Tests on hypotheses about osteoarthritis and hip joints

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Abstract
Hypotheses suggesting that hip joints which develop osteoarthritis are congruent, have a single area of peak pressure, and have peak pressure which exceeds normal values were tested. Of 100 hip joints examined on necropsy; two showed an early stage of osteoarthritis and the geometry and pressure distribution under load were assessed in these joints. One joint was congruent, in agreement with the hypotheses, but the other was incongruent. In both joints there were several areas of high pressure, the number and location of which depended on the orientation of the joint. The measured values of pressure in the congruent joint exceeded values found previously in normal hip joints. In the incongruent hip joint the peak pressures were within normal limits.

Studies of osteoarthritis, especially in the early stages, are complicated by problems of definition and recognition criteria. The complexities are indicated by the wide range of postulated aetiologies and pathogenesis. In spite of strenuous efforts, firm agreement has not been reached on details of the subsets which have been identified clinically and epidemiologically. This contributes to the problem of classification of osteoarthritis.

This diversity of data and opinion necessitates selection in formulating problems for investigation. We were stimulated by the ideas of Bullough et al. to study the mechanics of the hip joint at necropsy. Bullough et al. postulated that the incongruent geometry of the hip protects it from developing osteoarthritis by optimising the distribution of the load. This required a means of recognising normal and osteoarthritic joints, for which we used the criteria of Byers et al. In a study of 368 hip joints at necropsy, they established the distinction between progressive (osteoarthritis) and non-progressive lesions of articular cartilage on the basis of site and macroscopic appearance, which they corroborated by histological and statistical analysis. Of the 100 hips collected for mechanical studies in this work, two were in an early stage of osteoarthritis which were excluded from the studies of normal subjects, but which were ideal for testing the hypothesis of Bullough et al.

This hypothesis was restated by Bullough. The compressibility of cartilage brings greater areas of it into contact as the load is increased, thereby maintaining a constant load per unit area. The absence of incongruence, whether developmental or acquired through joint remodelling, has the effect of creating a single peak of pressure exceeding normal limits and could lead to failure of the cartilage and the onset of osteoarthritis. Atrophy of the cartilage least in use by reason of the geometry (that...
of 10 mm diameter removed from the anterior (lesional), superior, and posterior surfaces for comparative stiffness tests.

The specimens were stored frozen at -20°C. In preparation for testing they were thawed, disarticulated, and cleared of all soft tissue, including the labrum. The ilium and femoral shaft were cut across planes (X-X and X'-X', fig 1) perpendicular to the resultant force acting on the joint in the coronal plane; the angle at which it acted remained the same in that plane during flexion, the neutral position, and extension. The prepared components were placed in cups with their cut surfaces resting on the cup base, where they were held by dental cement and a wood screw into the bone. The acetabular cup was fixed to the ram surface of a Mayes servo controlled hydraulic testing machine. The head cup was fitted into a rig fixed to the cross beam of the testing machine (fig 2). The rig allowed the direction of applied force to be adjusted as required. Throughout the study the joint was kept moist with Ringer’s solution by wrapping it in moistened cloths during a test and by soaking for 30 minutes between tests.

To obtain a cast of the interarticular space, the specimen was set in the testing position at the required orientation and a small load of 40 N was applied (the procedure is fully described in Afoke and co-workers). The position of the acetabulum in relation to the femoral head was recorded by a dial gauge; the specimen was then disarticulated. A measure of the casting material, Impregum F (a polyether rubber impression material, manufactured by ESPE, Fabrik Pharmazeutischen Prparate, Seefeld, Oberbay, Germany) was placed in the acetabulum and the joint was rearticulated to the original dial gauge position. A previous study has shown that the interarticular space, as represented by the casts, is variable in size and shape in the same specimen at different orientations. It was clear from that study that the relative geometry of a joint could be categorized from the characteristics of the cast. The joint was considered to be incongruent if (a) a large femoral head relative to its acetabulum or (b) if a relatively small femoral head was seen. The joint was classified as congruent if the femoral head and acetabulum were similar in size. This classification meets our need for describing and classifying joint geometry.

The pressure sensitive film for determining the pressure distribution was Fujifilm (Prescale). This consists of two polyester films with a combined thickness of 0.2 mm. One film is coated with a layer of microencapsulated colour forming material, and the other with a colour developing material. Papers sensitive to four ranges of pressure are available; those covering 1-10 and 7-25 MPa were used here. In practice, the low range film was used first, and when a result near to 10 MPa was obtained a second test with the higher range film was carried out. The colour which develops in the film is proportional to the applied pressure and can be quantitated in a densitometer after calibration. Calibration was performed using known loads applied to a plane ended cylinder. The pressure film was
used in the instantaneous pressure mode during the calibration and the experiments. This means that the load is applied within five seconds and removed within another five seconds without a dwell time. Pressure measurements, using Fujiifilm, have been carried out on faceted joints of the spine,13 on patellofemoral joints,14 and on normal hip joints.7 In the last of these studies pressure contours in the loaded area of the hip were drawn, and the anterosuperior surface of the cartilage was found to bear the maximum pressure, ranging from 5 to 10 MPa. The table shows the values that have been reported using this technique and the technique of instrumented prostheses and acetabula.

**EXPERIMENTAL PROCEDURE**

The paired halves of the film were prepared for use by cutting into lancelolate shapes so that they could form a hemisphere when applied to the femoral head. A layer of cling film was first applied tightly to the femoral head; the cut-out pressure film rested on this and was held in position by adhesive tape at each end. To avoid water damage, another layer of cling film was stretched over the femoral head, and the specimen was then ready for testing. The pressure tests were made with the joint in three positions and with loads simulating three phases of the walking cycle: heel strike at 3.3 times body weight; neutral at 1.3 times body weight; and pre-toe off at four times body weight. Upon completion of each test, the pressure film was peeled off the femoral head and mounted on a board. Figure 3 shows a schematic of the femoral head and acetabulum together with a pressure print. On each, an equivalent point has been marked; this shows the convention adopted for viewing the print. A double beam analogue microdensitometer in the reflection mode was used to record the absorbance of the print. These were then used in conjunction with the calibration graph to draw the pressure contour lines manually.

**Results**

**JOINT GEOMETRY**

Figures 4 and 5 show the outline of the casts in the three positions tested for specimens 1 and 2, respectively. Those from specimen 1 show very little interarticular space, suggesting a nearly congruent geometry. In contrast, specimen 2 shows an interarticular space in all three positions, indicative of a femoral head larger than its acetabulum.4

**PRESSURE MEASUREMENT**

Figure 6 shows the pressure prints and the maximum levels in high pressure areas for the nearly congruent joint (specimen 1). Figure 7 shows these high pressure areas in relation to the cartilage lesion. In flexion there is one area of above normal pressure (area A of 13.9 MPa). This is the highest pressure we have ever recorded for a hip joint.5 In the neutral position the maximum pressure is 4.9 MPa. In extension there are two areas of high pressure: area A at 8.6 and area B at 9.8 MPa. Finally, it can be seen that area A is a high pressure site in both flexion and extension, whereas area B is only so in extension.

Figure 8 shows the pressure prints and the contour lines for the three positions tested in specimen 2. These are characteristic of an incongruent joint where the head is larger than its acetabulum. Unlike the prints for specimen 1, the contact areas are large with numerous high pressure focal sites. In flexion the cartilage anterosuperiorly and posteriorly is subjected to pressures up to 10.6 and 9 MPa, respectively. In the neutral position these same areas have reduced pressures of 7 and 8 MPa, whereas in extension a maximum pressure of 8.5 MPa was found anterosuperiorly. The cartilage lesion, lying anterosuperiorly, is therefore subjected to the maximum pressure in flexion and extension.

**Discussion**

The following conclusions may be drawn with
Published values for the range of contact pressures in normal joints under physiological loads. Results given as mean (SD)

<table>
<thead>
<tr>
<th>Joint (measurement method)</th>
<th>Maximum pressure (MPa)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apophyseal (Fujifilm)</td>
<td>5.7 at 4° flexion</td>
<td>13</td>
</tr>
<tr>
<td>Patellofemoral (Fujifilm)</td>
<td>2.0 (0.1-4) at 20° flexion</td>
<td>14</td>
</tr>
<tr>
<td>Hip (Fujifilm)</td>
<td>4.4 (1.1-9) at 90° flexion</td>
<td>5</td>
</tr>
<tr>
<td>Hip (with acetabulum</td>
<td>5.26-8.57</td>
<td>15</td>
</tr>
<tr>
<td>Right hip (using an endoprosthesi)</td>
<td>9.3-11.1</td>
<td>16</td>
</tr>
</tbody>
</table>

Osteoarthritis had been established in the two specimens for an unknown length of time. It would be reasonably safe to assume that this time is relatively short in the time scale of osteoarthritis, but it is more difficult to know its length relative to the time scale of joint remodelling. Moreover, there is no knowledge of remodelling rates. Indeed, although it is accepted that the surface contours of joints can be altered, there is scant detail of how it is achieved. Osteoarthritis, or paired joints of which only one was diseased. In the latter case, probability suggests that some of the matching, visibly unaffected joints would be in an incipient stage of the disease, which might be possible to confirm by independent means.