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Author

Charles, Michael

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MRI Based Topographical Differences between Control and Recurrent Patellofemoral Instability Patients

Michael Charles MS-IV, Sean Haloman MD, Lina Chen MD, Sam Ward PhD, Don Fithian MD, Robert Afra MD

ISP Project UCSD SOM

Abstract

Summary**:** MR imaging reveals significant topographical differences between controls and patients with patellofemoral instability with greater differences at the proximal trochlea and dysplasia of the condyles.

Objective: Plain films and CT based imaging were the first to establish measurements that evaluated patellar instability. Limited research has shown MRI's efficacy in evaluating these established measurements. The aim of this study is to identify morphological differences between normal knees and those with patellofemoral instability on MR imaging in order to determine what measurements are significant and the value at which each measurement signifies pathology.

Methods: Retrospective review of 81 patients with no history of patellofemoral joint pathology and 40 patients with recurrent patellar instability. Controls had no present symptoms or history of patellofemoral complaints and an exam negative for patellar grind, facet tenderness, and apprehension. Patients with patellar instability had a history of at least 2 frank patellofemoral joint dislocations (PFJD). MRI images were obtained with the knee in non-weight bearing and in full extension. Measurements of patellar tilt, trochlear morphology, and Tibial Tuberosity-Trochlear Groove (TTTG) distance were evaluated on axial slices and patellar height was measured on sagittal images. Trochlear morphology was assessed at the proximal (1^{st} cut) and distal (2^{nd} Cut) trochlea.

Results: All measurements of patellar tilt were found to be significantly different between the two groups and reflected an increase in the lateral rotation of the patella in patients with instability. For patellar height, only Insall Salvati (control: 1.08 ± 0.02; PFJD: 1.26 ± 0.03) and Caton Deschamps (control: 1.13 ± 0.02; PFJD: 1.29 ± 0.03) ratios proved to be significantly different. Trochlear morphology had numerous measurements prove to be significantly different proximally and distally. These included classic measurements like sulcus angle (control: 148.48° ± 0.94°; PFJD: 165.57° ± 2.65° at 1^{st} cut) and lateral trochlear inclination (control: 21.27° ± 0.66°; PFJD: 13.31° ± 1.36° at 1^{st} cut) and less established measurements like ETIT (control 1.51 ± 0.05; PFJD: 2.11 ± 0.17), a measurement of facet asymmetry. The difference between Controls and PFJD's was greater on average at the proximal trochlea.

Conclusions: Patellar tilt measures, such as Angle of Fulkerson, proved to be an excellent group of measurements for delineating between controls and those with instability. Patella alta ratios, such as Insall-Salvati and Caton-Deschamps, demonstrated statistically significant difference between normal and recurrent dislocators. Trochlear morphology measures such as Sulcus Angle, trochlear groove depth, and lateral trochlear inclination demonstrate statistical significance. Our findings of significant morphological differences between controls and PFJDs demonstrates that MRI may be appropriate to help discern recognized pathology that characterizes recurrent patellofemoral dislocation patients.

Introduction

While patellofemoral syndrome comprises 25% of patients presenting to sports medicine clinics[1], a lesser-understood subgroup of these patients are those with patellofemoral instability. This category includes those patients who experience frank dislocations and those who experience symptoms of subluxation. Incidence rates of pure dislocations have been calculated at 5.8 per 100,000 in younger age groups[2]. Factors that influence patellofemoral instability can be divided into four categories: (1) ligamentous stabilizers such as the medial retinaculum and patellofemoral ligament; (2) limb geometries in the axial plane (e.g. TTTG); (3) patellar height (the vertical position of the patella relative to the trochlea) with ratios like Insall-Salvati; (4) and trochlear morphology (e.g. trochlear depth and sulcus angle)[3-8].

Diagnosis of patellofemoral instability is difficult because patellar instability, patellofemoral pain, meniscal and cruciate insufficiency can produce a similar presentation[1, 9] thus careful examination and imaging are helpful in making the correct diagnosis. Accurate diagnosis is crucial since 15- 49% of patients who presented with primary dislocations may go on to have subsequent dislocations[2, 10], which has prompted some to recommend surgical interventions at initial presentation[11]. In addition to the history, common physical exam findings include the evaluation of limb alignment, patellar tilt, crepitus, patellar tracking, tenderness, apprehension, and laxity[5]. Imaging is another component to the diagnosis of patellofemoral instability. Fithian *et al.* demonstrated that recurrent dislocators had specific factors like smaller angles of Laurin (which is the angle formed between a line tangential to the most anterior aspects of the femoral condyles and a line tangential to the lateral facet of the patella. A smaller angle of Laurin demonstrates lateral rotation of the patella along in its cephalad-caudal axis) and larger lateral patellar overhang on imaging at the time of their first dislocation[2]. Historically, plain radiographic imaging and subsequently CT has dominated the clinician's attention regarding the evaluation of the patellofemoral joint. More recently, MRI has gained a more prominent role in the imaging armamentarium for patellofemoral instability because it gives the clinician the ability to visualize the cartilaginous articular surfaces in addition to the bony alignment observed on x-ray and CT.

Patellofemoral instability is a problem orthopedic surgeons have tried to address as early as Albee in 1915[6]. Merchant helped visualize the patellofemoral joint in 1974 with patient's knee flexed at 45° and the camera angled at 30°[12]. Dejour *et al.* utilized lateral radiographs to analyze osseous femoral morphology (i.e. trochlear dysplasia) to classify trochlear dysplasia into 4 types (I-IV) based on radiographic findings of the crossing sign, trochlear bump > 3 mm, and of trochlear depth <4 mm[6, 10]. Radiographic and CT based standard values for the patellofemoral joint are well established. Measurements of trochlear morphology such as lateral trochlear inclinination <11°, sulcus angle >145°, and trochlear groove depth < 4 mm are well documented cutoffs[5, 6, 10, 13]. Limb geometry evaluation with measurements like TTTG distance which was first established by *Judet et al.* have proven useful for evaluating patients with instability. A TTTG value greater than 20 mm is considered pathologic[6, 7]. Standards for Caton-Deschamps and Insall-Salvati ratios indicative of *patella alta* are based on either plain films or CT imaging[6, 14, 15]. Despite its limitations in capturing soft tissues, CT has classically been used to evaluate the non-osseous or cartilaginous stabilizers of the patellofemoral joint through patellar tilt[6, 8, 16-18].

More recently, research has started to implement MR imaging in the analysis of patellofemoral instability. MRI's ability to clearly show the articular cartilage improved the clinician's understanding of severe cartilaginous pathology that was not brought to light with previous radiographic studies [4, 19, 20]. Recent articles have highlighted discrepancies with previously established CT and radiographic cutoffs and tested MRI's reliability in evaluating the patellofemoral joint[4, 14, 21-26].

Currently, there is a limited amount of research applying MR imaging to patellofemoral instability. The purpose of this study is to identify key morphological differences between normal knees and those with recurrent patellofemoral instability and to provide a range for normal and abnormal knees. We anticipate that MRI based patellofemoral measures that involve trochlear height, depth, or angle will be altered somewhat (given that the measures will based on cartilage contour instead of subchondral bone contour), while measures that do not involve the trochlear or patellar chondral surface will not be affected to any significant degree when compared to XR/CT based values.

Methods

The study was a retrospective review of patients' charts and MRI images from UC San Diego and Kaiser San Diego databases between 2006-2010. In total 126 patients were initially selected for the study by chart review, however five patients were later excluded due to the absence of readable MRI images on file. 81 patients were collected as Controls who presented to the UCSD Sports Medicine clinic for knee complaints. Patients categorized as a control had no present symptoms or history of patellofemoral complaints and an exam negative for patellar grind, facet tenderness, and apprehension in their medical records. 40 patients with recurrent patellar instability based on history and clinical examination were collected. UCSD patients were obtained through a chart review of patients presenting to the Sports Medicine Clinic between January 2006 and January 2010 with associated diagnosis of patellofemoral instability. Kaiser patients were obtained through a review of operative records at Kaiser Foundation Hospitals of San Diego for the period from March 2008 through March 2010. Patients with patellar instability must have a history with at least 2 frank patellofemoral joint dislocations (PFJD).

MRI images were obtained with a non-weight bearing knee in full extension with a relaxed quadriceps. Patellar tilt was evaluated on axial slices and patellar height was measured on sagittal images. Trochlear morphology was assessed on axial images at the proximal and distal trochlea. The proximal trochlea (1st cut) was established at the slice in which trochlear articular cartilage spans the entire trochlear surface and in contact with the patella. The distal trochlea (2nd Cut) was established at the point with the greatest epicondylar width. In total 44 measurements were collected for each patient: these measures included variations on patellar height, patellar alignment, trochlear morphology, limb geometry, and others. The measurements were made to include articular cartilage: description of these measures can be found in **Table 1 and Figures 1-4**. A musculoskeletal radiologist collected the measurements for the initial ten Controls and five PFJD patients; the remaining measurements were collected by two medical students. Inter-observer variation was controlled by having the students periodically compare measurements on same patient. These measurements were also crosschecked with the senior researcher throughout the collection process. In order to minimize any inter-observer variability we required angular measures to be within 2° of each other and length measures to be within 10% of each other. The data then underwent basic statistical analysis with student t-tests to establish means, SD, significance, and confidence interval calculations.

Statistical Analysis

Our data was analyzed using SPSS (Version 19.0, Armonk, NY) using independent student T-tests for each groups means, standard deviation, error, and confidence intervals. Significance was set a p-value of < 0.05.

Results

Of the 81 Controls and 40 PFJDs some measurements were unobtainable due to location of slices on MR imaging. This was most prevalent in the patellar height measurements, which only allowed us to collect 34 PFJDs for those measurements. There was also difficulty obtaining the transepicondylar width for the initial patients collected by researcher L.C. This resulted in all of our measurements requiring transepicondylar width to have only 71 Controls and 35 PFJDs. Two of the PFJDs lacked adequate coronal images for condylar height, as result only 38 patients had those measurements. The number of patients undergoing each measurement is listed in **Table 2.**

All measurements are listed in **Table 3.**

Patellar Tilt: All patellar tilt measurements were found to be significant between the two groups. Angle of Laurin (Controls 10.10° ± 0.48°; PFJDs -5.23° ± 2.96°; p < .001) and Angle of Fulkerson (Controls 18.18° ± 0.56°; PFJDs -3.5° ± 2.62°; p < .001) are examples of classic measures that were found significant. As with all the measurements of patellar tilt, these angles reflect that patients with patellofemoral instability had an increase in the lateral rotation of the patella around its superior to inferior pole. The lateral displacement of the patella (Controls 3.28 mm ± 0.24 mm; PFJDs 6.59 mm ± 0.69 mm; p < .001) was also significant.

Patellar Height: Patellar height has been researched extensively and repeated in reviews with a variety of measurements[3, 5-7, 14, 23, 27-29], yet our research found significance only with the Insall-Salvati Ratio (Controls 1.08 ± 0.02; PFJDs 1.26 ± 0.03; p < .001) and the Caton-Deschamps Ratio (Controls 1.13 ± 0.02; PFJDs 1.29 ± 0.03; p < .001). The remaining measurements lacked both non-overlapping confidence intervals and p values <0.05.

Trochlear Morphology: Numerous measurements of trochlear morphology proved significant at the proximal and distal trochlea. At the proximal trochlea (1st Cut) significant measurement included classic measurements like Sulcus Angle (Controls 148.48° ± 0.94°; PFJDs 165.57° ± 2.65°; p < .001) and Lateral Trochlear Inclination (Controls 21.27° ± 0.66°; PFJDs 13.31° ± 1.36°; p < .001). But lesser known measurements like ETIT (Controls 1.51 ± 0.05; PFJDs 2.11 ± 0.17; p < .001), which is a measurement of facet asymmetry, were also found to be significant. Lateral Condylar Height(LCH) was the only condylar height measurement found to be significant at the proximal trochlea. The other condylar height measurements, including those expressed as a percent of epicondylar width, often had adequate p-values, but lacked adequate separation of their confidence intervals.

A greater proportion of measures at the distal trochlea demonstrated significance, though the difference between the means was often larger at the proximal trochlea. Interestingly, Lateral Condylar Height lost significance at the distal trochlea (p = 0.643). Also worth noting is that while all initial condylar height measurements lacked significance at the distal trochlea, when adjusted for epicondylar width they all proved significant. For example, LCH as a percent of epicondylar width had a mean of 81% ± 1 for Controls and 88% ± 1 for PFJDs.

Transepicondylar width demonstrates significant difference between groups (Controls 71.00 mm ± 0.76 mm; PFJDs 75.23 mm ± 0.95 mm; p < .001). The Trochlear Groove Thickness was not significant at either point along the trochlea.

Limb Geometry and Other Measures: Among the coronal and limb geometry measurements, only the Varus-Valgus and TTTG proved to be significantly different between the two groups. Varus-Valgus, which is anatomic alignment, had means of 5.45° ± 0.29° for Controls and 10.02° ± 0.53° for PFJDs (p < .001). TTTG (Controls 10.96 mm ± 0.39 mm; PFJDs 18.69 mm ± 0.81 mm; p < .001), was significant and corresponds to CT based values[6, 7].

Discussion

Axial radiographs and CT imaging of the patellofemoral joint is well documented and is the basis for many of our current diagnostic measurements. MR imaging has the distinct advantage of revealing chondral morphology, which more accurately depicts the patellar-trochlear relationship in comparison to subchondral bone morphology[4, 19, 20]. Recent MR-based studies have begun to show that previously established pathological cutoffs for those with patellofemoral instability, sulcus angle for example, are not exactly the same when applied to MRI[4, 21], while other measurements like Trochlear Groove Depth have remained similar[14, 21, 24]. Given these mixed results, one could question the reliability of applying current normal versus abnormal values to MRI measurements. Authors like Miller and Smith, however, have shown the reliability of MRI in performing many of the established measurements[23, 30]. Our research shows how these classic measurements change while some remain the same when applied to MR imaging.

Previous authors have utilized MR imaging to perform measurements of patellar tilt[14, 26]. Patellar tilt proved to be an excellent group of measurements for delineating between controls and those with instability. The confidence intervals between the two groups were separated by at least 5° for each measurement. For the Angle of Fulkerson the means of 18.18° ± 0.56° and -3.5° ±2.62° for Controls and PFJDs respectively support the established cutoff of <8° for pathology established by Schutzer *et al.*[31]. Patellar Inclination Angle is another well-studied measurement. Our means of 8.10° ± 0.55° for Controls and 24.03°± 2.42° for PFJDs differed from Dejour *et al.* (10° ± 4.3° vs. 16° ± 3.3°) CT based study[6]. Our results were very similar, however, to those by Escala *et al.* whose MRI based study found means of 9.2 and 21.7 for Controls and PFJDs respectively[14]. This is an interesting result as patellar inclination angle would not be predicted to change between CT and MR imaging as articular cartilage is not involved in its measurements. For the Angle of Laurin our results (Controls 10.10° ± 0.48°; PFJDs -5.23° ± 2.96°) again differed from Biedert's CT based study with means of -0.1° and -3.1°[13]. The Angle of Laurin relies on the articular cartilage both on the trochlea and the patella; thus this difference is to be expected. As mentioned earlier, all our measurements reflected an increase in the lateral tilt of the patella among PFJD compared to Controls. The increase in lateral tilt could be due to laxity of medial soft tissue structures, specifically the medial patellofemoral ligament (MPFL)[7]. Biedert *et al.* indirectly showed that even a weak vastus medialis could contribute to an increase in lateral tilt by demonstrating a difference in patellar angles with and without active quadriceps contraction[13].

The significance of *patella alta* is that an elevated patella will not engage the bony architecture of the proximal trochlea that is necessary to prevent lateralization of the patella. Patellar height, demonstrated limited success in terms of finding significant differences. One could assume that MRI inclusion of articular cartilage would make some of these measurements unreliable, however Miller *et al.* demonstrated that patellar height measurements could be reliably recorded on MRI[23]. The Insall-Salvati Ratio has a well-documented pathological value of >1.2 for *patella alta* based on XR measures[32]. Our means of 1.08 ± 0.02 for Controls and 1.26 ± 0.03 for PFJDs follows this initial cutoff. Our findings are also similar to what Escala *et al.* found in their MRI based study (1.11 and 1.35)[14]. Caton-Deschamps Ratio was the only other patellar height ratio found to be significant. Our means of 1.13 ± 0.02 and 1.29 ± 0.03 for Controls and PFJDs again reflect the standard cutoff of >1.2 significant for *patella alta*[6, 15].

Trochlear morphology was the main focus of our research and yielded some very interesting results. Our Sulcus Angle means 148.48° ± 0.94° (Controls) and 165.67° ± 2.65° (PFJD) reflect a difference from the classic cutoff of 145°[5, 6, 10, 13]. While they do reflect an increase in the angle, likely due to inclusion of articular cartilage, our patellofemoral instability patients did not have quite as large sulcus angle as found by Van Huyssteen *et al.* and Ali *et al.* Van Huyssten's group showed cartilage based mean sulcus angles of 186.5°[4] while Ali *et al.* published angles of 173°[21]. These differences could be attributed to a difference in the location where the measurement was made: Van Huuyssteen *et al.* made their measurements within 3 mm of the start of articular cartilage and Ali *et al.* based their location on the portion with the greatest ventral prominence. It should be noted that the sulcus angle means at our distal trochlea were closer to the classic cutoff. But since the initial cutoff was established on a Merchant view of the knee, one can see how the values may vary. Trochlear Groove depth is another classic measurement with a cutoff of < 4mm being pathological for patellofemoral instability[6]. Other authors have reported that MRI based trochlear depth measures have not varied much from the initial CT or X ray values[14, 21, 24]. Our means of 6.47 mm ±0.24 mm for Controls and 4.00 mm ± 0.43 mm for PFJDs at the proximal trochlea differ from the classic cutoff but prove similar to the results of Escala *et al.*[14]. This could be a result of better visualization of the articular cartilage but other MRI studies have actually reported means less than 3 mm for patients with patellofemoral instability[21, 24]. The means of trochlear groove depth at the distal trochlea of our patients were nearly equal to those at the proximal trochlea.

Lateral trochlear inclination is another measurement of trochlear morphology prevalent in patellofemoral literature[9, 20, 21, 33, 34]. These studies have primarily been performed in MRI based studies, with Carrillon *et al.* establishing the cutoff between controls and those with patellar instability at 11°[9]. This value is lower than our means of 21.27° ± 0.66° and 13.31° ± 1.36° at the proximal trochlea and 21.74° ± 0.52° and 15.95° ± 0.85° at the distal trochlea. Salzmann *et al.* had values closer to ours, but their research was based on patients selected on a radiographic criteria of trochlear dysplasia[20]. Carrillon's research was similar to our own in that patients were selected on basis of a history and physical examination consistent with patellofemoral dislocations. Carillon *et al.* also performed the measurements at the most proximal slice with complete articular cartilage. Our data still reflects the trend that a decrease in LTI results in less resistance to the lateralization of the patella, which increases chances of patellar instability.

Facet asymmetry is an aspect of trochlear dysplasia that has had very limited research until recently. This has mostly been studied in MRI based studies[20, 24]. Pfirrmann *et al.* first showed that a facet ratio greater than 5:2 (lateral to medial) could identify those with trochlear dysplasia with sensitivity and specificity of 100% & 96% (Pfirrmann *et al.* project was published with a facet ratio of less than 2:5, medial to lateral. We inverted this ratio to correspond to our lateral to medial ratio of ETIT). We found our means of 1.51 and 2.11 at the 1st cut and 1.40 and 1.97 at the 2nd cut for Controls and PFJDs respectively to be lower than the two and one half cutoff Pfirrmann documented. This difference may be due to difference in patient selection in that ours were selected on criterion of patellar dislocation, while Pfirrmann *et al.* divided patients based on radiographic evidence of trochlear dysplasia. Salzmann *et al.* also researched facet asymmetry in comparing axial radiographs to MRI. Their research did not find significance for the measurement, but their means for MRI saw the facet ratio increase from 1.6 to 1.9 as the degree of dysplasia increased[20]. This makes our research unique in that it was the first application of facet asymmetry in the clinical context of patellar instability.

Condylar height has thus far had limited research and it has lacked any clear answers. Escala *et al.* evaluated lateral, medial, and central condylar height measurements but none were found to be significant between controls and those with patellar instability[14]. Our data demonstrated that only LCH proved significantly different at the proximal trochlea (Controls 63.94 mm ± 0.61 mm; PFJDs 59.69 mm ± 0.89 mm), and none of our measurements at the distal trochlea proved significantly different. Interestingly, we also evaluated condylar heights as a proportion of epicondylar width as Biedert *et al.* published in 2009[35]. At the distal trochlea, despite having no significance with our standard condylar heights, all three condylar heights expressed as a percent of epicondylar width proved significant. Biedert's published means for LCH (Controls 81%; PFJDs 82%), Central Condylar Height (CCH) (Controls 73%; PFJDs 77%), and Medial Condylar Height (MCH) (Controls 76%; PFJDs 79%)[35]. Biedert's results proved similar to our own at the lateral condyle of the distal trochlea, but our groups differed at the central and medial condyle. Biedert *et al.* and our group, however, did find a larger difference between the Normal versus PFJD groups with the medial and central condylar heights than at the lateral condyle. The discussion of which condylar measurement is ideal for evaluating patellar instability is still muddled. While our standard measurement of the lateral condyle supports its biomechanical role in resisting lateral displacement of the patella, the significance of the central and medial condyles may reflect a lack of condylar development or failure to form trochlear groove. We find the use of the ratio of condylar height to Transepicondylar Width presents difficult to justify. The Transepicondylar Width mean of 71.00 mm ± 0.76 mm (control) is statistically different from the mean of 75.23 mm ± 0.95 mm (PFJD). This could explain the why our standard condylar measurements at the distal trochlea only became significant when expressed as a percent of Transepicondylar Width. Also, despite the increase in width and the decrease in condylar height when comparing controls to PFJDs, the measurements of percent of Transepicondylar Width were higher amongst patients with patellar instability. Therefore, inclusion of these condylar height ratios is inappropriate for evaluating patellofemoral instability from our standpoint.

The greater separation of means at the proximal trochlea does support the importance of the proximal trochlea in stabilization of the patella. Given that our standard error and confidence intervals were also larger, however, these results could also be due to a greater variation of the proximal trochlea.

Varus-Valgus is a measurement on coronal images that relies on the femoral and tibial axis. Q-angle can be found in countless literature reviews implicating its significance of this measurement with a cutoff of 10° with patellofemoral pain and instability[1, 10, 15, 36, 37]. It is interesting that despite being based on different anatomical structures our data reflects some parallels with this classic measurement as the Controls had a mean of 5.45° ± 0.29° and the PFJDs had a mean of 10.02° ± 0.53°.

TTTG has been well researched in patients with patellar instability since Judet *et al.* first established the measurement[5-7, 22, 25]. Researchers have had mixed results regarding the validity or reliability of MRI based TTTG measurements compared to CT[22, 25]. Our means (Controls 10.96 mm ± 0.39 mm; PFJDs 18.69 mm ± 0.81 mm) reflect the cutoff of 20 mm for certain pathology[6] and increase likelihood of instability in those with 15-20 mm[7]. TTTG is a measurement that is classically based in axial radiographs and CT scans, but as Schoettle *et al.* demonstrated, this measurement can reliably be applied to MRI[25] with similar cutoffs. Our research further corroborates this.

Our study had both strengths and weaknesses. A major strength of our study is the population size. Only five other studies on patellofemoral instability have had as many or more patients than our study[2, 6, 14, 26, 35], and one study was CT based studied. Another strength was that our location of measurements was based on morphological features. Unlike Pfirrmann *et al.* who performed their measurements at set distances from the joint line[24], our measurements will not vary from patient to patient by being at a fixed distance. This is particularly important at the proximal trochlea, because our location pinpoints the starting point between trochlear and patellar articular surfaces.

In terms of weaknesses some arose from one of our project's greatest strength, its size. In collection of the patients our MRI imaging protocol was not as precise resulting in some patients lacking the adequate slices to make proper measurements. This problem however could also be attributed to the patient population as patients with patellofemoral instability often have patellar mal-alignment. An increase in the lateral displacement of the patella could explain while patellar station measurements were most affected. Future projects should include a stricter protocol to ensure the sagittal images are true sagittal images increasing our chances of obtaining proper measurements. While we tried to account for the multiple researchers collecting data through routinely checking measurements on the same patient, one way we could have improved our study is to perform a statistical analysis of inter-observer and intra-observer variations. It would also have been ideal to have blinded the researchers making the measurements in order to prevent bias. Finally, by having controls selected from patients at the sports medicine clinic, our controls often had other knee pathology including meniscal and cruciate ligament tears. While these patients lacked any history or clinical signs of patellofemoral instability, this does not exclude them possibly having abnormal patellofemoral morphology.

An arguable simultaneous strength and weakness of the study is that our patients had their imaging performed with a straight leg without engagement of the quadriceps. While Ward and Biedert demonstrated active quadriceps contraction can be applied to these studies[3, 13] our goal was to create values that the everyday physician could utilize without concern for strict parameters. Many of these measurements of patellar angle, tilt, and trochlear morphology were originally obtained with the knee in various degrees of partial flexion. Our results demonstrate that with MR imaging a doctor could reliably discern between a patient who has patellar instability and one with normal knees.

Conclusion

By detecting significant morphological differences between the two groups these results justify that MRI could be used to obtain many of the measures of patellofemoral instability historically obtained with CT scan and plain radiographs. In fact, measures of all the four recognized factors of patellar instability were found significant. This demonstrates that patellofemoral instability is a result of multiple factors, with instances of some small changes over many measurements or a large change in a few key measurements. Patellar tilt measures, such as Angle of Fulkerson, proved to be an excellent group of measurements for delineating between Controls and those with instability. Patella alta ratios, such as Insall-Salvati and Caton-Deschamps, demonstrated statistically significant difference between controls and recurrent dislocators that coincided with established CT cutoff. Trochlear morphology measures such as Sulcus Angle, trochlear groove depth, and lateral trochlear inclination demonstrate statistical significance, though Sulcus Angle and Lateral Trochlear Inclination did differ from established values. The next logical step is to pursue statistical analysis of our data to create established cutoffs for MRI as previous groups have with CT and XR and apply them to prospective trials in order to establish which measurements remain a reliable delineator between normal knees and those with patellofemoral instability. By replacing the need for CT, the recurrent patellofemoral patient is exposed to significantly less radiation while providing a more detailed analysis of the articular surface of the patellofemoral joint and the soft tissue constraints involved in its stability. As such, MRI is an appropriate tool to aid the clinician in obtaining the radiographic information that would have been obtained by CT scan in patients with recurrent patellofemoral instability.

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Table 1

Measurement	
Transepicondylar Width	Length of a straight line parallel to the horizontal axis from the most medial to most lateral aspect of the femur at the 2nd cut.
Patellar Angle	
Angle of Fulkerson	Line 1 is drawn across the posterior margins of the medial and lateral condyles, and line 2 is drawn along the lateral facet of the patella. The angle between the two lines is PTF.
Angle of Grelsamer	Line 1 is drawn to be parallel to the horizontal axis. Line 2 is drawn through the transverse the axis of the patella. The angle between the two lines is PTG. A positive angle is designated as one that opens up to the medial
Angle of Laurin	Line 1 is drawn to be across the anterior margin of the medial and lateral trochlea. Line 2 is drawn tangential to the slope of the lateral facet of the patella. A positive angle is one that opens up to the laterally
Patellar Inclination Angle	Line 1 is drawn across the posterior margins of the medial and lateral condyles, and line 2 is drawn through the transverse the axis of the patella. A positive angle is designated as one that opens up to the medially.
Lateral Patellar Displacement	This is the shortest distance between the lateral margin of the trochlea and the lateral margin of the patella facet
Trochlear Morphology	
Sulcus Angle	The angle between the slopes of the medial and lateral trochlea
Congruence Angle	Line 1 is drawn to bisect the sulcus angle of the trochlear groove. Line 2 is drawn from the center of the trochlear groove to the patella apex. A positive angle is designated as one that is towards the laterally. Also known as Merchant Angle.
Trochlear Groove Depth	Line 1 is drawn across the anterior margins of the medial and lateral condyles. TGD is the distance from the center and deepest portion of the trochlear groove to Line 1.
Roman Arch	Line 1 is drawn across the posterior margins of the medial and lateral condyles. RA is the perpendicular distance from the center of the posterior femoral condylar groove to line 1.
Trochlear Groove Thickness	Line 1 is drawn across the posterior margins of the medial and lateral condyles. Two lines parallel to line 1 are drawn crossing the centers of the trochlear groove and the posterior femoral condylar groove respectively. TGT is the perpendicular distance between these two lines.
% of Epicondylar Width TGT	Is TGT distance expressed as a percentage of the transepicondylar width
ETIT	Measures the ratio of the lines drawn from the lateral and medial margins of the trochlea along the trochlear surface to the center of the

	trochlear groove. ETIT is the ratio of ET (lateral) to IT (medial). A ratio > 1.0 equates to having a lateral facet larger than the medial facet.
Lateral Condylar Height	Line 1 is drawn across the posterior margins of the medial and lateral condyles. LCH is the perpendicular distance from the most anterior margin of the lateral condyle to Line 1.
% of Epicondyalr Width LCH	LCH expressed as a percentage of the transepicondylar width
Biedert Central Condylar Height	Line 1 is drawn across the posterior margins of the medial and lateral condyles. CCH is the perpendicular distance from line 1 to the deepest part of the trochlear groove.
% of Epicondylar Width CCH	CCH expressed as a percentage of the transepicondylar width
Medial Condylar Height	Line 1 is drawn across the posterior margins of the medial and lateral condyles. MCH is the perpendicular distance from the most anterior margin of the medial condyle to Line 1.
% of Epicondylar Width MCH	MCH expressed as a percentage of the transepicondylar width
Lateral Trochlear Inclination	Line 1 is drawn across the posterior margins of the medial and lateral condyles. Line 2 is drawn along the lateral slope of the trochlear groove. LTI is the angle between the two lines. A positive angle opens laterally.
Limb Geometry	
TTTG	Two sets of measurements are made. The first measurement is made on the 1st cut and the second made at the level of where the patellar tendon inserts at the tibial tuberosity. Line 1 is drawn across the posterior margins of the medial and lateral condyles and will be applied to the distal image as well. Line 2 is perpendicular to line 1 and crosses the center of the trochlear groove in the 1st cut. Line 3 is perpendicular to 1 and runs through the insertion of patellar tendon on the distal image. The difference in distances of lines 2 & 3 to a fixed point on the image is TTTG.
Coronal Measurements	
Varus-Valgus	Line 1 is drawn through the axis of the femur, and line 2 is drawn through the axis of the tibia. CA is the angle between these two lines.
Lateral Condylar Height	LCH is the distance from the physeal scar to the lateral margin of the lateral femoral condyle articular surface.
Medial Condylar Height	MCH is the distance from the physeal scar to the medial margin of the medial femoral condyle articular surface
Patellar Height	**Using the sagittal image through the mid patella facet as determined on axial image, the following measurements are made** **Patella Height A:** Measured from the most proximal articular margin of the patella to the most distal (nonarticular) aspect of the patella **-Patella Height B:** Measured from most proximal to most distal articular margin of the patella

	-Patella Height C: Measured from the most distal aspect of the patella to the distal insertion of the patellar tendon at the tibial tuberosity (patella tendon length). **-Patella Height D:** Measured from the most distal articular surface of the patella to the anterior margin of the articulating surface of the tibia plateau. **-Patella Height E:** Measured from the most distal aspect of the articular surface of the patella to the distal insertion of the patellar tendon at the tibial tuberosity. **-Patella Height F:** Measured from the most distal aspect of the patella to the anterior margin of the articulating surface of the tibia plateau
Patellar Trochlear Overlap	Measures the length of the overlap between patellar and trochlear articulating cartilage.
Trochlear Bossing (AP)	Anterior posterior dimensions are measured on sagittal image at the presumed location of the middle/deepest portion of the trochlear groove.
Insall-Salvati Ratio	Height C divided by Height A
Modified Insall-Salvati Ratio	Height E divided by height B
Caton-Deschamps Ratio	Height D divided by height B
Morphology Ratio	Height A divided by height B
Femoral Contacting Surface Ratio	Height B divided by the trochlear overlap.

Table 2

Measurement	**# of Normal // # of PFJDs**	**Measurement**	**# of Normal // # of PFJDs**
Transepicondylar Width	71 // 35	*Coronal Measurements*	
Trochlear Morphology (1st cut)		Lateral Condylar Height	81 // 38
Sulcus Angle	81 // 39	Medial Condylar Height	81 // 38
% of Epicondylar Width TGT	71 // 35	*Patellar Height*	
% of Epicondyalr Width LCH	71 // 35	Patellar Trochlear Overlap	81 // 33
% of Epicondylar Width CCH	71 // 35	Trochlear Bossing (AP)	81 // 35
% of Epicondylar Width MCH	71 // 35	Insall-Salvati Ratio	81 // 34
Trochlear Morphology (2nd Cut)		Modified Insall-Salvati Ratio	81 // 34
% of Epicondylar Width	71 // 35	Caton-Deschamps Ratio	81 // 34
% of Epicondylar Width LCH	71 // 35	Morphology Ratio	81 // 34
% of Epicondylar Width CCH	71 // 35	Patellofemoral Contacting Surface Ratio	81 // 34
% of Epicondylar Width MCH	71 // 35		

Table 3

Measurement	Normal Means ± SE	PFJD means ± SE	CI 95% Normal PFJDs	Significance
Transepicondylar Width	71.00 ± 0.76 mm	75.23 ± 0.95 mm	80.14 - 83.16 73.30 - 77.16	< .001
Patellar Angle				
Angle of Fulkerson	18.18° ± 0.56	-3.5° ± 2.62	17.08 - 19.29 -8.79 - 1.79	< .001
Angle of Grelsamer	14.00° ± 0.73	24.82° ± 2.03	12.55 – 15.45 20.72 – 28.92	< .001
Angle of Laurin	10.10° ± 0.48	-5.23° ± 2.96	9.14 – 11.05 -11.23 – 0.76	< .001
Patellar Inclination Angle	8.10° ± 0.55	24.03° ± 2.42	7.02 – 9.19 19.14 – 28.92	< .001
Lateral Patellar Displacement	3.28 ± 0.24 mm	6.59 ± 0.69 mm	2.79 – 3.77 5.19 – 7.97	< .001
Trochlear Morphology (1st cut)				
Sulcus Angle	148.48° ± 0.94	165.57° ± 2.65	146.61 – 150.34 160.76 – 171.44	< .001
Congruence Angle	13.95° ± 2.00	40.14° ± 4.57	9.97 – 17.92 30.89 – 49.38	< .001
Trochlear Groove Depth	6.47 ± 0.24 mm	4.00 ± 0.43 mm	5.99 – 6.94 3.11 – 4.87	< .001
Roman Arch	17.13 ± 0.45 mm	15.39 ± 0.73 mm	16.23 – 18.02 13.91 – 16.87	.036
Trochlear Groove Thickness	42.90 ± 0.48 mm	42.73 ± 0.95 mm	41.95 – 43.86 40.81 – 44.64	.853
% of Epicondylar Width TGT	0.53 ± 0.00	0.56 ± 0.01	0.52 – 0.54 0.55 – 0.58	< .001
ETIT	1.51± 0.05	2.11 ± 0.17	1.42 – 1.61 1.77 - 2.46	< .001
Lateral Condylar Height	63.94 ± 0.61 mm	59.69 ± 0.89 mm	62.73 – 65.16 57.89 – 61.01	< .001
% of Epicondyalr Width LCH	0.78 ± 0.01	0.80 ± 0.01	0.77 – 0.79 0.78 – 0.82	.061
Biedert Central Condylar Height	60.03 ± 0.63	58.12 ± 1.43	58.78 – 61.29 55.22 – 61.01	.157
% of Epicondylar Width CCH	0.73 ± 0.01	0.76 ± 0.01	0.72 – 0.75 0.74 – 0.79	.018

Medial Condylar Height	58.77 ± 0.63 mm	55.53 ± 0.99 mm	57.52 -60.03 53.52 – 57.53	.005
% of Epicondylar Width MCH	0.72 ± 0.01	0.74 ± 0.01	0.70 – 0.73 0.72 – 0.77	.036
Lateral Trochlear Inclination	21.27° ± 0.66	13.31° ± 1.36	19.95 – 22.58 10.56 – 16.07	< .001
TTTG	10.96 ± 0.39	18.69 ± 0.81	10.19 – 11.73 17.06 – 20.32	< .001
Trochlear Morphology (2nd Cut)				
Trochlear Groove Depth	5.87 ± 0.15 mm	4.06 ± 0.37 mm	5.57 – 6.18 3.31 – 4.81	< .001
Roman Arch	24.25 ± 0.42 mm	21.28 ± 0.48 mm	23.42 – 25.08 20.30 – 22.25	< .001
Trochlear Groove Thickness	37.75 ± 0.65 mm	41.35 ± 0.93 mm	36.46 – 39.04 39.46 – 43.24	.002
% of Epicondylar Width	0.47 ± 0.01	0.57 ± 0.01	0.46 – 0.49 0.56 – 0.58	< .001
ETIT	1.40 ± 0.02	1.97 ± 0.07	1.36 – 1.44 1.83 – 2.12	< .001
Sulcus Angle	137.57° ± 0.93	155.33° ± 1.98	135.72 – 139.41 151.32 – 159.34	< .001
Lateral Condylar Height	65.63 ± 0.52 mm	65.21 ± 0.72 mm	64.59 - 66.67 63.76 – 66.66	.643
% of Epicondylar Width LCH	0.81 ± 0.01	0.88 ± 0.01	0.80 – 0.82 0.86 – 0.89	< .001
Biedert’s Central Condylar Height	62.00 ± 0.55	62.63 ± 0.74	60.90 – 63.10 61.13 – 64.12	.508
% of Epicondylar Width CCH	0.77 ± 0.00	0.84 ± 0.01	0.76 – 0.78 0.83 – 0.86	< .001
Medial Condylar Height	63.83 ± 0.52 mm	62.02 ± 0.73 mm	62.79 – 64.87 60.54 – 63.50	.048
% of Epicondylar Width MCH	0.78 ± 0.00	0.83 ± 0.01	0.77 – 0.79 0.82 – 0.84	< .001
Lateral Trochlear Inclination	21.74° ± 0.52	15.95° ± 0.85	20.71 – 22.77 14.24 – 17.66	< .001
Coronal Measurements				
Varus-Valgus	5.45° ± 0.29	10.02° ± 0.53	4.87 – 6.03 8.94 – 11.10	< .001
Lateral Condylar Height	27.94 ± 0.36	26.48 ± 0.50	27.22 – 28.67 25.47 – 27.49	.022

Medial Condylar Height	34.23 ± 0.44	33.08 ± 0.55	33.36 – 35.10 31.97 – 34.19	.122
Patellar Height				
Patellar Trochlear Overlap	14.49 ± 1.52	11.91 ± 1.00	11.89 – 14.29 9.88 – 13.94	.297
Trochlear Bossing (AP)	3.64 ± 0.13	3.97 ± 0.31	3.38 – 3.91 3.35 – 4.60	.245
Insall-Salvati Ratio	1.08 ± 0.02	1.26 ± 0.03	1.04 – 1.12 1.20 – 1.33	< .001
Modified Insall-Salvati Ratio	1.64 ± 0.03	1.72 ± 0.04	1.58 – 1.69 1.64 – 1.80	.085
Caton-Deschamps Ratio	1.13 ± 0.02	1.29 ± 0.03	1.09 – 1.17 1.22 – 1.35	< .001
Morphology Ratio	0.76 ± 0.01	0.79 ± 0.01	0.74 – 0.78 0.76 – 0.83	.029
Patellofemoral Contacting Surface Ratio	0.45 ± 0.05	0.37 ± 0.03	0.36 – 0.54 0.30 – 0.43	.240

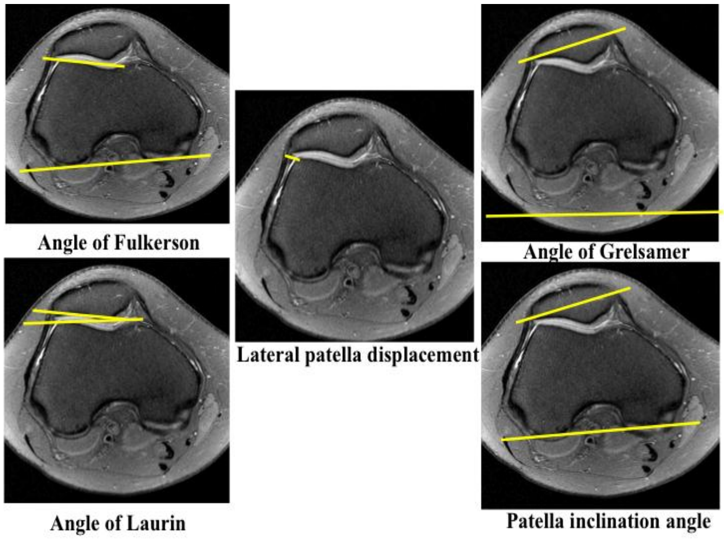


Figure 1: Patellar Alignment

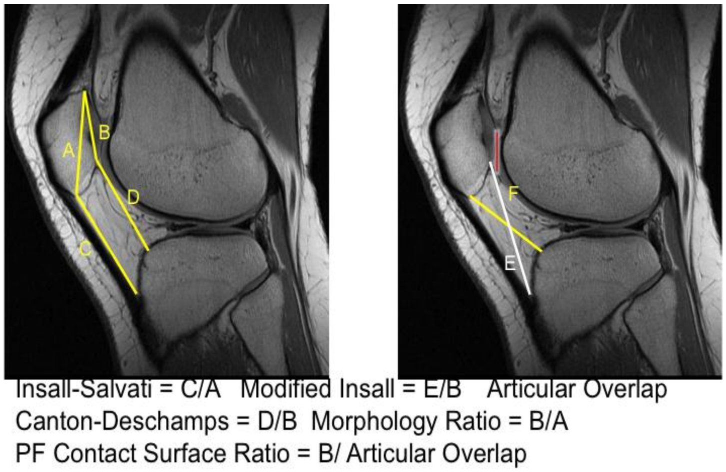
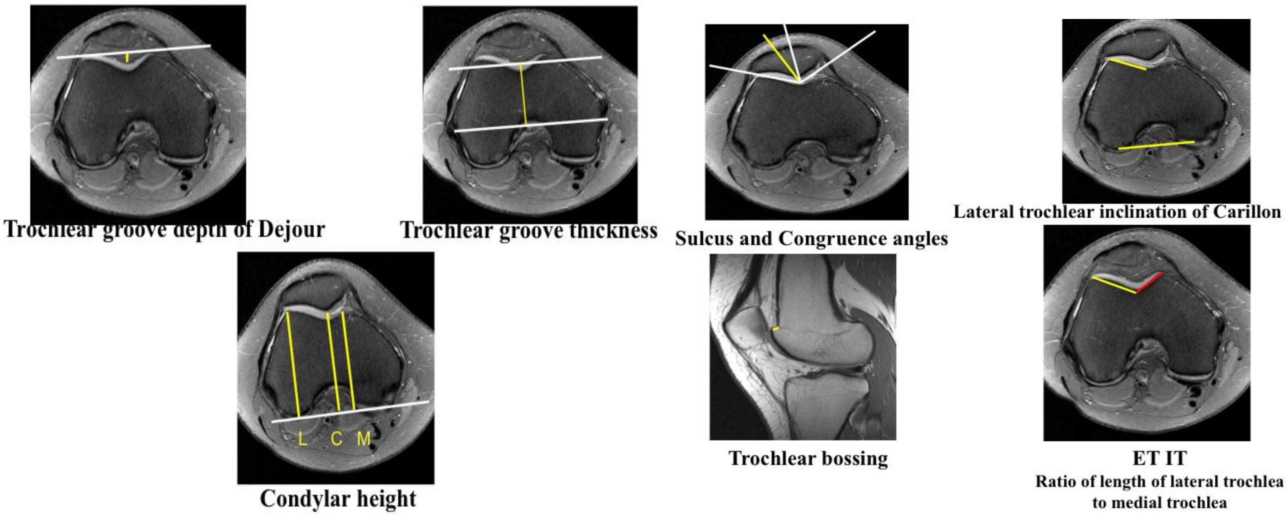


Figure 2: Patellar Height


Trochlear groove depth of Dejour

Trochlear groove thickness

Sulcus and Congruence angles

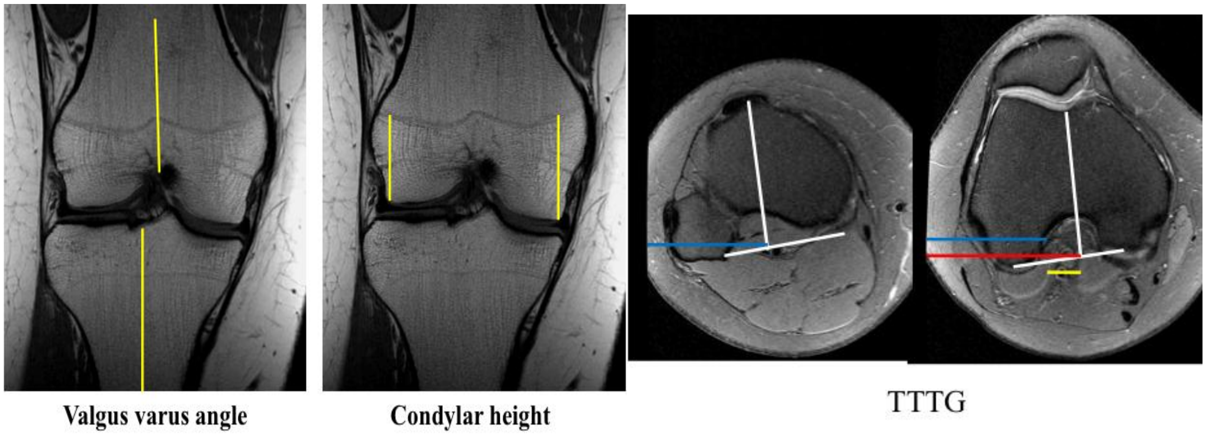
Lateral trochlear inclination of Carillon

Condylar height

Trochlear bossing

ET IT
Ratio of length of lateral trochlea to medial trochlea

Figure 3: Trochlear Morphology


Valgus varus angle

Condylar height

TTTG

Figure 4: Limb Geometry and Other measurements