Cartilage-bone mismatch in the dysplastic trochlea

AN MRI STUDY

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Trochlear dysplasia is an important anatomical abnormality in symptomatic patellar instability. Our study assessed the mismatch between the bony and cartilaginous morphology in patients with a dysplastic trochlea compared with a control group.

MRI scans of 25 knees in 23 patients with trochlear dysplasia and in 11 patients in a randomly selected control group were reviewed retrospectively in order to assess the morphology of the cartilaginous and bony trochlea. Inter- and intra-observer error was assessed.

In the dysplastic group there were 15 women and eight men with a mean age of 20.4 years (14 to 30). The mean bony sulcus angle was 167.9° (141° to 203°), whereas the mean cartilaginous sulcus angle was 186.5° (152° to 214°; $p < 0.001$). In 74 of 75 axial images (98.7%) the cartilaginous contour was different from the osseous contour on subjective assessment, the cartilage exacerbated the abnormality.

Our study shows that the morphology of the cartilaginous trochlea differs markedly from that of the underlying bony trochlea in patients with trochlear dysplasia. MRI is necessary in order to demonstrate the pathology and to facilitate surgical planning.

The main anatomical factors responsible for symptomatic patellar instability are trochlear dysplasia, an excessive distance between the tibial tubercle and the trochlear groove, and patella alta.¹ Trochlear dysplasia is an abnormality of the shape and depth of the trochlear groove, mainly in its proximal extent.^{2,3} The dysplastic trochlea has been described using radiography,^{4,5} CT⁶ and MRI.^{2,3,7,8} It has been well demonstrated that there is a mismatch between the bony and cartilaginous anatomy of the trochlea in normal knees.⁹⁻¹¹ To our knowledge our study is the first to assess this mismatch in the dysplastic trochlea.

Patients and Methods

MRI scans of 25 knees in 23 patients with patellar instability and trochlear dysplasia were reviewed retrospectively. The patients were referred for MRI from one consultant clinic on the basis of radiological evidence of trochlear dysplasia in the presence of symptomatic patellar instability. We included all patients with evidence of dysplasia on MRI scans who were seen between March 2002 and August 2004.

There were 15 women and eight men with a mean age of 20.4 years (14 to 30). A total of 11 patients had their left knee scanned, ten their

right knee and both knees in two. We also retrospectively reviewed the MRI scans of a control group of 11 knees in 11 randomly selected, aged-matched men without trochlear dysplasia. Their mean age was 24.8 years (10 to 42). In five, the left knee was scanned and in six the right. The sulcus angles and thickness of the articular cartilage were measured.

The scans were performed using a dedicated knee coil on a 1.0 Tesla MR scanner (Magnetom Impact Expert; Siemens Medical Systems, Erlanger, Germany) or a 1.5 Tesla scanner (Symphony Maestro; Siemens Medical Systems). The sequences examined were the axial fat saturation flash 3d gradient echo (FsFL3d; flip angle 40°, TR 50 ms, TE 11 ms, slice thickness 3.6 mm, field of view (FOV) 150 mm, 192 x 256 matrix, single acquisition over 3 minutes 52 seconds) on the first scanner and the axial fat saturation proton density (TR 3150 ms, TE 14 ms, slice thickness 3 mm, FOV 150 mm, 212 x 256 matrix, single acquisition over 2 minutes 55 seconds) on the second. The scans were loaded onto the Leonardo workstation (Siemens Medical Systems) using Syngo post-processing software. The most proximal cranio-caudal image on which the cartilage was visible was identified. The next three caudal images were assessed. Since the slice thicknesses were

Fig. 1a

Fig. 1b

Fig. 1c

Classification of trochlear dysplasia according to Tavernier and Dejour⁸ showing a) grade B which is a flat or convex trochlea, b) grade C with asymmetry of the condyles and c) grade D with a cliff pattern.

3 mm or 3.6 mm, three images between 3 mm and 15 mm from the start of the trochlear articular cartilage were assessed. A total of 75 sets of measurements from 25 knees were analysed.

Using the axial MRI scans, the trochlear shape was described according to the classification of trochlear dysplasia of Dejour and Locatelli¹ into grade A, B, C or D. The first scan, which was used for measurement, was used to grade the trochlea. Of the 25 knees with trochlear dyspla-

Fig. 2a

Fig. 2b

MRI scans showing a) the bony and cartilaginous sulcus angles and b) the cartilage thickness.

sia, 11 were classified as grade B, six as grade C and eight as grade D (Fig. 1). None was classified as grade A.

We measured the cartilaginous and bony sulcus angles (Fig. 2a) and the thickness of the cartilage in the sulcus at one-third and two-thirds along each condyle (Fig. 2b). The morphology of the bony and cartilaginous surface contour was separately assessed and described as flat, convex or concave.

Statistical analysis. The difference between the bony and cartilaginous sulcus angles was analysed as a repeated-measures analysis of variance. The method was then validated by recording the inter- and intra-observer error. The sulcus angles were separately measured by three of the authors (ALvH, AJB, JDJE), who were then blinded to the results and the measurements repeated. This was statistically analysed using pairwise comparisons calculating the mean difference between observers and sessions across all patients as an indication of any systematic difference (bias) between them. The subjective assessment of the bony and cartilaginous contours was validated in the same manner and the repeatability represented as a kappa statistic. It was

Table I. Statistical analyses for inter- and intra-observer error

	Bias (°)	95% CI*	p value
Interobserver error			
Sulcus angle (bone)			
Observer 1 vs 2	-0.57	(-1.81 to +0.66)	0.36
Observer 1 vs 3	-0.67	(-2.01 to +0.67)	0.32
Observer 2 vs 3	-0.09	(-1.74 to +1.56)	0.91
Sulcus angle (cartilage)			
Observer 1 vs 2	0.55	(-0.89 to +2.98)	0.45
Observer 1 vs 3	0.96	(-0.27 to +2.19)	0.23
Observer 2 vs 3	0.41	(-1.03 to +1.85)	0.57
Intra-observer error			
Sulcus angle (bone)			
Session 1 vs 2	0.34	(-0.18 to +0.86)	0.20
Sulcus angle (cartilage)			
Session 1 vs 2	0.69	(-0.05 to +1.42)	0.06

* 95% CI, 95% confidence interval

Fig. 3

MR scan showing that the cartilaginous morphology changes the bony contour from concave to convex.

also correlated with the objective measurements by assessing the mean and standard deviation (SD) of the sulcus angles in every group.

The measurements of the cartilage thickness produced data which were descriptive in nature and were not subjected to statistical analysis. A p value of < 0.01 was considered significant.

Results

The mean angle of the bony sulcus was 167.9° (141° to 203°; SD 14.6) whereas that of the cartilaginous sulcus was 185.0° (152° to 214°; SD 14.2). A sulcus angle of more than 180° indicated convexity. A repeated-measures analysis showed a highly significant difference in the distributions of the bony and cartilaginous sulcus angles ($p < 0.001$). In all 75 axial images the cartilaginous sulcus angle was greater than the bony sulcus angle by a mean of 18.1° (4° to 45°). The results of the statistical analysis of the inter- and intra-observer error are summarised in Table I. This indicated only slight systematic differences (bias). The confidence

intervals (CIs) around these estimates suggested that the true biases were likely to be in either direction and that the observed biases might simply be due to chance, a view which was supported by the p value.

The mean thickness of cartilage in the centre of the trochlea was 3.5 mm (1.4 to 5.2). The mean thickness one-third along the lateral and medial condyles was 2.8 mm (1.1 to 3.9) and 2.6 mm (0.9 to 4.6) respectively, thinning to 2.2 mm (1.8 to 3.5) and 1.9 mm (0.6 to 3.3) two-thirds along.

In 74 of 75 axial images (98.7%) the cartilaginous contour was different from the osseous contour on subjective assessment. In 58 of 75 images (77.3%) the cartilaginous morphology changed the bony contour from concave to flat or convex (Fig. 3), or from flat to convex. In 16 of 75 (21.3%) it reduced the concavity or increased the convexity. In the remaining image both contours appeared to be flat. Using kappa statistics the mean interobserver repeatability was 0.76 and intra-observer repeatability 0.87 for the bony contour. For the cartilage these figures were 0.81 and 0.86 respectively. A kappa of 0.61 to 0.80 represented a 'good' and more than 0.80 a 'very good' agreement. When correlating the subjective assessment with the objective measurements, the contours which were assessed as being flat had a mean sulcus angle of 178.9° (SD 4.1). The corresponding figure for the convex contour was 195.9° (SD 6.6) and for the concave contour 161.8° (SD 7.6).

In the control group the mean angle of the bony sulcus was 138.2° (126° to 157°; SD 7.2) whereas that of the cartilaginous sulcus was 147.0° (133° to 179°; SD 9.5). A repeated-measures analysis showed a highly significant difference between the bony and the cartilaginous sulcus angles ($p < 0.001$).

The mean thickness of articular cartilage in the centre of the trochlea in the control group was 3.7 mm (1.6 to 6.3). The mean thickness one-third along the lateral and medial condyles was 3.1 mm (1.2 to 6.1) and 2.7 mm (0.8 to 5.5), respectively, thinning to 2.7 mm (1.0 to 5.9) and 2.2 mm (0.8 to 5.4) two-thirds along.

Discussion

Patients with symptomatic patellar instability will have either objective patellar instability (true atraumatic dislocation with an anatomical abnormality) or potential patellar instability (pain, catching or locking of the patellofemoral joint and inability to rehabilitate quadriceps with an anatomical abnormality).¹

It is important to define the anatomical abnormality responsible for the patellar instability. The main anatomical factors are trochlear dysplasia, an excessive distance between the tibial tubercle and the trochlear groove, excessive patellar tilt and patella alta.¹ Secondary factors are excessive femoral anteversion, external rotation deformity of the tibia, genu recurvatum and genu valgum.

Trochlear dysplasia is an abnormality of the shape and depth of the trochlear groove mainly in its proximal extent.

This was defined radiologically by Dejour et al^{5,6} on the basis of the crossing sign (*croisement*). If the line of the trochlear floor crosses the anterior border of one or both condyles, the trochlea is said to be flat at that level. The same feature was described by Grelsamer and Tedder⁴ and called the lateral trochlear sign. Trochlear dysplasia was further classified by Dejour and Locatelli¹ and Tavernier and Dejour⁸ on the basis of the CT morphology of the index scan and the direct lateral radiograph.

With the help of CT and MRI, a number of authors have shown that the abnormality is in the proximal trochlea.^{2,3,7} They have pointed out that this will be missed on a transverse radiograph (or skyline view) of the knee taken with the knee at approximately 30° (20° to 50°) of flexion. This view shows the shape of the bony trochlea distal to the point at which the instability occurs.

Pfrrmann et al³ analysed the MRI scans of patients with trochlear dysplasia and compared them with those in patients without the abnormality. They describe a number of criteria visible on transverse MRI scans obtained at a static level of 3 cm above the joint line. We found it difficult to use this level because of differences in the size of the knee and the proximal extent of the trochlear cartilage between patients. We found that analysis of the second to fourth axial images where articular cartilage was seen was more reproducible.

Carrillon et al⁷ compared the lateral trochlear inclination on the most proximal axial MRI scan in patients with patellar instability with that of a normal population. There was a significant difference between the two. We elected to use a better known measurement (the sulcus angle) to differentiate the bony and cartilaginous morphology.

Stäubli et al,^{9,10} by using MR arthrotomograms from 30 patients and cryosections of a cadaver knee, clearly demonstrated differences in the surface geometry of the articular cartilage and corresponding subchondral osseous anatomy of the patellofemoral joint in normal knees. The surface anatomy of the articular cartilage and the underlying osseous contour of the trochlea matched in only seven of the 30 knees. Similar findings were reported by Shih et al.¹¹ We have shown this in our control group in which there was a highly significant difference between the bony and cartilaginous sulcus angles as measured on MRI.

Our results also show this difference in dysplastic trochleae. It confirms the impression at surgery that the bony dysplasia is exacerbated by the overlying cartilaginous morphology. There was a highly significant difference between the bony and cartilaginous sulcus angles ($p < 0.001$). In all 75 axial images the cartilaginous sulcus angle was greater than the bony sulcus angle. In general, the thickness of the articular cartilage was greatest in the centre

of the trochlea and decreased over the condyles. The MRI measurement of the sulcus angles showed good repeatability when the inter- and intra-observer error was assessed. The fact that the cartilaginous contour in the dysplastic trochlea was commonly convex, and a sulcus angle of greater than 180° was more difficult to measure, explains the slightly worse repeatability results for the cartilaginous sulcus angle.

We have found a simple way to assess the morphology of both the cartilaginous and bony proximal trochlea using axial fat saturation MRI scans. In all but one axial image the cartilaginous contour was different from the osseous contour on subjective assessment. Concave bony contours were made less concave, flat or convex by the cartilage. Flat contours were made convex and convex bony contours made more convex. We have validated this scoring system using kappa statistics with 'good' to 'very good' inter- and intra-observer repeatability. The subjective assessment also correlated well with the objective measurements.

Our study shows that the cartilaginous trochlear morphology differs markedly from that of the underlying bony trochlea in patients with trochlear dysplasia. Although the bony trochlea is dysplastic, the cartilage morphology worsens this abnormal shape. Since cartilage is poorly represented on routine radiography and CT, MRI is necessary to demonstrate both the bony and cartilaginous morphology in order to facilitate surgical planning.

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