Appendix

Clinical Tests Used to Classify Patellar Alignment

A number of tests have been described for the diagnosis of patellofemoral pain syndrome[21]; however, these tests are limited with respect to diagnostic accuracy, reliability, validity, and ability to predict the severity of the patellofemoral pain syndrome. Only five tests for patellofemoral pain syndrome have been described with respect to diagnostic accuracy (sensitivity and specificity) or cartilaginous changes in the patella[32,36]. Because of the low intrarater reliability of common clinical tests for assessing patellar alignment, several tests were used to determine group assignment[31].

The first group in our study comprised subjects with patellofemoral pain syndrome and clinical signs of patellar malalignment, defined as a history of patellar subluxation or dislocation and/or a positive result on one of the following clinical tests:

1. McConnell patellar glide test
   Subject positioning: Sitting with the femur supported on a plinth and rotated laterally.
   Instrument: None.
   Procedure: Patient performs an isometric contraction of the quadriceps muscle against the tester's manual resistance and holds it for ten seconds at five different angles of knee flexion (120°, 90°, 60°, 30°, and 0°). If there is pain at any of these angles, the tester passively returns the subject's knee to full extension and maintains passive support while pushing the patella medially. The medial glide is maintained while the knee is returned to the painful angle, and the subject performs the isometric contraction again.
   Interpretation: The test is positive if pain is decreased with passive medial glide of the patella.
2. Patellar apprehension test
   Subject positioning: Lying supine with the knee relaxed and positioned in 30° of flexion.
   Instrument: None.
   Procedure: The tester places his or her thumbs along the medial border of the patella and applies a laterally directed force.
   Interpretation: The test is positive if the subject looks apprehensive or resists the patellar movement.
3. Patellar tracking (compression) test
   Subject positioning: Lying supine with the knee in relaxed extension.
   Instrument: None.
   Procedure: The tester moves the patella proximally and distally while simultaneously compressing the patella against the femoral groove.
   Interpretation: The test is positive if painful.
4. Passive patellar tilt test
   Subject positioning: Lying supine with the knee in relaxed extension.
   Instrument: None.
   Procedure: The tester lifts the lateral border of the patella while maintaining the position in the femoral trochlear groove and visually estimates the angle.
   Interpretation: The test is positive if the angle is <10° for men or <15° for women.
5. Waldron squat test
   Subject positioning: Standing with the feet shoulder-width apart.
   Instrument: None.
   Procedure: The subject squats down fully (as far as possible) in a slow, controlled manner and slowly returns to standing while the tester palpates the patella.
   Interpretation: The test is positive if pain and crepitus occur at the same time during the movement. The subject is assigned to the first group if lower limb malalignment or catching of the patella is noted.

The second group comprised twenty subjects with patellofemoral pain syndrome and no clinical evidence of patellar malalignment, defined as no history of patellar subluxation or dislocation (as reported by the patient), a negative result on all of the first four preceding clinical tests, and a positive result on one of the following clinical tests:

1. Waldron squat test (see above)
   The subject is assigned to the second group if no malalignment or catching of the patella is noted.
2. Palpation of medial and lateral facets
   Subject positioning: Lying supine with the knee in relaxed extension.
   Instrument: None.
   Procedure: The tester displaces the patella medially and laterally in order to palpate articular surfaces with firm pressure.

Interpretation: The test is positive if pain is elicited.

3. Flexion test
   Subject positioning: Lying supine with the knee in relaxed extension.
   Instrument: None.
   Procedure: The tester passively flexes the patient's knee fully and holds that position for forty-five seconds.
   Interpretation: The test is positive if pain is elicited.

Magnetic Resonance Imaging Procedure

All images were acquired with a 1.5-T clinical scanner (Signa Echo Speed Plus LX System; General Electric Medical Systems, Milwaukee, Wisconsin) with the whole-body coil and a two-dimensional spin-echo imaging protocol using a variable bandwidth. The short-term reliability of this method was determined for a single experimenter replicating the method four times in the right knee of three healthy volunteers[18]. Within subjects, the mean error (and standard deviation) for patellar orientation ranged from 1.02° ± 0.40° for patellar spin to 1.4° ± 0.29° for patellar flexion. The mean error (and standard deviation) for patellar translations ranged from 0.32 ± 0.14 mm for anterior translation to 0.81 ± 0.37 mm for proximal translation[18]. Values for patellar motion measured with use of this magnetic resonance imaging-based method were compared with those measured with use of roentgen-stereophotogrammetric analysis of the same three cadaveric knee specimens, and the absolute mean error was <1.8° for patellar orientation and <0.9 mm for patellar translations[19].

The imaging parameters for acquisition of high-resolution images were: echo time, 6 ms; repetition time, 435 ms; field of view, 26 cm; slice thickness/spacing, 2/0 mm; slice number, 48; acquisition matrix, 512 × 256; and number of excitations, 2. The image acquisition parameters for the low-resolution scans were: echo time, 13 ms; repetition time, 555 ms; field of view, 32 cm; slice thickness/spacing, 2/5 mm; slice number, 15; acquisition matrix, 256 × 1285; and number of excitations, 1.

Hierarchical Linear Modeling

The first step of this process ("unconditional analysis") was to determine what order of model (e.g., linear or quadratic) best estimates the within-subject pattern of each component of patellar motion (intercept, instantaneous slope, and rate of change in slope) across the range of −4° to 60° of knee flexion. To optimize the confidence in the estimate of these parameters, the data were centered to 19° (all subjects had measurements around this angle, and this approximates the point at which the patella typically enters the trochlear groove). In separate tests, the kinematic data were centered to 5° of knee flexion to compare the patterns observed in the early range of knee flexion, and similar results were obtained (not shown). The second step ("conditional analysis") assessed the significance of predicted average differences in the intercept coefficient, the instantaneous slope coefficient, and the coefficient describing the rate of change of slope at the centered angle between the group with patellofemoral pain syndrome and clinical evidence of malalignment and the control group and between the group with patellofemoral pain syndrome and no clinical evidence of malalignment and the control group.

Hierarchical linear modeling is the appropriate statistical approach for comparing patterns of patellar motion because multiple measures are obtained through a range of knee flexion on a set of persons nested within groups. At Level 1, each subject's kinematic measures acquired at the different positions of knee flexion are considered to be nested within the person. The nesting of the multiple measurements enables the analysis of data points that may vary in spacing and number across subjects, which was the case in our study. The multiple measures are represented by an individual movement pattern that depends on a unique set of parameters. These parameters become the outcome variables in a Level-2 model, where they depend on the person-level factor, group (patellofemoral pain syndrome with clinical evidence of malalignment, patellofemoral pain syndrome without clinical evidence of malalignment, or control). Predictions about the pattern of patellar motion for individual subjects are anchored to the averaged fixed effects for the group—that is, if there are relatively few or highly variable data for a subject, the predicted pattern will be more influenced by the information for the whole group. We are therefore able to predict patterns of patellar motion across the entire range of knee flexion assessed for the groups with measures acquired at various angles and frequencies through that range. Similar hierarchical data structures are common in medical health research, but hierarchical analysis is not widely used for hypothesis testing. Unfortunately, there is no accepted, meaningful approach for calculating the power of a study to reject the null hypothesis when this type of statistical analysis is used. It is recommended that ten subjects per independent variable be recruited[34]. Therefore, twenty subjects per group is expected to be sufficient to ensure confidence that we had sufficient statistical power to detect differences in patterns of patellar motion between the groups with patellofemoral pain syndrome and the controls.