THE IMPORTANCE OF FEMORAL ROTATION IN CHONDROMALACIA PATELLAE AS SHOWN BY SERIAL RADIOGRAPHY

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A new radiological technique is presented in which serial axial radiographs of the patellofemoral joints are taken under conditions in which the muscles about the knee and hip are contracted in a manner similar to that during weight-bearing. A form of analysis has been developed whereby patellar rotation can be measured in two planes and femoral rotation about its long axis inferred.

A population of asymptomatic adults and children was investigated in this way and their results (regarded as normal) compared with those in fifteen children with idiopathic chondromalacia patellae. In the normal child the femur rotates medially with the onset of muscle activity; by contrast the children with chondromalacia show a reversal of this mechanism.

In the investigation of patellofemoral pain routine radiography plays an important part and certain specific features help to establish the cause. These features include signs of trauma, patellar displacement and lesions producing anatomical incongruity. The “skyline” view provides some of this information, some of the time, and helps elucidate the indisputably traumatic group. However in its simplest, routine, form it does little to elucidate patellofemoral relationships during activity.

Attempts have been made to assess dynamic aspects of the patellofemoral joint (Wiberg 1941; Merchant et al. 1974) and post-mortem techniques have been used to delineate the changing relationships of patella and femur (Goodfellow, Hungerford and Zindel 1976). All these studies have been carried out under highly artificial conditions. In those involving patients, skyline radiographs were taken with the knee in various positions of flexion, but with these positions held passively; in the post-mortem studies a limited attempt was made to simulate muscle action. In no study were the hamstrings and quadriceps contracted as in weight-bearing, nor was there activity in other muscles which could alter the line of action of the knee joint.

To overcome some of these deficiencies we have developed the technique of serial axial radiography under conditions of simulated weight-bearing. In order to provide detailed information on relative movements of the patella and femur we have also developed a form of analysis in which three-dimensional relationships can be inferred from two-dimensional radiographic images.

RADIOLOGICAL TECHNIQUE

Routine views (anteroposterior, lateral and axial projections) are followed by serial radiography, which requires a special technique. The patient is seated on an x-ray table (Fig. 1) facing the x-ray tube, with knees flexed and the feet firmly supported; the trunk is held upright by extending the arms backwards. The degree of knee flexion is adjusted by sliding the buttocks up or down the table. Three standard positions, with 60 degrees, 90 degrees and 120 degrees of flexion, are used. Radiographs are taken with the patient’s legs first relaxed, then tensed against the platform stop. Screen-type films in cassettes are used, supported on the anterior aspect of

Fig. 1
Axial radiography of the patellofemoral joint.

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the thighs. The lower part of the abdomen and pelvis is protected from radiation by a lead rubber sheet.

In order to guarantee reproducible and analysable results a number of precautions must be taken. First, the x-ray beam must be horizontal and parallel to the floor, and secondly, the x-ray cassette must be parallel to the x-ray tube. Errors introduced by malposition of the cassette can be compensated for at the analysis stage, provided that the film is sufficiently large to show the outline of the light-beam diaphragm on the radiograph.

2) axial projections at 60 degrees, 90 degrees and 120 degrees with the muscles tensed (simulated weight-bearing).

Analysis of radiographs
Patellar rotation was defined as the movement whereby the lower pole of the patella turns towards the head of the fibula (lateral rotation) or away from it (medial rotation). This movement was inferred from perspective changes seen on the radiographs. On the axial projec-

![Fig. 2](image)

Serial axial radiography of the patellofemoral joint. The relationship between the position of the knees and radiological appearance. (S.W.B. is simulated weight-bearing.)

The light-beam diaphragm is square and rotatable; its upper surface can therefore be aligned parallel to the floor at the time of exposure. Provided that the x-ray beam is parallel to the floor the edge of the light-beam diaphragm represents the transverse axis of the knee joint. The feet and knees of the patient are pressed together to prevent rotational artefacts.

The routine series consisted of seven radiographs: anteroposterior and lateral projections of both knees which are taken first, followed by an axial projection at 60 degrees of flexion with the patient relaxed, and (Fig.

![Fig. 3](image)

Perspective changes. Construction of lateral and medial facet lengths as used in inferring patellar rotation changes from axial radiographs.

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tions (Fig. 3) the patellar outline has a roughly triangular base and a rounded apex. The triangular base consists of the profile of the medial and lateral facets meeting at the central ridge. If the patella rotates laterally the medial facet outline comes towards the x-ray source and away from the x-ray plate; this medial facet therefore appears shorter. At the same time the lateral facet rotates away from the x-ray source and looks longer. Thus if, on the patellar outline, a triangle is drawn whose base is the maximum transverse diameter and whose sides approximate to the medial (M) and lateral (L) facets, then the lengths of these facets can be measured and an index (L/M) calculated. As the patella rotates this index changes; it increases as the patella rotates laterally and decreases with medial rotation. The ratio L/M must be used rather than individual values as this abolishes the apparent magnification produced by the knee as a whole being closer to the x-ray source.

Patellar tilt was defined as the angle which the maximum transverse diameter of the patella made to the transverse plane of the knee joint (Fig. 4), and was measured on the axial radiographs.

Condylar difference was defined as the difference in height of the lateral and medial femoral condyles as seen in the axial radiographs, these heights being measured in
relation to the horizontal (Fig. 4). Variations in condylar
difference were interpreted as indicating rotation of the
femur about its long axis. A positive condylar difference
is one in which the lateral condyle is above the medial.
With an increase in condylar difference the lateral
condyle becomes more prominent because the femur
rotates medially about its long axis. A negative condylar
difference is produced by lateral rotation of the femur;
the medial condyle rises to become more prominent
than the lateral.

All four axial views were analysed to give the $L/M$
ratio and the angle of patellar tilt. The condylar
difference was measured in the views taken at 60
degrees of flexion and the results in the passively held
knees compared with those under simulated weight-
bearing. This analysis provided information on patellar
rotation, patellar tilt and femoral rotation about its long
axis when muscle contraction was imposed on the
relaxed knee at 60 degrees of flexion. It also provided
information regarding the effect of increasing active
flexion on rotation and tilt of the patella.

EXPERIMENTAL VERIFICATION OF ANALYSIS

The above interpretations of patellar rotation and condylar differences
have been verified experimentally. An excised patella was marked
with three screws driven down its long axis at the lateral and medial
edges and at the lower pole at the junction of the facets (Fig. 5). A wire
pointer driven down the long axis was used to rotate the patella in a
controlled manner. The patella was mounted on a pile of foam
cushions and radiographs were taken at an angle and distance
comparable to the clinical situation. Radiographs of the patella were
taken in the neutral position, with the patella medially rotated, and
with it laterally rotated. The lengths of the lateral and medial facets
were measured by reference to the centre points of the screw heads.
These measurements confirmed that rotation of the patella produced
an increase in the apparent length of the facet on the side rotating
away from the x-ray source, and a decrease on the side rotating towards it.

A similar experiment was used to confirm the interpretation of the
condylar difference. Two wires were inserted into the lower end of the
femur, one through the transverse axis in the plane of the femoral
neck, and one at right angles to this through the intercondylar notch.
Radiographs of the femur were then taken in different degrees of
long-axis rotation. These confirmed that medial rotation of the femur
produced an increase in condylar difference and lateral rotation
produced a decrease.

MATERIAL

Three groups were investigated.

Asymptomatic knees in adults. Twelve knees were studied in eleven patients; with one exception these
adults had symptoms in the contralateral knee. The radiological analysis was performed on both knees, but only the asymptomatic knees are being considered in this paper. The subjects in this group were aged twenty or more, ranging from twenty to fifty-six.

Not only were the knees devoid of symptoms, they were apparently normal in all respects; there was no retropatellar tenderness or patellofemoral crepitus, nor had they been subjected to any operation. Exclusion on the basis of retropatellar tenderness or crepitus considerably reduced the number of subjects available, as many patients presenting with a lesion of one knee were found to have marked tenderness of the other. Any patient with an abnormal hip was also excluded since such abnormality might affect the alignment of the long axis of the femur.

Asymptomatic knees in children. This group consisted of ten children, aged less than twenty years (ranging from ten to nineteen) with lesions of the other knee. The criteria for inclusion were the same as in the adult group. Children with idiopathic chondromalacia patellae. Twenty knees in fifteen patients were studied. There were eight boys and seven girls; their mean age was thirteen years, ranging from nine to seventeen.

Idiopathic chondromalacia patellae was diagnosed on a history of diffuse retropatellar pain, worse on severe exercise, climbing or descending stairs, and sitting with the knees flexed, in patients less than eighteen years old at the onset of symptoms. On clinical examination all the patients had retropatellar pain brought on by a combination of patellar compression and quadriceps contraction, and all had patellar crepitus. Patients were excluded if they gave a history of patellar dislocation, subluxation, instability of the knee, locking, previous operations on the knee or hip, or if clinical or routine radiological assessment uncovered any other abnormality of the knee or hip.

Comparison of asymptomatic adults with asymptomatic children in equivalent positions failed to show any difference in patellar rotary alignment. Nevertheless the adult patella did rotate laterally, both during muscle contraction and on subsequent flexion under conditions of simulated weight-bearing, in a manner that the child’s patella did not.

In the idiopathic chondromalacic group (Fig. 7 and Table II) there was no significant change in the rotary alignment of the patella with the onset of weight-bearing, and the values measured were similar to those in asymptomatic children (the control group). With increasing flexion, however, the chondromalacic knees showed progressive patellar rotation. At 90 degrees the patella was more laterally rotated than at 60 degrees; at

Results

The results have been analysed for statistical significance by using Student’s t test or Student’s r test for paired data, whichever was appropriate. Individual values are presented as the mean of their group with the standard deviation.

Patellar rotation. In asymptomatic adults (Fig. 6 and Table I) the ratio of the length of the lateral facet to that of the medial \((L/M)\) increased from 0.94 to 1.03 on active muscle contraction at 60 degrees of flexion. The difference reached significance at the \(<0.05\) level and implied lateral rotation of the patella. On increasing active flexion the ratio increased further. No significant difference between the 60-degree and 90-degree positions was found, but comparison of the 60-degree and 120-degree positions demonstrated a real difference \((P<0.05)\). Thus active flexion was accompanied by a progressive lateral rotation of the patella in the normal adult knee.

In asymptomatic children similar analysis failed to uncover any patellar rotation, either during muscle contraction, or with increasing active flexion.

<table>
<thead>
<tr>
<th></th>
<th>Passive 60°</th>
<th>Active 60°</th>
<th>Active 90°</th>
<th>Active 120°</th>
<th>(P) 60°/120°</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adults</td>
<td>0.94±0.15</td>
<td>1.03±0.20</td>
<td>1.12±0.15</td>
<td>1.16±0.17</td>
<td>(&lt;0.05)</td>
</tr>
<tr>
<td>(P)</td>
<td>(&gt;0.10)</td>
<td>(&gt;0.10)</td>
<td>(&gt;0.10)</td>
<td>(&gt;0.10)</td>
<td></td>
</tr>
<tr>
<td>Children</td>
<td>1.11±0.29</td>
<td>1.06±0.12</td>
<td>1.01±0.07</td>
<td>1.08±0.13</td>
<td>(&gt;0.10)</td>
</tr>
<tr>
<td>(P)</td>
<td>(&gt;0.10)</td>
<td>(&gt;0.10)</td>
<td>(&gt;0.05)</td>
<td>(&gt;0.10)</td>
<td></td>
</tr>
</tbody>
</table>

The top and bottom \(P\) values refer to the sets of figures straddled; the centre \(P\) value compares the statistical validity of children with adults. On the far right the \(P\) values refer to a comparison of the 60-degree and 120-degree groups during simulated weight-bearing.
120 degrees the rotation was even greater. The increases were significant at the <0.01 level. Comparison of the rotary alignment of the patella in equivalent positions in the two groups revealed a comparable attitude at 60 degrees both in the passive and in the simulated weight-bearing phases. However, at 90 degrees with simulated weight-bearing the chondromalacic knee showed significantly greater lateral rotation of the patella than the unaffected knee and this difference persisted at 120 degrees.

**Patellar tilt.** In asymptomatic adults the angle of patellar tilt decreased from 14.0 degrees to 8.7 degrees on active muscle contraction at 60 degrees of flexion, the difference being statistically significant. Further active flexion resulted in no detectable change in the patellar angle (Fig. 8 and Table III).

In asymptomatic children also there was a reduction in the patellar angle with simulated weight-bearing at 60 degrees though the reduction (from 2.0 degrees to −3.5 degrees) did not reach statistical significance. On active flexion during simulated weight-bearing the angle increased so that in comparing the 60-degree and 120-degree positions a statistically significant (P<0.05) increase in patellar tilt of 12 degrees was seen.

In equivalent positions asymptomatic adult and children's patellae showed comparable degrees of tilt at 90 degrees and 120 degrees, but the two groups diverged at 60 degrees. In the passive state a mean difference of 12 degrees did not reach significance but with simulated weight-bearing a difference of 13 degrees was found (P<0.02). Thus in the more extended positions the patella was more angulated in relation to the transverse plane in adults than it was in children.

In idiopathic chondromalacia there was no detectable change in patellar tilt (Fig. 9 and Table IV), a situation different from that in the control group where there was increasing patellar tilt with active flexion.

**Femoral rotation.** This was inferred from the condylar difference.

In both asymptomatic adults and asymptomatic children there was an increased condylar difference when the passive position at 60 degrees of flexion was...
Figure 9 and Table IV—Patellar tilt in degrees in normal children (control) and children suffering from idiopathic chondromalacia patellae. The statistical analysis is as described under Table I.

Table V. Condylar difference in asymptomatic adults and children, measured in millimetres at 60 degrees of flexion in the passive and active (simulated weight-bearing) phases with the inferred changes in femoral rotation on an individual basis.

<table>
<thead>
<tr>
<th>Condylar difference</th>
<th>Femoral rotation (Per cent)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Passive 60°</td>
</tr>
<tr>
<td>Adults</td>
<td>11.2±9.9</td>
</tr>
<tr>
<td>Children</td>
<td>9.2±4.8</td>
</tr>
</tbody>
</table>

The statistical analysis is as described under Table I.

Table VI. Condylar difference in idiopathic chondromalacia, measured in millimetres at 60 degrees of flexion in the passive and active (simulated weight-bearing) phases with the inferred changes in femoral rotation on an individual basis.

<table>
<thead>
<tr>
<th>Condylar difference</th>
<th>Femoral rotation (per cent)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Passive 60°</td>
</tr>
<tr>
<td>Chondromalacia</td>
<td>10.3±7.6</td>
</tr>
<tr>
<td>Control</td>
<td>9.2±4.8</td>
</tr>
</tbody>
</table>

The statistical analysis is as described under Table I.
This evenly joint subjects.

In idiopathic chondromalacia the condylar difference decreased with simulated weight-bearing at 60 degrees (Table VI) the reduction being statistically significant (P<0.02) and occurring in 75 per cent of subjects. This indicated a lateral rotation of the femur in its long axis, the opposite of the normal response to weight-bearing in unaffected knees, where there was medial rotation of the femur as shown by an increase in the condylar difference.

When the two groups (asymptomatic children and those with idiopathic chondromalacia) were compared the condylar difference was comparable in the passively held knee, indicating that there was no significant lateral condylar hypoplasia in this group with chondromalacia. After muscle contraction the condylar difference was significantly greater in the control than in the chondromalacia group (Table VI).

DISCUSSION

It is accepted that the technique of simulated weight-bearing is not wholly physiological and two potential sources of error are recognised. First, the degree of hip flexion is excessive. Secondly, the positions that have been studied represent static muscle contraction rather than the fluid set of contractions and relaxations that occur during walking. Thus in strict terms simulated weight-bearing resembles a maintained squatting position more closely than it resembles standing or walking. Nonetheless, the comparison of relaxed and contracted views of the knee, at the same degree of flexion, does represent the effect of muscle activity. In addition, in its resemblance to squatting, this technique simulates a position which is known to stress the patellofemoral joint. We are further tempted to widen the application of these results by the belief that different forms of weight-bearing share common mechanisms, a belief that is reinforced by the findings of Mann and Hagy (1977) who showed that, at heel strike in normal walking, the femur rotates medially as a result of muscle contraction.

It is commonly assumed that a disturbance of normal patellofemoral relationships may give rise to patellofemoral pain. This is refined into the concepts of joint incongruity and malalignment, wherein the shearing and compression forces that fall on the patellofemoral joint during normal activity are not distributed evenly throughout the joint. The abnormal concentration of forces may occur because of anatomical incongruity of the joint, as with an osteochondral ridge (Outerbridge 1961) or following patellar dislocations and subluxations. The dynamic variant of incongruity is malalignment where the joint is apparently congruous but an abnormal line of muscle pull results in compression and shearing stresses not being distributed equally but being concentrated on a small part of the joint surfaces.

If gross examples of malalignment, such as patellar dislocation, are excluded, then a dynamic tracking abnormality of the patella in the intercondylar groove of the femur, can be produced in a number of ways. The patella can rotate or "yaw" so that the ridge between patellar facets drags across the intercondylar groove, rather than travelling straight down it. Alternatively, the patella could tilt so that one facet drags across the femur while the other lifts out of the articulation. The same effect could be produced by the femur rotating excessively one way or the other in relation to the patella. These abnormalities, if they occur, would be apparent only if the relationships of the patella to the femur are studied while the influences tending to produce them are active. Radiological assessments of the relaxed knee, in unspecified and variable rotary attitudes, would then be inadequate, as would studies which exclude the hip or which simulate only a small part of the normal muscle activity about the knee.

Using the technique of simulated weight-bearing we have shown that normal adult knee muscle contraction at 60 degrees of flexion is accompanied by lateral patellar rotation, a decrease in patellar tilt and medial rotation of the femur. In children the same happens except that there is no patellar rotation. With increasing active flexion the adult patella continues to rotate laterally but there is no further change in patellar tilt. In children there is no patellar rotation on active flexion but there is an increase in patellar tilt.

It is probable that the lie of the patella, as expressed by the patellar tilt, is simply a passive reflection of the rotary position of the long axis of the femur. This interpretation is supported by the fact that the changes in condylar difference run parallel to those in the patellar tilt: when condylar difference increases the patellar tilt decreases and vice versa. If this interpretation is correct then there is a lateral rotation of the child's femur which is not present in adults.

To summarise the foregoing discussion, we believe that the static representation of patellofemoral relationships by conventional "skyline" views has only a limited application. If information is required on patellofemoral relationships during activity then a dynamic assessment is needed, which takes into account the rotary alignment of the long axis of the lower limb. We propose that serial axial radiography, with simulated weight-bearing, goes some way to meet these requirements. Hence it seems a useful technique for the investigation of chondromalacia patellae.
There is a great deal of confusion surrounding both the diagnosis and the etiology of chondromalacia patellae. Some authors (Insall, Falvo and Wise 1976) use the term to cover all causes of patellofemoral pain except degenerative arthropy. Others think of it in terms of macropathological changes of the patellar articular surface (Goodfellow, Hungerford and Woods 1976). Unfortunately the relationship of the clinical syndrome to visible changes on the patella is not an absolute one (Dandy and Jackson 1975). Therefore in looking for the cause of chondromalacia it is important to define the term at the start.

We believe that chondromalacia patellae should be regarded as two separate entities, the first an idiopathic disorder in which there is no easily indentified patellofemoral lesion, and the other a secondary condition in which a well-established causative abnormality can be seen. We suspect that most lesions of the patellofemoral joint, however caused, will give rise to retropatellar pain, worse on prolonged sitting, on climbing stairs and on patellar compression. If the reason for this pain is obvious, as after injury, or with established rheumatoid arthritis, the "chondromalacia" is secondary and is obviously a different clinical entity from the condition which commonly affects adolescents with idiopathic disease.

This differentiation is important. It is valueless looking for a common cause in widely disparate afflictions. If a person has been hit on the patella his pain has a different cause from that of one who has not suffered violence. Nor does the fact that patellofemoral pain may be caused by (say) patellar subluxation, necessarily imply that all patients with patellofemoral pain have subluxing patellae.

It seems logical to marshal all the syndromes in which the cause of the retropatellar pain is known under the banner of secondary chondromalacia and then to dismiss them as aetiological factors in the idiopathic group. Thus when there is documented patellofemoral injury, dislocation, subluxation, gross joint incongruity, obvious limb deformity, muscle imbalance or established arthritis the patients are suffering from secondary chondromalacia. Retropatellar pain with no other abnormality of the patellofemoral or other compartment of the knee should be considered as idiopathic. One object of research is to reduce the idiopathic group by discovering more causal factors.

We have shown that in taking weight on the flexed knee there is usually a medial rotation of the femur. This presents a larger lateral condyle to the patella and presumably distributes both shearing and compression forces over a larger area. The patella then tracks without rotation or angulation in its long axis. In idiopathic chondromalacia this normal medial rotation mechanism is reversed so that the medial femoral condyle rises. It is possible that it may then abut on the medial facet of the patella, a hypothesis that would explain the finding that the pathological changes of chondromalacia tend to start on the medial patellar facet (Outerbridge and Dunlop 1975; Abernethy et al. 1978).

However, we do not claim that all patients who have retropatellar pain, or the macroscopical changes associated with chondromalacia have a common cause for their symptoms. Neither do we feel that the femoral rotation abnormality supplants all other postulated causes for the idiopathic syndrome. We simply propose that an abnormality of femoral rotation is one cause of "idiopathic chondromalacia".

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REFERENCES


