The patho-anatomy of patellofemoral subluxation

Patella subluxation assessed on dynamic MRI has previously been shown to be associated with anterior knee pain. In this MRI study of 60 patients we investigated the relationship between subluxation and multiple bony, cartilaginous and soft-tissue factors that might predispose to subluxation using discriminant function analysis.

Patella engagement (% of patella cartilage overlapping with trochlea cartilage) had the strongest relationship with subluxation. Patellae with >30% engagement tended not to sublux; those with <30% tended to sublux. Other factors that were associated with subluxation included the tibial tubercle-trochlea notch distance, vastus medialis obliquus distance from patella, patella alta, and the bony and cartilaginous sulcus angles in the superior part of the trochlea. No relationship was found between subluxation and sulcus angles for cartilage and bone in the middle and lower part of the trochlea, cartilage thicknesses and Wiberg classification of the patella.

This study indicates that patella engagement is a key factor associated with patellar subluxation. This suggests that in patients with anterior knee pain with subluxation, resistant to conservative management, surgery directed towards improving patella engagement should be considered. A clinical trial is necessary to test this hypothesis.

Anterior knee pain is common. In some cases it is thought to be related to patellofemoral subluxation and instability,1 which has a spectrum of severity ranging from mildly abnormal patellofemoral tracking to complete dislocation, where no part of the patella remains in the trochlea groove. Within this spectrum there exists patellar subluxation, where the apex of the patella is not sliding centrally down the trochlea groove. This can be assessed using dynamic MRI.2,4 The measurement of patellar subluxation from dynamic MRI scans, based on a cine-loop of sequential axial images, is reproducible and reliable.2,5 There is an established relationship between increasing subluxation and worsening pain.2,4,5 O'Donnell et al5 found an association between pain and subluxation in asymptomatic volunteers and patients with anterior knee pain. In an asymptomatic group, 91% had no or mild subluxation, 9% had moderate subluxation and no subjects had severe subluxation; in contrast in the group with anterior knee pain 17% had moderate subluxation and 7% had severe subluxation.

To date there have been few MRI studies exploring the relationship between bone and soft-tissue variability and the kinematics of the patellofemoral joint. In addition, while studies allude to the contribution of trochlea and quadriceps dysplasia to patella maltracking,6,7 few have quantified their relative importance.

The aim of this study was to examine the relationship between specific anatomical variables measured on MRI scans and patellofemoral subluxation, and to quantify their importance. The variables studied were those thought to create a predisposition to subluxation and included: position of the patella relative to the trochlea in extension, the length of the vastus medialis tendon, bony dysplasia in both the trochlea and patella, and cartilage thickness.

Patients and Methods
Between April 2006 and February 2008, 270 consecutive patients with anterior knee pain and possible patellofemoral maltracking were referred by specialist orthopaedic surgeons for MRI at our institution. Exclusion criteria included previous surgery to the knee, any bony abnormality (including previous fracture or arthritic change) and any major cartilage defects (≥10 mm × 10 mm) diagnosed on MRI. The principal inclusion criterion was that there were axial, coronal, sagittal and dynamic scans of adequate quality to allow assessment. A power calculation was...
performed using the Tibial Tubercle to Trochlea Notch Distance (TTD) as a representative variable. The calculation was based on differences seen at full extension. In order to identify a difference of 1 mm, 2n was found to be 30 subjects for 90% power (standard deviation (SD) = 3.3, Standardised Difference = 1.1). A total of 60 patients out of the 270 (22%) who met the inclusion criteria were then randomly selected. There were 37 females and 23 males, with 30 right and 30 left knees.

MRI scans were carried out using a Siemens 1.0 Tesla Expert Magnetic Resonance Image system (Siemens AG, Munich, Germany). This examination consisted of routine three-dimensional (3D) acquisition sequences with the knee at rest in extension, including fat suppression images, a sagittal orientated T2 gradient sequence, and axial sequences (inter-slice distance 1.6 mm). An additional patellofemoral dynamic MRI examination was performed using a previously developed technique. This was carried out with the knees raised on a cushion and strapped together. An inflated plastic ball was placed between the distal tibiae and the upper part of the magnet. During the scan, the patient operated a hand-held valve that released air from the plastic ball, whilst simultaneously extending their knees against the resistance of the deflating ball. A series of seven slices were obtained for each patient; six of these were axial (inter-slice distance 5 mm) and one sagittal, with the axial slices including the full excursion of the patella. The sagittal image was orientated along the long axis of the patella; this slice was used to ensure alignment. Over two minutes the sequence was repeated 15 times. A cine-loop feature then combined the axial slice closest to the centre of the patella from each of the 15 repeat sequences to provide a dynamic coronal plane evaluation throughout the range of extension.

Two independent consultant radiologists (including one author (SO)) assigned a grade of subluxation to each patient’s dynamic MRI scan, with each knee being ascribed a degree of subluxation; measurements were made of the maximum lateral movement of the apex of the patella in the trochlea sulcus. The degree of subluxation was graded based on the maximum lateral movement using the following scale established by McNally et al: none/mild, 0 mm to 5 mm subluxation; moderate, > 5 mm to 10 mm subluxation; severe, > 10 mm subluxation.

The study sample included 10 patients (16.7%) with mild subluxation, 32 (53.3%) with moderate subluxation, and 18 (30%) with severe subluxation as established by dynamic MRI assessment.

For each subject the following variables were measured using 3D post-processing software (Centricity PACS-IW; GE Healthcare, New York, New York) with the knee in extension.

**Tibial tubercle to trochlea notch distance (TTD).** This was defined as the distance between the mid-tibial plane (mid-point of the patella tendon) and the mid-sulcal plane located on axial MRI slices. Both lines were drawn perpendicular to a line joining the posterior aspect of the femoral condyles (Fig. 1).
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Patellar type. Based on the Wiberg classification of patellar shape and assessed on axial slices: Type I, the facets are concave, symmetrical and of equal size; Type II, the medial facet is rather smaller than the lateral facet and the lateral facet is concave; Type III, the medial facet is markedly smaller than the lateral facet.

Patella alta. A modified Insall-Salvati ratio (Fig. 2) was used based on the length of the patella divided by the length of the patellar tendon measured along its deep surface from sagittal slices, a value of less than 0.8 representing patella alta.

Patellar engagement. Engagement of the patella into the trochlear sulcus in full extension was expressed as a percentage. The highest point of the articular surface of the sulcus was identified using the highest axial slice on which cartilage could be identified. Using the multi-planar localisation tool available in the viewing software, this point was identified on the sagittal view, allowing the corresponding point on the articular surface of the patella to be identified. The height of this point from the inferior aspect of the articular surface of the patella was then measured. From this measurement, the percentage of the patella articular surface engaged in the sulcus was calculated (Fig. 3).

Trochlear sulcus angles. The angle subtended by the walls of the trochlear sulcus at the base of the groove was measured for both bone and cartilage (Fig. 4). Whilst routine MRI uses axial slices perpendicular to the femoral axis, for the purposes of this study measurements were taken from reconstructed axial slices, to achieve the plane perpendicular to the articulating surface.

Both the bone and cartilage sulcus angles vary as a function of height within the trochlea, therefore sulcus angle measurements were taken at three reproducible points within the trochlea. First, the axial slice 3.2 mm distal to the most proximal axial slice showing articular cartilage in the trochlea; the measurements of sulcus angle at this level were termed the proximal bone sulcus angle (SA_prox. bone) and the proximal cartilage sulcus angle (SA_prox. cartilage). Secondly, the axial slice 1.6 mm proximal to the first axial slice showing the inter-condylar notch; the measurements of sulcus angle at this level were termed the distal sulcus angles (SA_dist. bone and SA_dist. cartilage). Thirdly, midway between the slices described in 1 and 2 above (Fig. 4); these were termed the middle sulcus angles for both the bone and the cartilage (SA_mid. bone and SA_mid. cartilage).

The distance of vastus medialis obliquus muscle from patella (VMOP). This was defined as the shortest distance between the superomedial aspect of the patella, to the edge of the vastus medialis obliquus muscle.

Patellar apex cartilage thickness (Δp). This was defined as the cartilage thickness at the apex on the posterior aspect of the patella.

Trochlear sulcus cartilage thickness (Δt). This was defined as the maximum thickness of cartilage in the trochlear groove, as measured from axial slices.

Statistical analysis. The data were analysed in SPSS v18.0.1 (SPSS Inc., Chicago, Illinois). In order to assess characteristics within the three radiological subluxation groups, descriptive statistics for each measured variable were calculated: mean with SD for normally distributed variables and
median with the interquartile range (IQR) for non-normally distributed variables. Analysis of variance (parametric and non-parametric Kruskal-Wallis) was used to determine the statistical significance of any group difference in individual variables, in particular whether there was any significant linear trend across the groups. A linear trend was taken to be significant as long as its accompanying departure from a linear trend was non-significant.

Discriminant function analysis, a type of multivariate analysis of variance (ANOVA), was applied to establish whether the measured variables, when considered together, could discriminate between the three subluxation groups. Wilks’ lambda, $\lambda$, was used in an ANOVA (F) test of mean differences, such that the smaller the lambda for an independent variable, the more that variable contributes to the discriminant function.$^{11}$ Lambda varies from 0 to 1, with 0 meaning group means differ (thus the more the variable differentiates the groups), and 1 meaning all group means are the same. The F test of Wilks’ lambda shows which variable’s contributions are significant.$^{12}$

In addition, an approach based on diagnostic test methodology (Receiver Operator Curve (ROC) analysis)$^{10}$ was used to determine if any thresholds for radiological stability or instability were evident. ROC curves plot sensitivity (y-axis) against 1-specificity (x-axis) for all possible cut-off points. Sensitivity is defined as the proportion of all patients with a ‘positive’ outcome correctly identified (proportion of true positives identified), while specificity refers to the proportion of patients with a ‘negative’ outcome so identified (proportion of true negatives). The most efficient cut-off value, giving equal weight to specificity and sensitivity, is associated with the point closest to the top left hand corner of the ROC curve. The greater the area under the ROC curve (AUC) the greater the ability of the measure to differentiate. If the area under the curve is 0.5, this represents a test that is not predictive; the closer to 1.0, the better the differentiation of the measure.

## Results

The characteristics of the patients in each of the three radiological subluxation groups are shown in Table I. There were statistically significant differences between the groups in terms of TTD, patella alta, patella engagement, $\text{SA}_{\text{prox. bone}}$, $\text{SA}_{\text{prox. cartilage}}$, VMOP, and $\Delta t$, with there being linear trends across the groups for all variables except patella engagement for which the relationship was strong but non-linear. Severity of subluxation increased with increasing values of TTD, $\text{SA}_{\text{prox. bone}}$, $\text{SA}_{\text{prox. cartilage}}$.

### Table I. Characteristics of the three radiological subluxation groups (mild, moderate, severe). Data are shown as mean (SD) unless otherwise stated

<table>
<thead>
<tr>
<th>Severity of subluxation</th>
<th>Mild (n = 10)</th>
<th>Moderate (n = 32)</th>
<th>Severe (n = 18)</th>
<th>p-value$^*$</th>
</tr>
</thead>
<tbody>
<tr>
<td>TTD$^\dagger$ (mm)</td>
<td>12.0 (4.1)</td>
<td>15.4 (5.5)</td>
<td>20.7 (4.3)</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Patellar type (Wiberg classification$^8$), n (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type 1</td>
<td>2 (20.0)</td>
<td>5 (15.6)</td>
<td>3 (16.7)</td>
<td></td>
</tr>
<tr>
<td>Type 2</td>
<td>8 (80.0)</td>
<td>25 (78.1)</td>
<td>14 (77.8)</td>
<td></td>
</tr>
<tr>
<td>Type 3</td>
<td>0 (0)</td>
<td>2 (6.3)</td>
<td>1 (5.6)</td>
<td>0.82$^+$</td>
</tr>
<tr>
<td>Patella alta$^9$</td>
<td>0.97 (0.10)</td>
<td>0.85 (0.17)</td>
<td>0.82 (0.13)</td>
<td>0.013</td>
</tr>
<tr>
<td>Patellar engagement (%)</td>
<td>41.4 (7.5)</td>
<td>20.5 (12.5)</td>
<td>16.2 (8.4)</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Trochlear sulcus angles $^{**}$ (°)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\text{SA}_{\text{prox. bone}}$</td>
<td>142.0 (7.9)</td>
<td>155.2 (16.7)</td>
<td>172.2 (22.2)</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>$\text{SA}_{\text{mid. bone}}$</td>
<td>136.1 (10.1)</td>
<td>141.3 (13.4)</td>
<td>144.0 (18.5)</td>
<td>0.18</td>
</tr>
<tr>
<td>$\text{SA}_{\text{dist. bone}}$</td>
<td>127.9 (11.6)</td>
<td>131.5 (13.8)</td>
<td>133.0 (13.8)</td>
<td>0.35</td>
</tr>
<tr>
<td>$\text{SA}_{\text{prox. cartilage}}$</td>
<td>150.2 (10.9)</td>
<td>163.0 (20.7)</td>
<td>175.3 (18.5)</td>
<td>0.001</td>
</tr>
<tr>
<td>$\text{SA}_{\text{mid. cartilage}}$</td>
<td>143.8 (11.8)</td>
<td>155.1 (15.4)</td>
<td>150.7 (12.9)</td>
<td>0.22</td>
</tr>
<tr>
<td>$\text{SA}_{\text{dist. cartilage}}$</td>
<td>134.6 (13.2)</td>
<td>138.4 (13.4)</td>
<td>143.0 (16.6)</td>
<td>0.15</td>
</tr>
<tr>
<td>VMOP$^{\dagger\dagger}$ (mm)</td>
<td>3.3 (2.9)</td>
<td>6.2 (4.2)</td>
<td>8.2 (2.8)</td>
<td>0.001</td>
</tr>
<tr>
<td>Median</td>
<td>4.9</td>
<td>5.6</td>
<td>8.0</td>
<td>0.004$^+$</td>
</tr>
<tr>
<td>Interquartile range</td>
<td>0 to 6.0</td>
<td>3.7 to 8.5</td>
<td>6.4 to 10.7</td>
<td></td>
</tr>
<tr>
<td>$\Delta p^{\ddagger}$ (mm)</td>
<td>4.8 (1.3)</td>
<td>4.4 (0.7)</td>
<td>5.2 (1.1)</td>
<td>0.36</td>
</tr>
<tr>
<td>$\Delta t^{\S\S}$ (mm)</td>
<td>3.0 (0.6)</td>
<td>4.0 (1.1)</td>
<td>4.3 (0.8)</td>
<td>0.001</td>
</tr>
</tbody>
</table>

$^*$ one-way analysis of variance, unless otherwise stated
$\dagger$ TTD, tibial tubercle to trochlear notch distance
$\ddagger$ Kruskal-Wallis test
$\ddagger$ patella alta: patellar length / tendon length
$\ddagger$ deviation from linear trend
$^{**}$ $\text{SA}$, sulcus angle; prox., proximal; dist., distal
$^{\dagger\dagger}$ VMOP, distance of vastus medialis obliquus muscle from patella
$^{\ddagger}$ $\Delta p$, patellar apex cartilage thickness
$^{\S\S}$ $\Delta t$, trochlear sulcus cartilage thickness
VMOP, and Δt; decreasing values of patella alta and patellar engagement were associated with greater severity of subluxation.

From the discriminant function analysis, six of the measured variables in combination were found statistically significant in discriminating between the three grades of subluxation (Table II; variables given in order of the strength of the relationship): Patella engagement (percent overlap of patella in trochlea sulcus), TTD (distance between tibial tuberosity and apex of trochlea notch), VMOP, patella alta, SAprox. bone, SAprox. cartilage. Patella engagement had a notably stronger relationship (λ = 0.6, p < 0.001) than the other variables (λ = 0.8 to 0.9, p ≥ 0.001). The variables that showed no discrimination included: Wiberg classification, Δt, Δp, SAprox. cartilage, SAdist. bone, and SAdist. cartilage.

The variable with the strongest association with subluxation, patellar engagement (λ = 0.644) had a strong but non-linear relationship with subluxation (p < 0.001, Table I), with mean engagements of: 41% (34% to 48%) for no/mild subluxation, 20% (12% to 32%) for moderate and 16% (8% to 24%) for severe subluxation. The non-linearity of the relationship is demonstrated in Figure 5, while there were a few patients with patellar engagement ≥ 30% who had moderate or severe subluxation, no patient with engagement of < 30% appeared in the mild or no subluxation group. From the ROC analysis, a threshold of ≤ 30% was found to be the best cut-off point for predicting radiological instability. The threshold is indicated at 30%. The box represents the median and interquartile range (IQR) and the whiskers represent the maximum and minimum of data considered (*, outliers between 1.5 and 3 times the IQR; **, extreme values > 3 times the IQR).

Figure 5a – box plot showing the relationship between patellar engagement and radiological instability. The threshold is indicated at 30%. The box represents the median and interquartile range (IQR) and the whiskers represent the maximum and minimum of data considered (*, outliers between 1.5 and 3 times the IQR; **, extreme values > 3 times the IQR). Figure 5b – receiver operator curve (ROC) showing the relationship between patellar engagement and radiological stability. The best threshold is indicated by an arrow.

With increasing grade of subluxation, the TTD increased from a mean of 12.0 mm (SD 4.1 mm) for mild/no subluxation to a mean of 20.7 mm (SD 4.3 mm) for severe subluxation (linear trend p < 0.001; Table I). There was overlap between the subluxation grades with the best cut-off point from ROC analysis found to be a value of 14.5 mm: values greater than this had a sensitivity of 80% and specificity of 70% for detecting radiological instability (AUC = 0.80, p = 0.003).

An increasing severity of subluxation was significantly (p = 0.001) associated with increasing distance of the VMO muscle from the patella (VMOP); VMOP increased from 3.3 mm (SD 2.9 mm) for the mild/no subluxation group to 8.2 mm (SD 2.8 mm, Table I) for the severe group. From the
ROC analysis (AUC = 0.75, p = 0.014), a VMOP threshold of ≥ 4.6 mm had a sensitivity of 74% and specificity of 50% for detecting instability.

The sulcus angles for bone and cartilage (SA_{prox. bone} and SA_{prox. cartilage}) in the superior trochlea were significantly associated with subluxation, both individually and in combination (Tables I and II, respectively). With increasing sulcus angle (flattening of the trochlear groove) the degree of subluxation increased. Whilst all stable patients had a sulcus angle < 155°, there was much overlap between the subluxation grades, with a number of patients in the moderate and severe subluxation groups also having a sulcus angle of < 155°. From the ROC analysis, a threshold of ≥ 152° for SA_{prox. bone} had a sensitivity of 68% and specificity of 100% for detecting at least moderate instability (AUC = 0.82, p = 0.002); the threshold of ≥ 151° for SA_{prox. cartilage} had a sensitivity of 76% and specificity of 80% for detecting at least moderate instability (AUC = 0.79, p = 0.004).

Discussion

Abnormal patellofemoral tracking contributes to anterior knee pain, although the reason why maltracking causes pain is not well understood. Abnormal patellar tracking contributes to anterior knee pain. During knee flexion, subluxation of the patella leads to abnormal stresses being transferred through surrounding soft tissues, the cartilage and subchondral bone. These factors may contribute to anterior knee pain.

The causes of patellofemoral subluxation are highly likely to be multi-factorial. Although certain aberrant anatomical features are known to contribute to subluxation, to date there have been no studies that have attempted to identify which anatomical features are the most relevant.

Our analysis suggests that important anatomical factors associated with subluxation include the position of the patella relative to the trochlea (patellar engagement, patella alta), the position of the tibial tubercle (TTD), the VMO position and the morphology of the proximal trochlea (proximal bony and cartilage sulcus angle). The factors which probably do not cause subluxation include: the shape of the patella, the morphology of the middle and lower parts of the trochlea (sulcus angles for cartilage and bone) and cartilage thickness of the trochlea and patella.

Patellar engagement had the strongest association with subluxation; this variable effectively assesses the start position of the patella in relation to the trochlear sulcus in extension, expressed here as percentage overlap. This implies that as percentage engagement in the trochlea increased, the degree of subluxation decreased. The data in Figure 5 show that no patient within the mild or no subluxation group had a patellar engagement of < 30%. This suggests that a threshold exists to distinguish between the mild or no radiological subluxation group and the moderate and severe groups; < 30% engagement was associated with either moderate or severe subluxation.

Previous authors have documented the relevance of a high riding patella as a pre-requisite to subluxation, supported by the fact that patella alta is a feature present in over 50% of cases of dislocation. In this study, patellar engagement showed a more significant relationship with the degree of subluxation in the discriminant analysis test than patella alta. In addition, there was a clear threshold between no or mild subluxation and moderate or severe subluxation in terms of patellar engagement, but this was not evident for patella alta. Intuitively, it seems likely that patellar engagement will directly affect stability, whereas patella alta will only have an indirect effect via its relationship to patellar engagement. This is because the measurement of patella alta is also dependent on many other factors such as the anatomy of the proximal tibia.

Problems with the radiological measurement of patella alta have been well documented, the most notable being the difficulty in establishing the origin and insertion of the patellar tendon. The measurement of patellar engagement from MRI images provides an alternative measurement with well-defined landmarks offering a more precise description of the patella’s position relative to the trochlea. It has been shown that quadriceps contraction can cause significant changes in the position of the patella measured radiologically. While the position of the patella with the quadriceps contracting may be more representative of the functional condition, the MRI acquisitions at extension were performed with the patients at rest to avoid variability in contraction during the relatively long scan time.

The findings reported here suggest that if patellar engagement can be optimised, the risk of patellar subluxation should be decreased. The data suggest a clear cut-off at a level of 30% engagement between subluxation and no subluxation. Therefore, surgery aimed at preventing subluxation should perhaps aim to achieve patellar engagement between 30% and 50%.

Subluxation and dislocation have been shown to occur typically during 0° to 30° flexion and infrequently in the terminal phases of extension. During the first 30° of flexion and approaching full extension, the patella will be in the superior aspect of the trochlea. This study shows that a relatively flat superior trochlea correlates with worsening subluxation. The shape of the trochlea further distally has no significant effect on subluxation.

The position of the belly of VMO in relation to the patella was shown to be a significant feature associated with patellar subluxation. It follows, therefore, that interventions that enhance the action of VMO should improve symptoms related to patellofemoral subluxation. However, this study demonstrated no clear cut-off in VMOP between patients who sublux and those that do not.

Previous assessments of the contribution of increasing TTD to patellofemoral subluxation have shown similar findings. McNally et al noted that all but one of 44 knees with normal tracking had a TTD of < 20 mm and that...
patients with severe maltracking had a TTD of > 20 mm. The current study confirms this relationship, with a clear threshold evident at 19 mm for severe subluxation. However, the current study’s moderate subluxation group overlaps both the no or mild subluxation and severe subluxation groups; the threshold for radiological instability is suggested by our findings to be TTD ≥ 14.5 mm. This threshold is lower than that suggested by McNally et al, but probably reflects the differences in patient cohorts, as the previous study only examined subjects with either normal tracking or severe maltracking. Alteration of the position of insertion of the patellar tendon during surgery effectively modifies TTD.

It is clear that the cause of subluxation is multifactorial, although engagement was the most important factor from our analysis. Closer analysis of the engagement data reveals insights into the key elements leading to subluxation. All patients with no or mild subluxation had > 30% engagement and all but five (10%) with moderate or severe subluxation had < 30% engagement. This would suggest that in patients with anterior knee pain resistant to conservative measures and with moderate or severe subluxation, surgery directed at improving engagement, by distalising the tibial tubercle, should be considered. The five outliers of the moderate and severe subluxation groups with patellae above the threshold of 30% patellar engagement all had dysplastic proximal trochleas (range of bony trochlea sulcus angles 138° to 205°) with only two having in addition a TTD of > 19 mm (20 mm to 21 mm). This suggests that altering the shape of the trochlea as well as improving engagement might be beneficial. However, this is probably unnecessary as there are many patients with dysplastic trochleas who do not sublux.

Anterior knee pain is a common and poorly understood problem. This study ranked the relative importance of bony, cartilaginous and soft-tissue features, measurable on MRI images in causing patellofemoral subluxation. The degree of overlap of the patella in the trochlear groove was the most important factor and suggested that the overlap in extension should be > 30% to avoid subluxation. Other factors related to subluxation include the distance of the VMO muscle from the patella, tibial tubercle – trochlea notch distance and the sulcus angle at the top of the trochlea. This study suggests that if patients, for whom conservative measures prove ineffective, have symptoms related to subluxation, surgery should be focussed on improving patellar engagement. A clinical study is required to test this hypothesis.

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References