groove of the femoral sulcus that extended 2 cm inferior from the sulcus terminalis. There were no significant medial or lateral compartment changes documented.

There were 4 subsequent surgeries: 2 arthroscopic debridements and closed manipulations for flexion deficits, 3 screw removals, and 1 repeat proximal realignment surgery. A normal range of knee motion was restored in all patients.

Three patients (23%) would not repeat the surgery; however, 11 patients (85%) were satisfied with the result.

The mean passive patellar tilt was 5.2° (range, –5° to 15°). Crepitation was present in 11 patients (85%). Six patients (46%) had a gradual return of symptoms, which began a mean of 24.7 months (range, 22-34 months) postoperatively.

Postoperative radiographs revealed all tubercle transfers healed. Two patients demonstrated a decrease in patellar height of 6 to 8 mm. Four patients demonstrated at least a 3-mm loss of patellofemoral joint space compared with preoperative radiographs (mean, 3.6 mm; range 3-5 mm). Merchant view congruence angles demonstrated a mean improvement of 13.6° (range, 0°-20°). Standing alignment radiographs revealed 1 patient was in 3° of varus, 3 patients were in 1° of varus, 5 patients were at 0°, and 4 patients were between 1° and 4° of valgus.

Kujala, KOOS, and SF-36 Scores

Before surgery, there were no significant differences between groups 1 and 2 in any of the Kujala or KOOS scores (Table 2). The postoperative reduction of symptoms and increase in activities in group 1 was significant in every category except the KOOS activities of daily living score (Figure 7). However, in group 2, only 2 categories had significant improvements in the mean scores compared with the preoperative value.

There was a statistically significant increase (*P* < .001 for all comparisons) in all of the SF-36 scales in group 1 at follow-up except for the role limitations due to emotional problems scale (Table 3). In contrast, no significant improvements were found for group 2 in these scales. Group 1 had a greater mean improvement than group 2 for all scales except role limitations due to emotional problems.

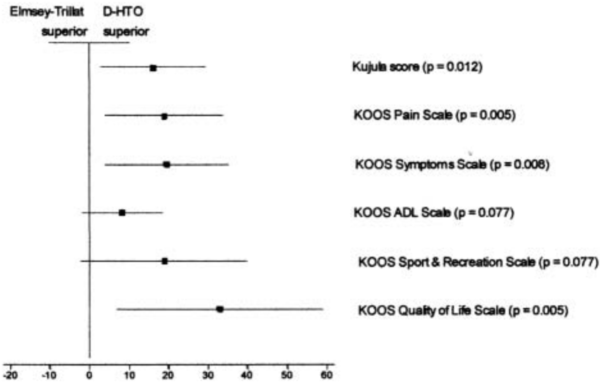

Figure 7. Comparison of groups on 6 primary outcomes for the Kujala and Knee injury and Osteoarthritis Outcome Scores. Shown are the group differences in mean improvement and 95% confidence intervals from multivariable linear regression models that controlled for time to follow-up and baseline scores, with *P* value and confidence interval widths adjusted for multiple comparisons. If the results for the 2 groups were equal (per the study's hypothesis), then all of the data points would appear on the center line. The data clearly demonstrate the superior subjective and functional ratings of the derotational high tibial osteotomy (D-HTO) group.

Gait Analysis

Table 4 provides a comparison of the stride kinematics between the groups. The most striking difference was the asymmetry of the stride times between the operated and control limbs. Group 2 subjects spent significantly less time on the surgical limb, with key differences in both single and double stance. The single-stance times for group

TABLE 3
Short Form-36 Scores Preoperatively and at the Most Recent Follow-up Evaluation[a]

	Group 1 (Derotational High Tibial Osteotomy)			Group 2 (Proximal-Distal)			
Factor	Preoperative	Follow-up	*P* Value	Preoperative	Follow-up	*P* Value	*P* Value Group 1 vs Group 2 Follow-up
Physical functioning	47.1 ± 25.4	87.9 ± 22.4	< .001	44.2 ± 30.3	50.0 ± 27.1	NS	.004
Role limitations due to physical health	20.8 ± 41.0	100 ± 0.0	< .001	65.4 ± 48.0	78.8 ± 41.2	NS	.001
Role limitations due to emotional problems	75.0 ± 43.9	94.4 ± 23.2	NS	64.1 ± 48.6	74.4 ± 44.2	NS	NS
Energy/fatigue	55.4 ± 21.9	86.7 ± 15.1	< .001	60.8 ± 24.7	65.8 ± 22.2	NS	.007
Emotional well-being	56.0 ± 19.1	88.0 ± 16.5	< .001	68.6 ± 20.3	68.0 ± 20.9	NS	< .001
Social functioning	45.8 ± 22.9	85.4 ± 14.6	< .001	59.6 ± 22.4	65.0 ± 19.1	NS	< .001
Pain	51.5 ± 22.5	95 ± 10.0	< .001	72.5 ± 16.4	77.7 ± 13.1	NS	< .001
General health	34.2 ± 27.6	78.3 ± 22.4	< .001	51.4 ± 32.2	53.4 ± 28.5	NS	.001

[a] All values are mean ± standard deviation. NS, not significant. Between-group comparisons were done using a multivariable linear regression comparing the follow-up scores, while controlling for the preoperative scores and time to follow-up evaluation.

TABLE 4
Stride Kinematics[a]

	Group 1 (Derotational High Tibial Osteotomy)			Group 2 (Proximal-Distal)			
	Surgery	Nonsurgery	Difference (SD)	Surgery	Nonsurgery	Difference (SD)	*P* Value
Total stride time (sec)	0.671	0.673	–0.002 (.005)	0.665	0.680	–0.014 (.005)	.004
Single-stance time (sec)	0.380	0.382	–0.002 (.005)	0.374	0.388	–0.014 (.005)	.004
Double-stance time (sec)	0.144	0.147	–0.002 (.004)	0.153	0.138	0.015 (.007)	.004
Total limb contact time (sec)	0.289	0.293	–0.004 (.009)	0.277	0.306	–0.028 (.011)	.004

[a] Shown are means and mean differences (standard deviation [SD]) of surgery-side limb minus the nonsurgery-side limb. The *P* value is from an independent-samples Fisher-Pitman permutation test to allow for skewness in the difference score distributions. The double-stance time value indicates which limb was forward during each period of double stance within each stride.

2 were significantly shorter on the surgical limb, while the double-stance times were significantly longer on the surgical limb. The total limb contact time (indicating how long each limb was in contact with the treadmill) was significantly shorter on the surgical limb for group 2 subjects. All stride time values were similar between limbs for group 1. The data show that group 2 patients attempted to keep the control limb in contact with the treadmill longer and limited the time the surgical limb was in contact with the treadmill. In contrast, the stride kinematics in group 1 were very similar between the surgery and control limbs.

The degree of external rotation of the foot at heel strike for both limbs in all subjects is shown in Appendix 2 (see online Appendix for this article at http://ajs.sagepub.com/supplemental/). The amount of external rotation at heel strike in the surgery-side foot was smaller than the control side for all subjects in group 1. This was not the case for group 2, as some subjects had a larger amount of external rotation on the surgery side, while others had similar or smaller external rotation angles on the surgery side. Statistical comparison of the between-limb symmetry patterns revealed that group 1 had significantly less external rotation of the foot on the surgery side than the control side as compared with differences between limbs in group 2 (median difference, group 1 minus group 2, 4.3; 95% confidence interval [CI], 0.4 to 8.1; *P* = .039).

A comparison of the knee flexion and frontal plane angles at midstance between limbs for each group is shown in Appendix 3 (see online Appendix for this article at http://ajs.sagepub.com/supplemental/). All the subjects in group 2 exhibited less knee flexion at midstance on the surgery side, whereas almost all subjects in group 1 had slightly more knee flexion on the surgery side at midstance. The difference in the symmetry of knee flexion between limbs was significantly different between groups (median difference, –4.8; 95% CI, –8.5 to –0.7; *P* = .035). There was no difference between the groups on knee frontal midstance (median difference, –0.1; 95% CI, –1.7 to 1.3; *P* = .68).

The peak and average frontal plane moments at the knee during stance are illustrated in Appendix 4 (see online Appendix for this article at http://ajs.sagepub.com/supplemental/). All peak frontal plane knee moments were negative, indicating a net valgus moment from the clinician's perspective. Comparison of the symmetry between limbs in each group indicated that the surgery-side peak moment values were slightly greater than the control-side moments for all subjects in group 1 (median difference, –0.18; 95% CI, –0.50 to 0.12; *P* = .035). There was no clear pattern of between-limb differences in peak frontal plane moments for group 2 (median difference, –0.03; 95% CI, –0.33 to 0.24; *P* = .74). The average frontal plane knee moments throughout stance were also more similar between limbs in group 1 compared with those in group 2, which were quite large and variable in 3 of the 5 subjects. The most interesting finding was the large difference in variability of the peak and average frontal plane knee moment values, as group 2 showed significantly more variability in these values both between limbs and from stride to stride.

To test for a difference in the magnitude of variability, or standard deviations, between groups, illustrated by group 2's cluster of lines being higher on the graph than group 1's, the average of the surgical and nonsurgical limbs for each patient was computed. Group 1 had significantly less variability in the peak frontal knee moment standard deviation (median difference, –0.24; 95% CI, –0.33 to –0.21; *P* = .004), as well as the average frontal knee moment standard deviation (median difference, –0.13; 95% CI, –0.18 to –0.11; *P* = .004). These findings are consistent with the asymmetry found in the stride kinematics, as group 2 subjects walked with much greater asymmetry in trying to minimize the time spent on their surgery-side limb.

The angle between the patella and tibia in the frontal plane at mid-stance for all subjects in each group is shown in Appendix 5 (see online Appendix for this article at http://ajs.sagepub.com/supplemental/). Values normalized to standing posture as well as the absolute angle between the segments in the frontal plane are shown. Subjects in group 1 demonstrated a more neutral patella-tibial alignment between limbs than group 2, when comparing values either normalized to standing posture (median difference, 5.5; 95% CI, –2.7 to 7.8; *P* = .087) or in absolute terms (median difference, 8.2; 95% CI, 5.7 to 11.4; *P* = .004).

DISCUSSION

Many publications have reported axial as well as coronal and sagittal plane correction for associated limb malalignment and patellar disorders.[7,8,44,48] However, the description of these procedures and their comparative results in an adult population are rare. Pediatric orthopaedists are more likely to deal with these issues than their orthopaedic colleagues who see only adults. However, many adolescents transition into adulthood without the benefit of detection and correction of their malalignment and resultant patellar instability. Significant torsional malalignment is more common than generally appreciated and very often missed, despite being easy to detect. The approach to adults with patellar instability rarely includes evaluation, let alone correction of rotational abnormalities. Instead, most orthopaedists choose to deal independently with the consequences of the malalignment, such as patellar instability, patella alta, shallow femoral sulcus, increased Q-angle, lateral patellar compression, and so forth. Many of the corrective procedures for these associated conditions have enjoyed popular acceptance with good short-term results. However, in reviewing the literature and the senior author's own results, a significant number of patients appear to develop late symptoms and arthritis.[11,14,30,33,52,53] Thus, in many cases, these other procedures may need to be performed in combination with torsional realignment procedures, or may even be avoided altogether by restoring normal mechanical alignment (D. DeJour, unpublished data, 2007).[7,19,20,36,37] Relative to the inconsistent results of tibial tubercle transfer, many surgeons have chosen to use only proximal soft tissue procedures. In our opinion, failure to correct significant limb malalignment and the resultant valgus vector (patella) may ultimately invite soft tissue fatigue and stretching, even with the most robust reconstructions (A. T. Moeller, unpublished data, 2007).[2,31,32,38,49]

Determination of the T/S angle and its associated thigh-foot angle, either clinically or by computerized axial tomography scan, is not only simple but also an important first step when evaluating a patient with patellar instability.[5,12,15,27,35,39,45] By determining the T/S angle, one can determine the severity of the valgus vector on the patella during activities, as well as determine if the correction of this abnormality will contribute enough compensation to hip rotation to avoid a femoral osteotomy. A normal (valgus) T/S angle of 0° to 10° associated with patellar instability is rare unless there is an associated knee ligament, patellar ligament, or quadriceps insufficiency. If, on the rare occasion (usually secondary to trauma or surgery) there is a rotational deformity, patellar instability, and a normal T/S angle, then tibial correction should occur independent of, or below, the tubercle. This is also true for young patients with open physeal plates.

In 1995, Meister and James[28] reported 11 cases of supratubercle derotation osteotomy. The proximal tibiofibular joint was not excised and mobilized. Dr James subsequently discussed the difficulty of obtaining and holding the desired position in several of the patients (personal communication). The senior author, before employing the D-HTO, developed and performed the procedure on 4 cadaver limbs and compared the degree of rotation and torque required to maintain position, with and without partial fibular head resection and mobilization. With partial excision and posterior capsular release, there was an added increase of internal tibial rotation of 15°, while the torque to hold correction was reduced approximately 50% (from 5 to 2.3 N·m). The tension observed in the peroneal nerve at the fibular neck was obviously less. With lower restraining forces required, the surgeon may use less hardware and avoid longer incisions and extensive dissection. No patient in the D-HTO group demonstrated or complained of tenderness, pain, or instability of the proximal tibiofibular joint.

In 2004, Bruce and Stevens[7] reported 14 cases of tibial derotation in patients with an average age of 14.9 years. These authors used a midshaft osteotomy and an intramedullary nail for fixation. The T/S angle was not noted or disturbed, but a lateral retinacular release and a 3-compartment release of the lower leg were also performed. Despite the fact that their reported results were excellent, we were hesitant to ignore an increased T/S angle (persistent valgus vector), reluctant to perform compartment releases, and wished to avoid a second surgery to remove the tibial nail. Therefore, the supratubercle technique described in this article was developed. The need to include or not include T/S angle correction with correction of torsional deformities will need to be the goal of future studies. However, supratubercle osteotomy provides several other important advantages. First, compression from the extensor mechanism through the large surface area of the proximal tibia increases stability and facilitates healing. Second, by correcting the T/S angle simultaneously with tibial torsion, the surgeon partially corrects femoral torsion. In turn, the need for functional hip compensation is diminished. Finally, infratubercle osteotomy functions only during weightbearing activities, whereas a supratubercle osteotomy reduces the valgus forces on the patella even during nonweightbearing activities, such as jumping and the swing-through phases of walking and running.

Clinicians have traditionally been required to evaluate and correct patellar instability based mostly on static observations. More recently, with the development of cine-MRI studies and the use of "real time" gait analysis (as used in our study), we now have a greater understanding and appreciation of patellofemoral dynamics throughout the gait cycle.[20,24,26,46,54] As a patient strides forward, 1 leg is lifted while full weight is placed on the opposite leg. The swing leg is subjected to hip compensation, rotational alignment, and T/S angle positioning of the tibial tubercle to the femoral sulcus just before heel strike. Much like "lining up a putt" in golf, the patella is aligned with the sulcus just before heel strike. At heel strike, the hip and femur finish rotating to the midpoint between internal and external hip rotation to keep the foot pointed forward during the foot-flat and toe-off phases of gait. The femoral sulcus is thus prepositioned in its relationship to the tibial tubercle. If this fails to occur, depending on the static and geometric restraints present, the patella will track laterally and can spontaneously subluxate or dislocate during gait just before the foot-flat phase. Maximum compensation for malalignment of the limb occurs proximally (at the hip) and then becomes less effective, proceeding distal to the foot, wherein the foot again minimally compensates through midfoot pronation.

As long as there is adequate internal and external hip rotation (normally internal equals external), minor to moderate degrees of abnormal lower limb alignment can be tolerated. Appreciating the fact that functional compensation can occur at several levels helps one understand that successful reports of surgical correction for significant malalignment with either hip and/or tibial derotation surgery are less contradictory than they appear.[20,24,26,46,54] If there is inadequate active hip rotation (severe femoral anteversion), then there is less available hip rotation to compensate for the fixed external torsion of the tibia. Thus, either an external rotational osteotomy at the hip or an internal rotational osteotomy of the tibia and foot will help. By moving the tubercle with the foot, the amount of compensatory active rotation of the hip required is reduced and the need for hip derotational surgery lessened. If only the tubercle is moved, then the potential for more joint incongruity and increased joint reaction force is created because tracking is only corrected in 1 plane (axial), while the other planes remain the same or are worsened. After surgical correction of torsional malalignment, the gait becomes more "symmetrical," less variable, and requires less forceful joint compensation to keep the foot pointed straight ahead and the patella tracking central. Patients have less knee pain, grinding, and weakness, and less hip and back discomfort on the corrected side. When the patella tracks more central in the femoral sulcus, there is better joint congruence and dispersal of joint reaction forces. The valgus vector on the patella is significantly reduced and patellar instability is minimized.

Using detailed preoperative and postoperative examinations, questionnaires, and unique force-plate gait studies, the highly significant results observed were surprising. Group 1 was clearly the more satisfied group and demonstrated the largest improvement between preoperative and postoperative complaints. These patients returned to significantly higher activity levels more quickly. In contrast, group 2 patients, although initially improved, were never as happy or active and tended to redevelop symptoms 24 to 36 months after surgery. Gait studies demonstrated inconsistent symmetry measurements, with less time spent on the operated limb and a more straight-leg gait with or without surgery. Postoperative gait patterns would be difficult to predict after the typical proximal-distal realignment.

The subtle recurrence of discomfort, crepitation, and swelling occurred at approximately 2.3 years postoperatively in group 2. In contrast, fewer patients had recurrence of symptoms in group 1 (Table 1). Both groups shared essentially the same intra-articular findings at surgery, preoperative activity level, body weight/height proportion, number of preoperative dislocations, and number of prior knee surgeries. Three patients in group 2 experienced recurrent patellar instability (mean, 2.6 years postoperatively), while no patient in group 1 experienced this problem ($P = .22$). These 3 patients in group 2 required further surgery. One had a proximal realignment only and, further contrasting the results of patient groups, the other 2 patients subsequently had a retrotubercle D-HTO. At the most recent follow-up evaluation, these 2 patients were graded as excellent and good.

During the course of this study, the hardware chosen to fix the D-HTO changed from a 7-hole HTO locking plate (Arthrex, Naples, Florida) to standard HTO step staples (Richards Orthopaedics, Memphis, Tennessee), to low-profile, heat compression Nitinol step staples (BME). It became apparent that it was unnecessary to use extensive hardware fixation for an inherently stable osteotomy and there was no significant difference in outcomes other than the need to secondarily remove the tibial plate hardware.

A second change since completion of this study has been the reduced number of MPFL reconstructions performed. It appears that with better mechanical limb alignment, there is less need to reconstruct or tighten medial retinaculum restraints.

Another change under consideration is a change in the threshold for performing a D-HTO. When one compares the significant difference in the results of group 1 compared with group 2, it becomes apparent that the threshold of a 30° thigh-foot angle, chosen by Bruce and Stevens in their study, may be too conservative. Given the unpredictable response of recovery and gait mechanics to medialization of the tibial tubercle (without tibial torsion correction), it may be more prudent to perform a D-HTO rather than a medial tubercleplasty when correction of the T/S angle is required in patients with increased thigh-foot angles.

One weakness of this study is the retrospective comparison of the D-HTO to the ETF procedure. Although every attempt was made to match patient populations, the most significant difference was the average in follow-up time. By nature of a prospective versus retrospective study, the latter will have a longer follow-up period. However, by reinterviewing group 1 patients a year after the clinical evaluation, and by statistically employing a regression model that adjusted for follow-up time, this problem was minimized. Still, the stark contrast in results between groups could change over time. However, it should be noted that mild symptoms returned in over half of the group 2 patients within the first 2.5 years. The minimum follow-up period for group 1 was 3 years, and few symptoms had returned. This suggests that the follow-up time for group 1 was probably long enough to adequately compare the 2 surgical procedures, particularly with the follow-up time adjustment in the regression models. Another weakness in this study is the small number of participants in each group. A fact that supports this point is that the large majority of patients with patellofemoral maladies do not require surgery.[10] However, by tightly controlling variables and evaluation tools, we were able to demonstrate highly significant findings.

SUMMARY

Two operative procedures for correcting patellofemoral instability were evaluated in 2 patient populations, each demonstrating increased T/S and thigh-foot angles. All patients were studied using preoperative and postoperative history, physical examination, intraoperative forms, and subjective evaluation using the Kujala, KOOS, and RAND SF-36 (1.0) scoring systems. Participants also received preoperative and postoperative radiographs that included “gun-sight” CT scans, and postoperative dynamic force-plate gait analysis. All results were tabulated and analyzed using appropriate statistical methods. Regardless of the severity of associated findings, and in contrast to our original hypothesis, significantly better results were obtained in those patients undergoing a D-HTO compared to those receiving the traditional proximal-distal (ETF) realignment procedure.

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