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Dynamic tracking influenced by anatomy in patellar instability

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ABSTRACT

Background: The current study was performed to correlate anatomical parameters related to trochlear dysplasia, tibial tuberosity position, and patella alta with in vivo patellar tracking for subjects with recurrent patellar instability.
Methods: Eight subjects with recurrent patellar instability that failed conservative treatment were evaluated using computational reconstruction of in vivo knee motion. Computational models were created from dynamic CT scans of the knee during extension against gravity. Shape matching techniques were utilized to position a single model of each bone (femur, patella and tibia) to represent multiple positions of knee extension. Patellar tracking was characterized by the bisect offset index (lateral shift) and lateral tilt. Anatomical parameters were characterized by the inclination of the lateral ridge of the trochlear groove, the lateral distance from the tibial tuberosity to the posterior cruciate ligament attachment (lateral TT–PCL distance), and the Caton–Deschamps index. Stepwise multivariable linear regression analysis was used to relate patellar tracking to the anatomical parameters at low ($<20°$) and high flexion angles.
Results: At low flexion angles, both lateral trochlear inclination and lateral TT–PCL distance were significantly correlated with bisect offset index ($p = 0.02$). Only lateral trochlear inclination was significantly correlated with lateral tilt ($p < 0.001$). At high flexion angles, bisect offset index and lateral tilt were correlated with only lateral TT–PCL distance ($p \leq 0.02$).
Conclusion: Parameters related to trochlear dysplasia and tibial tuberosity position were both related to patellar tracking, but the relationship changed with the flexion angle.
Clinical relevance: The anatomical parameters related to patellar tracking can be used to evaluate the risk of continued instability and guide surgical treatment.

1. Introduction

Patellar instability accounts for more than 10% of the office visits to musculoskeletal specialists [1]. While patients are initially treated non-operatively, the redislocation rate following conservative treatment is typically reported as greater than 40% [2–4]. Several surgical options are available to treat patients with recurrent instability, including medialization of the tibial tuberosity and reconstruction of the medial patellofemoral ligament. Several anatomical contributors to patellar instability have been identified, with limited information to date relating each parameter to lateral maltracking that can lead to instability. Improved understanding of the relationship between anatomy and patellar maltracking will help clinicians determine when surgical treatment is needed to stabilize the patella and select appropriate surgical approaches to alter the anatomical conditions contributing to instability.

The most commonly noted anatomical features related to patellar instability from radiographic studies are a lateralized tibial tuberosity [5–8], trochlear dysplasia [5,8–12], and patella alta [8,9,13]. A lateralized tibial tuberosity increases the lateral force acting on the patella from the patellar tendon. Patella alta increases the flexion angle at which the patella becomes captured by the trochlear groove. Trochlear dysplasia decreases the resistance to lateral tracking provided by the trochlear groove. Imaging studies performed with asymptomatic subjects and subjects with patellar pain with the knee positioned at various flexion angles have related increased lateral shift and tilt of the patella to patella alta [14–16] and trochlear dysplasia [15,17,18]. For subjects with patellar pain and instability, lateral position of the tibial tuberosity has been correlated with increased lateral patellar shift and tilt during dynamic motion [19, 20]. A study performed with knees experiencing instability statically positioned at multiple flexion angles indicated that trochlear dysplasia was the primary contributor to lateral patellar tracking, with lateral position of the tibial tuberosity a secondary factor [21]. The relationship between trochlear dysplasia and patellar tracking was particularly strong with the knee at full extension.

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The current study was performed to further investigate the influence of lateral position of the tibial tuberosity, trochlear dysplasia and patella alta on lateral patellar tracking related to patellar instability. All three anatomical parameters were related to dynamic patellar tracking for subjects being treated for instability. In addition, separate relationships between anatomy and tracking were established for low knee flexion angles, when the patella is not fully captured by the trochlear groove, and higher knee flexion angles, to determine if the relationship between anatomy and tracking varies throughout the flexion range.

2. Materials and methods

Computational reconstruction of in vivo motion was used to characterize the relationship between knee anatomy and patellar tracking. The study was approved by the Institutional Review Board (IRB) of the Johns Hopkins Medical Institutions. Eight subjects, four of them female, with recurrent lateral patellar subluxation or dislocation episodes were included in the study. All subjects were scheduled for surgical patellar realignment of the knee that was evaluated [22]. The average age ($\pm$standard deviation) for the subjects was 22 ± 6 years. Subjects with a previous tibial tuberosity realignment procedure were excluded from the study. Two subjects had a previous soft tissue patellar stabilization procedure. These were included based on the assumption that the soft tissue procedure had failed with continued instability.

Dynamic computerized tomography (CT) imaging (Aquilion ONE scanner, Toshiba Medical Systems, Tokyo, Japan) was utilized to capture in vivo motion at several knee flexion angles [22]. Subjects extended their knees against gravity as the rotating gantry acquired 21 volumes of 320 axial images (0.5 mm separation, 512×512 pixel in plane resolution) over 10 s. Models of the femur, tibia and patella were computationally reconstructed (3D Doctor, Able Software Corp, Lexington, MA) from five or six volumes that spanned the extension range and provided the clearest images. For each subject, all representations of the knee were aligned to the femur with the knee most extended by shape-matching the distal femurs with an iterative closest point algorithm [23]. The patella and tibia from the most extended position of the knee were copied and individually shape-matched to replace the corresponding bones from all other positions of knee flexion. Tibial shape-matching was based on only the proximal tibia since the length within the volume varied with the flexion angle. The transepicondylar axis and long axis of the femur were identified on the models to create a local femoral coordinate system [22]. A local coordinate system was similarly identified for the tibia to quantify tibiofemoral flexion [22] based on the floating axis convention [24].

Patellar tracking was characterized in terms of the bisect offset index and patellar lateral tilt (Figure 1) [14,16,21]. The bisect offset index quantifies lateral shift by the portion of the patellar width lateral to the deepest point of the trochlear groove. Lateral tilt measures the angle between a line along the medial–lateral axis of the patella and a line along the posterior condyles of the femur.

Anatomical parameters focused on the lateral position of the tibial tuberosity, trochlear dysplasia and patella alta. Lateral position of the tibial tuberosity was characterized in terms of the distance from the midpoint of the tibial tuberosity to the medial border of the posterior cruciate ligament attachment on the tibia (TT–PCL distance) [25,26]. The TT–PCL distance was used instead of the more commonly used tibial tuberosity to trochlear groove distance [19–21] to focus on the position of the tibial tuberosity without including variations in trochlear anatomy into the measurements. For the current study the parameter was modified from measurements described for clinical use to characterize the distance in the lateral direction with respect to the femur (lateral TT–PCL distance), as opposed to the fixed distance along the medial–lateral axis of the tibia, thereby allowing for variations in the measurement with rotation of the tibia as the flexion angle changed. Trochlear dysplasia was characterized based on the lateral trochlear inclination, the angle of the lateral ridge of the trochlear groove with respect to the posterior condyles [15,21,27,28]. Patella alta was characterized based on the Caton–Deschamps index, the ratio of the distance from the distal point of the patellar cartilage to the anterior–superior border of the tibia to the articular length along the patella [9,14,21].

At each flexion angle, the lateral direction was established along the posterior condylar axis of the femur within a plane perpendicular to the long axis of the patella (Figure 1). The medial–lateral axis of the patella was identified from the most medial and lateral points on the patella. The other landmarks identified on the patella were the proximal and distal extents of the articular surface. On the tibia, the anterior–superior border, the medial border of the PCL attachment, and the center of the tibial tuberosity were identified. The medial border of the PCL attachment was identified with a landmark posterior to the medial intercondylar tubercle at the medial edge of the PCL fossa. The deepest point of the trochlear groove and the most prominent point of the lateral trochlear ridge varied with knee flexion and were quantified using an automated algorithm (Matlab, MathWorks, Natick, MA). To select points within the trochlear groove that were engaged with the patella, the most prominent lateral point was taken within the region from

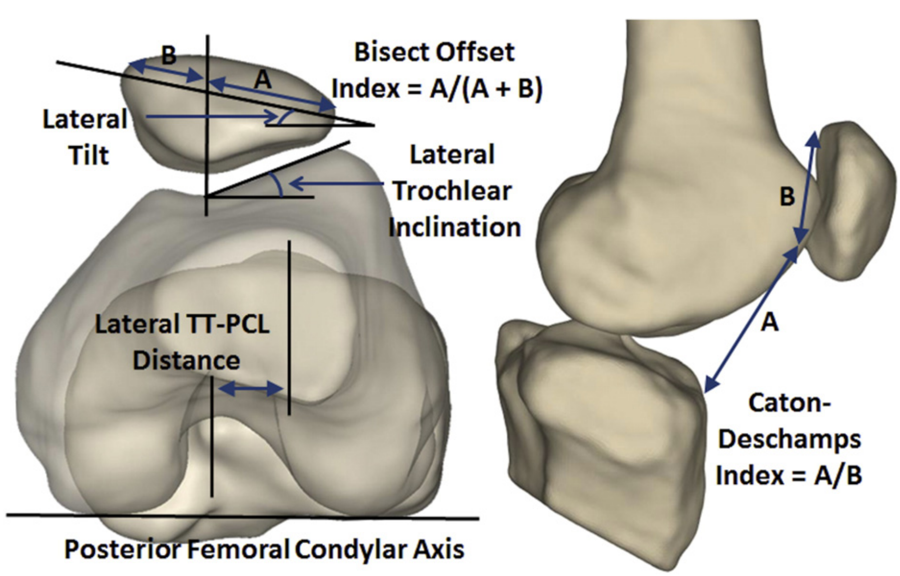

Figure 1. Schematic diagram showing the measures of patellar tracking and anatomy quantified from the computational models.