Case Report

Quantitative MRI of Tibial Tubercle Transfer During Active Quadriceps Contraction

Kyle Duchman BA, Chloe Mellecker BS,
Ahmad Y. El-Hattab BS, John P. Albright MD

Received: 16 March 2010 / Accepted: 16 September 2010 / Published online: 13 October 2010
© The Association of Bone and Joint Surgeons® 2010

Abstract

Background The evaluation of distal transfer procedures relies primarily on qualitative clinical findings. Although quantitative MRI measurements provide an objective supplement to qualitative clinical findings, an association between qualitative clinical findings and quantitative patellofemoral indices has yet to be established.

Case Description A 21-year-old man presented with frequent episodes of patellar dislocation. Clinical and radiographic findings identified the patient as a candidate for realignment. MR images were obtained with the quadriceps contracted at 30° flexion and in full extension preoperatively and postoperatively. The procedure eliminated the clinical J-sign, defined as lateral movement of the patella over the lateral femoral condyle during active leg extension, which

was confirmed quantitatively using established patellofemoral indices in conjunction with MRI.

Literature Review Movement of the patellofemoral joint is complex and dependent on many factors, including skeletal geometry, dynamic muscle action, and soft tissue restraints. Therefore, proper clinical and radiographic evaluation of patellar tracking requires observation during active quadriceps contraction. However, it is unclear whether there is any association between quantitative radiographic indices and qualitative clinical assessment during active quadriceps contraction.

Purposes and Clinical Relevance We believe objective measurements are valuable in determining the radiographic assessment of patellar realignment procedures. Lateral patellar edge appears to quantify the clinical J-sign. The association between radiographic medialization of the patella and clinical improvement postoperatively in this patient warrants additional investigation in a larger group of patients with longer followup.

Each author certifies that he or she has no commercial associations that might pose a conflict of interest in connection with the submitted article.

Each author certifies that his or her institution has approved the reporting of this case, that all investigations were conducted in conformity with ethical principles of research, and that informed consent for participation in the study was obtained.

This work was performed at the University of Iowa Carver College of Medicine, Iowa City, IA, USA.

Electronic supplementary material The online version of this article (doi:10.1007/s11999-010-1598-8) contains supplementary material, which is available to authorized users.

K. Duchman, C. Mellecker, A. Y. El-Hattab
University of Iowa Carver College of Medicine, Iowa City, IA,
USA

J. P. Albright (✉)
Department of Orthopaedics and Rehabilitation, University of
Iowa Hospitals and Clinics, 200 Hawkins Drive, 01008 JPP,
Iowa City, IA 52242, USA
e-mail: john-albright@uiowa.edu

Introduction

Traditional assessment of patellar realignment procedures relies primarily on qualitative clinical information. Many surgeons consider realignment procedures successful if patients do not experience another episode of dislocation and do not require additional procedures. Restored stability may be assessed clinically by elimination of the J-sign, defined as movement of the patella from a reduced position in the trochlear groove at 30° flexion to a relatively lateral position as the patella travels over the lateral femoral condyle during active extension of the leg, and the apprehension sign.

Quantitative MRI measurements supplement traditional clinical evaluation criteria more objectively. These measurements can be used to supplement standard evaluation procedures, providing a standard under which research from different investigators can be compared. It is the belief of the senior author (JPA) that under current, less stringent standards, the literature has implied higher success rates than what is seen clinically and that the addition of the J-sign and MRI measurements provides a more complete picture of corrected patellar tracking.

In this case report, we associate elimination of recurrent dislocation and elimination of the qualitative J-sign with quantitative MRI measurements that reflect medialization of the patella postoperatively during active quadriceps contraction.

Case Report

A 21-year-old man presented with left knee pain and frequent episodes of instability. The patient previously had experienced two episodes of patellar dislocation of the left knee, the first occurring 3 years before surgery and the second occurring 8 weeks before surgery, after tripping while playing soccer. The second episode caused him to seek care because the pain restricted him from his carpentry work. He received physical therapy and wore a brace to prevent dislocation. He thought these options did not help, however, and sought a more permanent option after the second dislocation.

Physical examination revealed a continuously positive apprehension sign from 0° to 90°. The patient had a grossly positive J-sign, especially in the final 30° of active leg extension ((Video 1, Supplemental Website Material; supplemental materials are available with the online version of CORR). Medial tenderness suggested rupture of the medial patellofemoral ligament (MPFL). Quadriceps strength in the left, affected leg was weakened (4/5), whereas the right leg maintained full strength (5/5). Active ROM was restricted from 5° to 135°.

Subsequent to that visit, he experienced several additional dislocations before surgery. Immediately before the operation, the patient described brief episodes of knee locking and catching while climbing stairs and ladders. The patient also explained that it was difficult to kneel, squat, and rise from a chair immediately before surgery.

Preoperative Knee Injury and Osteoarthritis Outcome Score (KOOS) [15] revealed restricted activity with scores of: symptoms, 75; pain, 75; activities of daily living, 87; sport/recreation, 25; and quality of life, 17. WOMAC scores [2] were similar with pain, 85; stiffness, 87; and function, 87.

Fig. 1 A preoperative CT scan of the left leg reveals incongruence of the patella in relationship to the trochlear groove. The most posterior aspect of the patella is substantially lateral to the deepest portion of the trochlear groove with the leg in passive extension.

Fig. 2 Using CT with the knee in passive extension, axial slices containing the apex of the tibial tubercle and the deepest point of the trochlear groove were overlaid to measure the tibial tubercle-trochlear groove distance (TT-TG). The distance between the apex of the tibial tubercle and the deepest point of the groove was measured as the TT-TG. The measurement was parallel to the line tangential to the posterior femoral condyles [10].

Preoperative CT revealed incongruence of the left patella in relationship to the trochlear groove with the leg in full extension (Fig. 1). The tibial tubercle-trochlear groove (TT-TG) distance was measured at 20.3 mm (Fig. 2), exceeding a standard 20-mm threshold for surgery [5, 7, 10]. Because of the patient's symptoms, failure of nonoperative treatment, and imaging findings, which included an absence of abnormal femoral torsion, we recommended a medial tibial tubercle transfer with MPFL

reconstruction through a semitendinosus allograft as originally described by McManus et al. [11].

Measurements were made on MR images of the knee obtained with the quadriceps concentrically contracted at 30° flexion and full extension with the patient in the supine position. Previous research has established that lateral subluxation and patellar instability are greatest in the range of 0° to 30° knee flexion [6, 14, 18]. MRI was the chosen modality because it allowed observation of soft tissue and bony landmarks required to measure patellofemoral indices. All images were collected using a Siemens TIM Trio (Siemens Medical Solutions, Erlangen, Germany) 3.0-T MRI (T2 fat-saturated, TE: 62/TR 3300).

The following patellofemoral indices (Fig. 3) were measured at 30° flexion and active extension before and after surgery. All measurements were made in the axial plane: (1) bisect offset (BSO), as described by Stanford et al. [18]: a line was drawn tangential to the medial and lateral posterior condyles. A perpendicular line then was drawn through the deepest point of the sulcus. BSO is the ratio of the patella lateral to the perpendicular line compared with the total width of the patella (Fig. 3A); (2) lateral patellar displacement (LPD), as described by Laurin et al. [8]: a line was drawn tangential to the medial

and lateral anterior condyles. A perpendicular line is drawn through the apex of the medial condyle. The distance from this line to the most medial part of the patella was measured (Fig. 3B); (3) lateral patellar edge (LPE), as described by Brossman et al. [3]: this measure is identical to LPD except the apex of the lateral condyle is used (Fig. 3C); (4) patellar tilt angle as described by Sasaki and Yagi (PTA-S) [16]: this angle is defined as the angle between the line that passes through the widest part of the patella and a line tangential to the anterior femoral condyles (Fig. 3D); (5) sulcus angle as described by Merchant et al. [12]: the angle between the sulcus and the medial and lateral condyles (Fig. 3E); (6) congruence angle as described by Merchant et al. [12]: the angle created by the bisect of the sulcus angle and a line from the deepest point of the sulcus to the most posterior aspect of the patella (Fig. 3F); and (7) TT-TG as described by Lustig et al. [10]: the horizontal distance between the tibial tubercle and trochlear groove (Fig. 2).

Three authors (KD, CM, AE) each completed the measurements three times with a minimum of 48 hours between measurements. These authors were blind to each other's measurements and their previous results during each session. Kappa coefficients were used to determine

Fig. 3A–F The illustrations show previously established patellofemoral indices used in this study. (A) Bisect offset (BSO) measures the percentage of total patellar width lateral to the deepest point of the sulcus. (B) Lateral patellar displacement (LPD) measures the distance from a line perpendicular to the apex of the medial femoral condyle to the medial edge of the patella. Positive values are assigned when the patellar edge is medial to the perpendicular line. (C) The lateral patellar edge (LPE) is identical to LPD except that the lateral femoral condyle and lateral edge of the patella are used. Positive values are

assigned when the lateral patellar edge lies lateral to the perpendicular line created at the apex of the lateral femoral condyle. (D) The patella tilt angle of Sasaki (PTA-S) is created by the line passing through the widest aspect of the patella and the line tangential to the anterior femoral condyles. (E) The sulcus angle is created by two lines extending from the deepest point of the trochlear groove to the medial and lateral femoral condyles. (F) Congruence angle values are positive when the line connecting the sulcus to the most posterior aspect of the patella is lateral to the bisect of the sulcus angle.

intraobserver and interobserver reliability [17]. Interobserver reliability for the indices displayed consistently lower reliability as compared with intraobserver values (Table 1).

The patient returned to work within 1 month and made a self-described full recovery within 1 year of the procedure. After 1 year, he had no pain at rest and reported being able to engage in strenuous activities such as running, soccer, cutting activities, and deceleration with minimal pain. The patient showed no signs of apprehension and had no J-sign. Postoperative KOOS scores for the left knee were 86 for symptoms, 97 for pain, 100 for activities of daily living, 85 for sport, and 83 for quality of life. Postoperative WOMAC scores improved to 100 for pain, 100 for stiffness, and 100 for function. All scores showed improvement when compared with the preoperative scores.

Table 1. Intrarater and interrater reliability for patellofemoral indices

Index	Intrarater reliability		Interrater reliability	
BSO	0.905	0.783	−0.012	0.468
LPD	0.958	0.948	0.895	0.807
LPE	0.855	0.974	0.758	0.296
PTA-S	0.817	0.867	0.939	−0.193
Sulcus	−0.346	0.829	0.451	−0.434
Congruence	0.992	0.996	0.992	0.954

BSO = bisect offset; LPD = lateral patellar displacement; LPE = lateral patellar edge; PTA-S = patellar tilt angle of Sasaki.

Surgery produced improvement in patellar congruence as indicated by qualitative and quantitative MRI (Fig. 4). Postoperative changes in LPD [8], LPE [3], and BSO [18] indicate medialization of the patella at 30° and 0° flexion (Table 2). The postoperative reduction in these values suggests an improved relationship between the patella and trochlear groove during the critical degrees of flexion when patellar instability is greatest. The tibial tubercle was transferred 22 mm medially intraoperatively, reducing TT-TG to a value below the surgical threshold of 20 mm (Table 2) [10]. Because a trochleoplasty was not performed in this case, adequate medial transfer was essential to correct the patellofemoral relationship in the setting of a relatively shallow trochlear groove compared with a normal mean value of 142° described previously (Table 2) [4, 12]. The MPFL was reconstructed after the medial tibial tubercle transfer to create a check rein to prevent apprehension.

Discussion

This case illustrates an association between relief of dislocations after a realignment procedure with the J-sign and quantitative values obtained using MRI during active quadriceps contraction. The J-sign allows clinical evaluation of patellar tracking during active extension, but it is unknown whether it correlates with patient function or whether it could be used to recommend surgery or predict postoperative function. It is our belief that the J-sign could

Fig. 4A–D Preoperative MR images in (A) 30° active flexion and (B) active extension and postoperative MR images in (C) 30° active flexion and (D) active extension show reduced patellar lateralization postoperatively when comparing the lateral edge of the patella with the lateral femoral condyle (Table 2).

Table 2. Preoperative and postoperative indices of patellofemoral kinematics

Index	Preoperative		Postoperative		Change	
	Extension	Flexion	Extension	Flexion	Extension	Flexion
BSO	0.786 ± 0.090	0.798 ± 0.087	0.635 ± 0.060	0.676 ± 0.052	0.151 ± 0.108	0.121 ± 0.101
LPD	5.84 ± 1.68	4.97 ± 2.44	(-)4.01 ± 3.94	(-)2.91 ± 1.80	9.86 ± 4.28	7.88 ± 3.03
PTA-S	26.3 ± 10.1	27.1 ± 4.70	22.8 ± 2.11	24.0 ± 2.00	3.56 ± 10.3	3.11 ± 5.11
Sulcus	152 ± 2.42	153 ± 2.35	152 ± 5.61	153 ± 1.92	(-)0.333 ± 6.11	0.111 ± 3.03
Congruence	29.6 ± 11.5	36.2 ± 5.70	9.78 ± 3.70	(-)27.8 ± 6.61	19.8 ± 12.1	64.0 ± 8.73
LPE	19.8 ± 4.09	15.7 ± 5.98	11.0 ± 5.36	10.4 ± 3.00	8.76 ± 6.74	5.30 ± 8.53
TT-TG	20.3 ± 1.30		14.2 ± 1.01		6.11 ± 1.65	

BSO = bisect offset; LPD = lateral patellar displacement; LPE = lateral patellar edge; PTA-S = patella tilt angle of Sasaki; TT-TG = tibial tubercle-trochlear groove.

provide such a tool. We quantified medialization of the patella using established patellofemoral indices during active quadriceps contraction. This medialization coincided with relief of recurrent dislocation. We believe LPE, which measures how much the patella overhangs the lateral femoral condyle, best reflects the clinical assessment of patellar tracking during critical ROM because the physician can observe the position of the patella relative to the lateral femoral condyle. This measure provides the surgeon with additional quantitative information that may be useful for surgical planning and preoperative and postoperative assessment.

Preoperatively, when the J-sign was present, LPD and LPE increased as the leg moved from 30° flexion to extension, suggesting the patella translated laterally near extension (Table 2; Fig. 4). Postoperatively, negative LPD values suggest the medial patellar edge actually moved medially in relationship to the medial femoral condyle (Table 2). Also, the more negative LPD values in addition to the nearly identical LPE measurement as the leg moves from 30° flexion to extension suggests the elimination of the J-sign, just as was noted in the postoperative clinical findings (Table 2).

One shortcoming of this quantitative measure is the difficulty identifying the apex of the anterior femoral condyle in patients with trochlear dysplasia, a common finding in patients experiencing patellar instability [10]. This difficulty is reflected by the poor interobserver reliability associated with the LPE measurement in this case. However, the high intraobserver reliability associated with the measurement suggests one observer can consistently locate what he or she believes to be the apex of the lateral femoral condyle (Table 1) [17].

Although the tibial tubercle was moved 22 mm intraoperatively by measuring from the edge of the tubercle to the edge of the bone cut, the postoperative TT-TG measurement, using MR images with the leg in full extension, shows only a 6.11-mm reduction (Table 2). The external

rotation of the tibia as the leg nears extension may provide a possible explanation for the difference between the intraoperative and postoperative TT-TG measurements [1, 13]. When the tubercle is moved medially, it creates a longer lever arm with the quadriceps tendon, increasing external rotation of the tibia and artificially increasing the TT-TG measurement although the patella falls within the trochlear groove. The inconsistencies in the intraoperative and postoperative TT-TG measurements have been investigated previously and may be at least partially attributed to correctly locating the depth of the sulcus in patients with trochlear dysplasia [10].

Movement of the patellofemoral joint is complex and dependent on a multitude of factors, including skeletal geometry, dynamic muscle action, and soft tissue restraints [7]. Because of this, proper clinical and radiographic evaluations of patellar tracking require observation during active quadriceps contraction [3, 9, 13]. Although many qualitative and quantitative techniques have been used to assess the patellofemoral joint, a strong correlation between specific qualitative or quantitative findings and restoration of stability and patient function has yet to be established. We propose the J-sign as a test to evaluate patellar tracking during active quadriceps contraction and introduce techniques to quantify that sign using established radiographic measures. The elimination of the J-sign and relief of symptoms after tibial tubercle transfer as described in this case report warrant further investigation of the utility of the J-sign in a series of patients with longer followup.

Acknowledgments We thank the University of Iowa Carver College of Medicine and the University of Iowa Hospitals and Clinics, Department of Orthopaedics, for the support and resources required to complete this study.

References

- Amis AA. Current concepts on anatomy and biomechanics of patellar stability. *Sports Med Arthrosc.* 2007;15:48–56.

2. Bellamy N, Buchanan WW, Goldsmith CH, Campbell J, Stitt LW. Validation study of WOMAC: a health status instrument for measuring clinically important patient relevant outcomes to antirheumatic drug therapy in patients with osteoarthritis of the hip or the knee. *J Rheumatol*. 1988;15:1833–1840.
3. Brossman J, Muhle C, Bull CC, Zieplies J, Melchert UH, Brinkmann G, Schröder C, Heller M. Cine MR imaging before and after realignment surgery for patellar maltracking: comparison with axial radiographs. *Skeletal Radiol*. 1995;24:191–196.
4. Davies AP, Costa ML, Shepstone L, Glasgow MM, Donell S. The sulcus angle and malalignment of the extensor mechanism of the knee. *J Bone Joint Surg Br*. 2000;82:1162–1166.
5. Dejour H, Walch G, Nove-Josserand L, Guier C. Factors of patellar instability: an anatomic radiographic study. *Knee Surg Sports Traumatol Arthrosc*. 1994;2:19–26.
6. Ebinger TP, Boezaart A, Albright JP. Modifications of the Fulkerson osteotomy: a pilot study assessment of the adequacy of tubercle transfer. *Iowa Orthop J*. 2007;27:61–64.
7. Feller JA, Amis AA, Andrich JT, Arendt EA, Erasmus PJ, Powers CM. Surgical biomechanics of the patellofemoral joint. *Arthroscopy*. 2007;23:542–553.
8. Laurin CA, Dussault R, Levesque HP. The tangential x-ray investigation of the patellofemoral joint: x-ray technique, diagnostic criteria and their interpretation. *Clin Orthop Relat Res*. 1979;144:16–26.
9. Lavery M, Bell J, Rickelman T, Boezaart A, Albright JP. Patellofemoral realignment: dynamic intraoperative assessment. *Iowa Orthop J*. 2005;25:160–163.
10. Lustig S, Servien E, Ait Si Selmi T, Neyret P. [Factors affecting reliability of TT-TG measurements before and after medialization: a CT-scan study] [in French]. *Rev Chir Orthop Reparatrice Appar Mot*. 2006;92:429–436.
11. McManus F, Rang M, Heslin DJ. Acute dislocation of the patella in children: the natural history. *Clin Orthop Relat Res*. 1979;139:88–91.
12. Merchant AC, Mercer RL, Jacobsen RH, Cool CR. Roentgenographic analysis of patellofemoral congruence. *J Bone Joint Surg Am*. 1974;56:1391–1396.
13. Powers CM, Shellock FG, Pfaff M. Quantification of patellar tracking using kinematic MRI. *J Magn Reson Imaging*. 1998;8:724–732.
14. Powers CM, Ward SR, Fredericson M, Guillet M, Shellock FG. Patellofemoral kinematics during weight-bearing and non-weight-bearing knee extension in persons with lateral subluxation of the patella: a preliminary study. *J Orthop Sports Phys Ther*. 2003;33:677–685.
15. Roos EM, Roos HP, Lohmander LS, Ekdahl C, Beynnon BD. Knee Injury and Osteoarthritis Outcome Score (KOOS): development of a self-administered outcome measure. *J Orthop Sports Phys Ther*. 1998;28:88–96.
16. Sasaki T, Yagi T. Subluxation of the patella: investigation by computerized tomography. *Int Orthop*. 1986;10:115–120.
17. Shoukri MM, Pause CA. *Statistical Methods for Health Sciences*. Ed 2. Boca Raton, FL: CRC Press; 1998.
18. Stanford W, Phelan J, Kathol MH, Rooholamini SA, el-Khoury GY, Palutis GR, Albright JP. Patellofemoral joint motion: evaluation by ultrafast computed tomography. *Skeletal Radiol*. 1988;17:487–492.