Functional Data for the Diagnosis of Patellofemoral Laxity Obtained by MRI During Quadriceps Isometric Contraction

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Abstract

Patellofemoral instability is related to anatomy. Magnetic resonance imaging (MRI) provides anatomic detail, but spoiled gradient echo (SPGR) imaging during isometric quadriceps contraction provides objective functional data for diagnosing patellofemoral laxity.

Knee MRI studies and medical charts of 398 patients were retrospectively reviewed. Two independent blinded observers evaluated the knee MRI studies for patellofemoral morphology and patellar position on axial SPGR images during relaxation and isometric quadriceps contraction for lateral patellar migration. Charts were reviewed for history of patellofemoral instability or dislocation. Patients were divided into 2 groups: group 1 comprised patients with 2.5 mm or more of lateral patellar migration on axial SPGR images, and group 2 comprised patients with less than 2.5 mm of patellar subluxation. Logistic regression models were used to determine relationships between patellofemoral subluxation of 2.5 mm or more and (1) history of dislocation or clinical patellofemoral instability, (2) grade 4 chondromalacia on MRI, (3) corrected central trochlear height, and (4) differential trochlear height (corrected for lateral condylar height). Statistically significant associations were found between patellar subluxation and each of the above 4 clinical/morphologic measures. Lateral patellar migration of 2.5 mm or more on SPGR obtained during quadriceps contraction had statistically significant associations with the above 4 measures.

Evaluation of SPGR of quadriceps contraction provides objective functional information about patellofemoral instability for management decisions.
Patellofemoral instability, generally applied to the spectrum from patellofemoral subluxation to frank patellofemoral dislocation, is a common musculoskeletal problem that may account for signs and symptoms in as many as 11% of patients presenting with anterior knee pain. A common symptom, anterior knee pain has many etiologies in addition to patellofemoral instability. Even a complete patellofemoral dislocation may be challenging to diagnose because few specific complaints follow spontaneous reduction. However, significant clinical sequelae include chronic patellofemoral malalignment, patellofemoral instability, and unicompartmental chondromalacia.

A battery of clinical tests is used to evaluate for patellofemoral instability. Occasionally, patellar laxity can result in lateral dislocation during passive lateral patellar excursion. The J sign describes visualization of abrupt medial excursion of the patella when the patient initiates knee flexion. More commonly, the patient experiences apprehension on manual lateral excursion of the patella.

Imaging is useful for morphologic characterization. Descriptions of trochlear and patellar morphology on radiographs and their relative associations with patellofemoral instability are well documented. Lateral and Merchant view (tangential) patella radiographs views are used for initial imaging evaluation. Axial computed tomography (CT) and magnetic resonance imaging (MRI) provide similar structural information. In particular, they have been used to measure the tibial tubercle–trochlear groove.

Because part of the physical examination entails functional analysis, imagers have tried to replicate functional analysis. However, imaging during stress loading is impractical because standardization is problematic and the time requirement is impractical in a busy practice. Axial CT imaging during isometric quadriceps flexion has been described, but radiation exposure is concerning because these patients are often children or young adults. Shellock et al. described a technique for dynamic assessment of patellofemoral motion using MRI. Axial gradient echo sequences were obtained during active knee flexion in the prone position within the confines of the bore. Although upright MRI units may afford a more physiologic assessment of the patellofemoral joint, these units are not available in most clinical practices.

Because assessment of patellar position during isometric quadriceps contraction has been shown to be valuable on physical examination, it may be valuable to apply this technique to MRI. Unilateral functional analysis during quadriceps relaxation and contraction can be completed at the conclusion of standard MRI with a minimal time investment and can provide objective morphologic and functional information for the orthopedic surgeon contemplating surgical management. Patellar migration during isometric quadriceps flexion can be detected with the patient supine, with knees neutral and flexed.

**MATERIALS AND METHODS**

Institutional review board review granted completion of this study with the provision of protected patient information, waiving the requirement for written consent. Magnetic resonance imaging records were sampled to identify 500 consecutive MRI knee examinations between January 1, 2001, and December 31, 2003, on patients older than 18 years seen by 1 orthopedist (P.T.) specializing in sports medicine. Repeat and postoperative examinations were excluded. Examinations with nondiagnostic axial views or omitting spoiled gradient echo images were excluded. This resulted in a study group of 398 patients.

Clinical charts were reviewed by 1 blinded observer (M.N.) for data, including patient age and sex. Indications for MRI were noted. Clinical history was reviewed for reports of anterior knee pain or history of patellofemoral dislocation. Physical examination findings including joint effusion, anterior knee pain, anterior crepitus, and reproducible lateral patellar subluxation or apprehension were recorded.

As part of the routine knee MRI protocol, 2 noncontrast-enhanced static axial MRI sequences were obtained on a 1.5-T system (Signa; GE Medical Systems, Milwaukee, Wisconsin) in a quadrature knee coil (GE Healthcare, Milwaukee, Wisconsin) in all cases. Spooled gradient echo (SPGR) images (slice thickness, 3.5 mm; gap, 0 mm; 256×128 matrix; average repetition time, 500 ms; echo time, 2.4 ms; flip angle, 20°; field of view, 14 cm) and T2-weighted fast spin echo images with fat saturation (slice thickness, 3 mm; gap, 0.5-mm; 256×160 matrix; average repetition time, 2200 ms; echo time, 68 ms; field of view, 14 cm) were reviewed. Prior to examination, the patient was instructed on how to complete isometric quadriceps contraction. As part of the routine MRI examination, without coil change, 6 axial SPGR images (slice thickness, 5 mm; gap, 5 mm; repetition time, 34 ms; echo time, 13 ms; flip angle, 40°; 256×128 matrix; field of view, 16 cm; time to acquisition, 17 seconds) were obtained through the trochlea and patella in the relaxed position. The patient was then instructed to begin and maintain isolated quadriceps contraction, and the sequence was repeated. Despite a decrease in contrast resolution, SPGR sequences were used to allow rapid imaging that would accommodate required sustained muscle contraction without pain or fatigue. Total image time for these 12 axial images was approximately 35 seconds.

Two observers (M.N., N.H.F) blinded to clinical information analyzed the patellofemoral joint for anatomical structure using the MPGR and T2 axial images; morphologic values and cartilage assessment were determined by consensus. Condylar height and central height at the trochlear apex were measured using the technique described by Biedert and Gruhl. On the
axial image providing maximum profile of the trochlea, a line was drawn connecting the posterior cortices of the femoral condyles. Perpendicular lines were drawn to the anterior apex of the medial and lateral condyles and the apex of the trochlear groove (Figure 1A). In addition, an attempt was made to normalize measures in light of potential bias based on individual structural variations by expressing condylar and central height as a percentage relative to maximum condylar diameter on the same axial image. To determine condylar width, the distance was measured between lines drawn from the perimeter of the condyles oriented perpendicular to the initial line drawn at the posterior condylar margin (Figure 1B). Corrected height was then calculated as trochlear or condylar height divided by condylar width. A differential trochlear height was also calculated (corrected lateral trochlear height minus corrected trochlear height) because an exaggerated lateral condylar height or trochlear depth may affect outcomes for patellofemoral instability.

To measure lateral patellar subluxation, the separation between perpendicular lines drawn from the trochlear apex and patellar apex relative to the posterior condylar line was calculated, and measures of 2.5 mm or more were recorded (Figure 1C). Numerical measurement techniques were validated by a third observer (L.M.L.).

The articular cartilage of the patella and trochlea was inspected on the axial T2 fat-saturated sequences for findings of chondromalacia according to the arthroscopic description of Outerbridge and the MRI correlation of Hayes: grades 0 and 1 represent normal and discolored or blistered cartilage; grade 2 shows thinning or fissures less than 50% thickness; and grades 3 and 4 are more severe injuries with more than 50% thickness signal or volume abnormality, but grade 4 also has subchondral bone marrow changes, including cysts or reactive edema (Figure 2; Table 1).

In addition to this structural analysis, spoiled gradient echo images during quadriceps isometric contraction and relaxation were evaluated for lateral patellar subluxation. Using the previously described method for determining perpendiculars for the trochlear and patellar apex, the position of the patella was compared during quadriceps relaxation and flexion, and the difference was calculated. Patellar lateral migration of 2.5 mm or

Table 1

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group 1</th>
<th>Group 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average age, y</td>
<td>43.65</td>
<td>42.53</td>
</tr>
<tr>
<td>Sex, % F/M</td>
<td>41.1/58.9</td>
<td>42.2/57.8</td>
</tr>
<tr>
<td>Knee laterality, % left/right</td>
<td>42.2/57.8</td>
<td>48.7/51.3</td>
</tr>
<tr>
<td>Average PF dislocation/instability, cm</td>
<td>0.14</td>
<td>0.06</td>
</tr>
<tr>
<td>Average chondromalacia grade</td>
<td>1.72</td>
<td>1.42</td>
</tr>
<tr>
<td>Chondromalacia grade 4, %</td>
<td>25</td>
<td>16</td>
</tr>
<tr>
<td>Average lateral condylar height, %</td>
<td>79.48</td>
<td>78.77</td>
</tr>
<tr>
<td>Average intercondylar height, %</td>
<td>72.20</td>
<td>70.97</td>
</tr>
<tr>
<td>Average medial condylar height, %</td>
<td>76.39</td>
<td>75.42</td>
</tr>
<tr>
<td>Average differential trochlear depth, %</td>
<td>7.29</td>
<td>7.80</td>
</tr>
</tbody>
</table>

Abbreviation: PF, patellofemoral.

*Positive magnetic resonance imaging findings of lateral patellar subluxation of 2.5 mm or more on quadriceps flexion.

*Negative magnetic resonance imaging findings of lateral patellar subluxation of 2.5 mm or more on quadriceps flexion.
more was considered positive, and these patients composed group 1 (Figures 3, 4). Group 2 comprised patients with patellar migration of less than 2.5 mm.

All numerical and categorical variables, including demographic variables such as patient age and sex, from the 398 patient records were examined. Descriptive statistics are summarized in Table 1. Logistic regression statistical models were used to investigate the following relationships: (1) association between positive patellar subluxation and a combined history of patellofemoral dislocation and clinical symptoms of instability; (2) association between clinical variables, including positive patellar subluxation and the presence of individual or grouped grades of chondromalacia; and (3) association between anatomic variables, including positive patellar subluxation and direct, corrected, or differential trochlear and condylar height.

**RESULTS**

Examinations for 398 patients were included for review. Ninety patients had positive lateral patellar migration of 2.5 mm or more on quadriceps flexion on MRI (group 1), and 308 patients had negative patellar subluxation on quadriceps flexion (group 2). Groups 1 and 2 were similar with regard to average age, sex distribution, and percentages of right vs left knee examinations (Table 1). No statistically significant differences were found in sex, age, and right vs left knee examinations with respect to MRI patellofemoral subluxation (Table 2).

A small number of patients had prior patellofemoral dislocation (n=6) or positive clinical examination for patellofemoral instability (ie, positive apprehension and mechanical laxity) (n=27). Therefore, these conditions were combined for the statistical analyses. Using logistic regression models, a statistically significant association was found between positive MRI patellar migration and a positive history of patellofemoral dislocation or instability. The odds of a positive MRI patellar migration increased 1.46 times when a positive history existed of patellofemoral dislocation or instability (P=.0206).

When assessed relative to structural anatomy, no statistically significant association was found between positive MRI patellar motion and the corrected lateral or corrected medial condylar height. However, a strong statistically significant association was found between positive MRI patellar motion and the corrected central trochlear height. The odds of a positive MRI patellofemoral subluxation motion increased 10.7% with each percent unit increase of the corrected trochlear height (ie, increased subluxation potential with decreased trochlear depth) (P=.0033). As a more accurate evaluation of relative trochlear depth, the differential measurement of the corrected lateral condylar height to the corrected central trochlear height was examined (ie, the corrected lateral height minus the corrected central height). A statistically significant association was found with this comparative measure. The odds of a positive MRI patellofemoral subluxation motion decreased 13% with each percent unit increase of the differential measure (P=.0281). In the assessment of the association between abnormal patellar motion and chondromalacia, groups 1 and 2 had av-

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**Table 2**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Log Odds</th>
<th>T-Stat</th>
<th>P</th>
</tr>
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<tbody>
<tr>
<td>Age</td>
<td>0.9975</td>
<td>-0.25</td>
<td>.8004</td>
</tr>
<tr>
<td>Sex</td>
<td>1.728</td>
<td>1.9</td>
<td>.058</td>
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<tr>
<td>Knee laterality</td>
<td>1.3211</td>
<td>1.11</td>
<td>.265</td>
</tr>
<tr>
<td>PF dislocation/instability</td>
<td>2.4659</td>
<td>2.31</td>
<td>.0206</td>
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<tr>
<td>Chondromalacia grade</td>
<td>1.1223</td>
<td>1.31</td>
<td>.1891</td>
</tr>
<tr>
<td>Grade 4 chondromalacia</td>
<td>1.9497</td>
<td>2.07</td>
<td>.0382</td>
</tr>
<tr>
<td>Corrected central trochlear height</td>
<td>1.1069</td>
<td>2.94</td>
<td>.0033</td>
</tr>
<tr>
<td>Differential trochlear depth</td>
<td>0.8799</td>
<td>-2.2</td>
<td>.0281</td>
</tr>
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</table>

Abbreviation: Log Odds, logit odds; PF, patellofemoral; T-Stat, t statistic.
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which calculates the relative lateral coil change and patient reposition.0382) (Table 2).

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Trochlear depth, orientation of the patellar facets relative to the trochlear apex, and position of the patellar apex relative to the trochlear apex are measured in the static position. The lateral view is used to determine patellar position using the method described by Insall and Salvati,11 and a method for measuring troclear depth on the lateral view has also been described.12 None of these parameters reflect the dynamic movement of the patella under the strong influence of quadriceps tension. The use of CT to define the bony anatomy at the patellofemoral joint has been described by Biedert and Gruhl.7 Extrapolated from the physical examination, patellar position is determined during quadriceps flexion and relaxation.7,13 However, CT is not sensitive enough for identifying many sources of internal derangement, including chondromalacia, limiting its use for routine imaging. Also, some methods of measurement are problematic, such as the method of Dejour et al,14 which calculates the relative lateral position of the tibial tubercle compared with the position of the point of maximum depth of the trochlea because leg orientation perpendicular to gantry is critical for this measure. Furthermore, radiation exposure, albeit a small dose, exists given the focused peripheral appendicular imaging.

Magnetic resonance imaging is routinely used for interrogation of joints for internal derangement. This modality excels for identification of specific abnormalities following patellofemoral dislocation, including tearing of the medial retinaculum and bone bruise or fracture of the medial patella and lateral femoral condyle. Abnormalities of the extensor mechanism, such as quadriceps or patellar tendinopathy and tear, are clearly depicted. Furthermore, its accuracy for documentation of higher grades of chondromalacia has been well documented.15,16 Finally, morphology of the patellofemoral joint, including trochlear depth, condylar height, and patellar congruence, can be characterized and measured using the standards from radiography and CT.29,17

As shown in the current study, comparison of patellar position on axial SPGR images of the patellofemoral joint during quadriceps relaxation to the position on isometric contraction can provide objective functional information about patellofemoral instability. The addition of this series to the standard imaging protocol of the knee requires less than 1 minute of imaging time. In contrast to a previously reported technique described by Shellock et al,4 coil change and patient repositioning, both of which contribute to increased imaging time, are not required. Also, the patient remains supine, avoiding the conflict of evaluating an anterior muscle or tendon system in the prone position.

Due to the small number of patients with documented patellofemoral dislocation, the current study did not have a sufficient sample size to evaluate the statistical significance of patellar subluxation on quadriceps contraction with a specific history of patellar dislocation. Therefore, it was elected to evaluate patients with confirmed dislocation in conjunction with those at potential risk (clinical instability) to achieve sufficient sampling, acknowledging that these populations may not be identical. However, when the number of confirmed dislocations is combined with the number of patients showing instability on clinical examination, the relationship to lateral patellar subluxation of 2.5 mm or more on isometric quadriceps contraction is statistically significant. In fact, the odds of a positive MRI quadriceps contraction study increased 1.46 times when a history of prior patellofemoral dislocation or a positive clinical history of patellofemoral instability existed, in contrast to patients without this history. Additional significant associations to patellofemoral migration on isometric quadriceps flexion are morphologic, specifically corrected trochlear height and differential trochlear height. This association is logical because shallow trochlear groove and deficient lateral condylar height have been previously shown to be risk factors for patellofemoral dislocation.12,14

The other statistically significant association is between grade 4 chondromalacia.
and patellar lateral migration of 2.5 mm or more on quadriceps flexion. If one accepts the premise that patellar maltracking predisposes one to chondromalacia development, using this additional sequence for routine knee interrogation identifies an at-risk population. Early intervention with quadriceps-strengthening programs and other conservative measures may improve the long-term course of these patients. An objective assessment of this nature could also be valuable for patients being considered for operative management, including tibial tubercle advancement and tubercle translocation.

Although retrospective, this preliminary investigation into the use of axial SPGR imaging of the patellofemoral joint during isometric quadriceps contraction provides information valuable for clinical management of patients who have chondromalacia patellae and patellofemoral instability on clinical examination. This study has the benefit of a large, diverse sampled population from a single sports orthopedist. At the same time, the broad patient group resulted in relatively few documented cases of dislocation. In addition, chart review for information beyond the image reference point was limited, and subsequent dislocations or patellofemoral complaints would not be recorded. A prospective study with a larger sampled population of confirmed patellofemoral instability patients is warranted.

CONCLUSION

Patellofemoral instability and patellofemoral maltracking are common problems in orthopedic practices, with short- and long-term consequences. Although clinical history and examination combined with radiography are most often used for evaluating this complex articulation, MRI is frequently added to the armamentarium. With less than 1 minute of additional imaging time, axial SPGR during isometric quadriceps contraction and relaxation provides objective functional information. A statistically significant association was found between lateral patellar subluxation of 2.5 mm or more and a history of patellofemoral dislocation or instability on physical examination and grade 4 chondromalacia. This is a means of providing objective functional information for the management of patients, whether in the form of training and physical therapy or operative intervention.

REFERENCES