THE RADIOLUCENT LINE BENEATH THE TIBIAL COMPONENTS OF THE OXFORD MENISCAL KNEE

SHEO B. TIBREWAL, KEITH A. GRANT, JOHN W. GOODFELLOW

From the Nuffield Orthopaedic Centre, Oxford

Radiolucent lines at the bone-cement interface beneath the tibial components were assessed in 91 consecutive Oxford meniscal knee replacements in 78 patients. Of 80 knees in which radio-opaque cement was used, a radiolucent line was observed in 77, with a radiodense line in the bone immediately adjoining. Radiolucent lines developed in the majority of patients within one year after operation. In 11 knees fixed with radiolucent cement (which precluded assessment of the radiolucent line) a radiodense line was observed beneath the lucent cement in all cases.

Histological examination of the interface obtained from secure tibial components showed the lucent zone to be composed of fibrocartilaginous connective tissue and the radiodense line to be a thick lamella of bone. It is suggested that the living bone under a rigid prosthesis requires a layer of relatively compliant fibrocartilaginous material at its interface to accommodate load-bearing. Attention is drawn to the importance of the radiodense line: its presence may constitute positive evidence that healing at the level of bone section is complete and that equilibrium is established; its absence at a mature interface may indicate disequilibrium and impending failure.

A radiolucent line is frequently observed at the interface between bone and polymethylmethacrylate cement after total joint arthroplasty. In hip arthroplasties this phenomenon has been reported to occur more frequently on the acetabular side than on the femoral side (Charnley 1970), while in total knee arthroplasties, lucency has been more commonly observed beneath the tibial component (Reckling, Asher and Dillon 1977).

Reckling \textit{et al.} (1977) observed radiolucent lines at the bone-cement interface beneath 42 of 59 geometric implants and beneath 3 of 16 modular prostheses. Insall \textit{et al.} (1976) observed a radiolucent line under the tibial components in 60\% of condylar replacements and around the femoral components in 45\% of \textit{GUEPAR} replacements. In a more recent study Insall, Lachiewicz and Burstein (1982) reported a 32\% incidence of incomplete tibial radiolucent lines with the posterior stabilised total condylar prosthesis, as compared to an incidence of 36\% in patients with total condylar prostheses followed up for five years.

The clinical significance and precise aetiology of this radiolucent line is not fully understood. However, it would appear that its presence does not necessarily indicate loosening or impending prosthetic failure (Charnley 1970; Galante, Rostoker and Doyle 1975; Reckling \textit{et al.} 1977; Beckenbaugh and Ilstrup 1978; Galante 1980).

Various theories have been proposed to explain the phenomenon:

1. Failure to pack radiodense cement tightly against the interstices of the cancellous bone (Andersson, Freeman and Swanson 1972).
2. Thermal necrosis due to the polymerisation heat of cement, with subsequent bone absorption (Charnley 1970; Slooff 1971).
3. Micromotion at the bone-cement interface causing the formation of a layer of condensed cancellous bone, distant from the cement, and a radiolucent zone of fibrous tissue between the bone and the cement (Charnley 1970; Willert, Ludwig and Smailitch 1974).
5. O'Connor, Goodfellow and Perry (1982) suggested that the cut trabeculae at the plane of bone section joined together to form a new subchondral bone plate. On the surface of this plate a layer of connective tissue formed; this was reminiscent of normal articular cartilage. Under these circumstances, it was proposed that living bone could thrive in the stress field applied to it.

Previous reports provided little information on the time of development or on the extent and progression of the radiolucent line. We have studied its formation and progress at the bone-cement interface beneath the tibial
components of 91 Oxford knee replacements. As will appear, the flat undersurface of the metal tibial component of this prosthesis makes it easy to assess the appearance of a radiolucent line in the radiographs.

The prosthesis. The Oxford knee consists of metal tibial and femoral resurfacing components; between these are mobile "meniscal" bearings. Figure 1 shows a tibial component. Its undersurface is flat and carries a keel 11 mm deep and 3 mm thick. It is seated on the cut surface of the tibia, in which a narrow groove is cut to receive the keel. A small quantity of polymethylmethacrylate cement is used as a grout. Three sizes of tibial component were used to match the various sizes of bone. A detailed description of the prosthesis is presented elsewhere (Goodfellow and O'Connor 1978, 1982). Since the upper surfaces of the tibial components are flat, the meniscal bearings are free to slide in any direction upon them. The tibial components of the prosthesis are therefore spared from transmitting shear or tensile forces; the bone beneath them experiences mainly compressive stress (O'Connor et al. 1982).

METHODS
Anteroposterior radiographs were usually taken three months and six months after the operation and thereafter at yearly intervals. These follow-up films were taken on a standard fluoroscopic screening table with an undercouch tube and image intensifier. The use of screening allowed the knee to be flexed or extended until the surface of the tibial prosthesis in the anteroposterior projection lay parallel to the x-ray beam. This meant that the distances of the x-ray anode from the knee and from the film varied, causing different degrees of magnification. By measuring the apparent thickness of the tibial component, a correction factor could be applied so that direct comparison was possible from film to film. As the two tibial components are not necessarily exactly parallel with each other, two films in this projection were taken, one for the medial and the other for the lateral component.

We have only considered the lucent lines beneath the tibial components of the prosthesis. It is not easy to obtain comparable serial radiographs for the assessment of lucency beneath the femoral components because of their curved form. In 11 of the earlier prostheses.

PATIENTS
Between June 1978 and December 1981, 93 Oxford knee replacements were performed on 82 patients at the Nuffield Orthopaedic Centre, Oxford. Four of these patients were excluded from the study, because two died before the first follow-up and two were lost to follow-up for other reasons. One patient, with bilateral knee replacement, emigrated immediately after his second operation and this joint was excluded from the study. Three patients had had a prototype meniscal knee replacement* in the other knee in 1977 and the opportunity was taken to include these prostheses in the study. We assessed therefore 91 knee prostheses in 78 patients followed up to January 1983.

*The tibial component in this implant was similar, but not identical, to that used in the Oxford knee.
radiolucent cement was used. Obviously this precludes assessment of the radiolucent line but it was still possible in these to assess the appearance of the radiodense line surrounding the cement.

Each follow-up film was assessed by two observers, an orthopaedic surgeon and a radiologist (SBT and KAG respectively), who made their observations without knowledge of the clinical condition of the patient. For the purpose of evaluating the extent of the lucent zones, the tibial prosthesis was divided into four parts (Fig. 1). A diagrammatic representation of the bone-cement interface is shown in Figure 2.

RESULTS

Of the 80 knees with radio-opaque cement, 77 developed a radiolucent line around the whole or part of a tibial component at some stage of the follow-up period. In the remaining three knees (three patients; two with osteoarthritis and one with peroneal muscular dystrophy) no radiolucent line was seen at their last follow-up. For these patients the mean follow-up time was 19 months.

Table I. The pre-operative diagnoses and time at which radioluency first developed

<table>
<thead>
<tr>
<th>Time at which radioluency first developed (months)</th>
<th>Number of knees</th>
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<tbody>
<tr>
<td></td>
<td>Osteoarthritis</td>
</tr>
<tr>
<td>≤ 3</td>
<td>10</td>
</tr>
<tr>
<td>4-6</td>
<td>8</td>
</tr>
<tr>
<td>7-12</td>
<td>16</td>
</tr>
<tr>
<td>13-18</td>
<td>1</td>
</tr>
<tr>
<td>19-24</td>
<td>1</td>
</tr>
</tbody>
</table>

Table II. Extent and site of radiolucent lines around tibial components

<table>
<thead>
<tr>
<th></th>
<th>Both components</th>
<th>Medial component only</th>
<th>Lateral component only</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complete radiolucent line</td>
<td>9</td>
<td>9</td>
<td>6</td>
</tr>
<tr>
<td>Incomplete radiolucent line</td>
<td>39</td>
<td>12</td>
<td>14</td>
</tr>
</tbody>
</table>

Table III. Site of incomplete radiolucent lines around various parts of tibial component

<table>
<thead>
<tr>
<th></th>
<th>Both components</th>
<th>Medial component only</th>
<th>Lateral component only</th>
<th>No involvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flat outer component</td>
<td>33</td>
<td>13</td>
<td>15</td>
<td>4</td>
</tr>
<tr>
<td>Flat inner component</td>
<td>8</td>
<td>7</td>
<td>11</td>
<td>39</td>
</tr>
<tr>
<td>Keel</td>
<td>14</td>
<td>9</td>
<td>12</td>
<td>30</td>
</tr>
<tr>
<td>Lip</td>
<td>5</td>
<td>10</td>
<td>15</td>
<td>35</td>
</tr>
</tbody>
</table>

complete around one component in 15 (medial component only in 9; lateral component only in 6; Table II). Four of the 15 knees with a complete radiolucent line under one of the components did not have a line under the other.

An incomplete radiolucent line was seen in 65 knees; under both components in 39, under the medial component only in 12, and under the lateral component only in 14. Of these 65 with incomplete lucency under one of the components a complete lucent line was seen under the other component in 12.

When incomplete, the radiolucent lines lay under the various parts of the prosthesis as follows: the flat outer component in 61 of the 65 knees, the flat inner component in 26, the keel in 35, and the lip in 30. Table III shows the distribution.

Progress of the radiolucent line. Once developed, the radiolucent line remained static in its extent and its thickness in 71 cases. Figures 4 and 5 show two stages in the development of the line and Figure 6 the final stage.
which usually remained unaltered. In six cases the luency progressed. In these the lucent line was observed immediately after operation in five; in the remaining case it appeared at three months. The lucent lines in these cases progressed in extent, but not in thickness, for a variable period of 6 to 12 months after first appearing and then became static. The maximum thickness of the radiolucent line at the last follow-up was as follows: 1 mm in 64 knees, 2 mm in 10 knees, and 3 mm in 3 knees.

No correlation was found between the presence or absence of radiolucent lines and the clinical results as measured by the British Orthopaedic Association knee assessment form (Aichroth et al. 1978).

The radiodense line. Eighty-eight cases (with and without radio-opaque cement) were studied, excluding three in which there was no lucent line. In 85 knees (out of 88) a sclerotic margin developed in the bone adjacent to the lucent area. In the 11 knees in which radiolucent cement was used the radiodense line completely surrounded the bone-cement interface of both components (Figs 7 and 8). The mean time for the sclerotic margin to appear was 11 months, ranging from 2 to 22 months.

In three knees no sclerotic margin had developed at the bone-cement interface at the time of maximum follow-up. Two of these had regular margins to the lucent zone. In one patient there were irregular, non-sclerotic edges under the lateral component with a radiolucent line 3 mm wide which had progressively thickened; the medial component in this knee had a sclerotic margin.
Cases requiring re-operation. In this series there were five cases which required re-operation. Two patients had dislocation of a meniscal bearing. Of these, one had received radiolucent cement and had well-defined sclerotic margins around the prosthesis. The other had radiopaque cement and a complete lucent line, 1 mm thick, under both tibial components. At re-operation, in both these cases, it was found that the tibial components were securely fixed to the bone. Histological specimens of the radiolucent zone were obtained from one of these two patients when arthrodesis was performed for progressive stretching of ligaments. Figures 9 and 10 show a section through the radiolucent zone and the bone beneath it.

In two patients, both with rheumatoid arthritis, a radiolucent area developed in the bone at a distance from the radiolucent line. In one of these cases partial collapse of the tibial condyle occurred, three years after the lucency was first observed, and finally a fracture of the medial tibial condyle developed (Figs 11 to 13). In the second case no collapse or fracture was observed but the patient presented with a dislocated meniscal bearing and, at operation, the tibial component was found to be loose.

In a further case radiographs taken 16 months after operation suggested sinking of the medial tibial component. The radiolucent line increased in thickness up to 3 mm and had ill-defined margins, without the normal sclerosis. This patient also presented with a dislocation of the meniscal bearing and at operation was found to have a loose medial tibial component (which was re-cemented).

DISCUSSION

In our study a radiolucent line was observed to develop in 77 of 80 knees in which radio-opaque cement was used, an incidence of 96.25%.

Our radiographic technique, using screening, allows comparable follow-up films to be obtained so that the development, extent and progress of the radiolucent lines can be accurately assessed. For various reasons several of our patients had standard radiographs of the knee taken. In these the radiolucent line was often not visible or its extent was greatly underestimated as compared to that on properly aligned films. We believe that the different incidence of radiolucent lines observed by previous authors may reflect no more than differences in radiographic techniques (Figs 14 and 15).

Radiolucent lines developed within one year of the operation in the majority of patients: indeed, many lucent lines were observed to have already developed during the first six months after operation. The thickness of the lines was usually about 1 mm and never more than 3 mm. Once developed their appearance usually remained static and no significant increase in thickness or extent was seen on the further follow-up films (Figs 4 to 8). The six knees which had a radiolucent line immediately after operation probably represent cases of failure to pack the cement at the bone-cement interface.

Radiographically the bone-cement interface consists of two zones, the lucent line, already discussed, and a thin radiodense line in the bone immediately adjoining. In the 11 cases with radiolucent cement, in which it was best seen, a complete radiodense margin developed at the interface in every instance. In these, the radiolucent line cannot be seen but its presence may be inferred.

The histology of the interface (Figs 9 and 10), obtained from the secure tibial components in one case, shows the lucent area to be composed of fibrocartilaginous connective tissue and the sclerotic zone to be a thick lamella of bone. Charnley (1970) reported a similar histological picture at the bone-cement junction up to seven years after implantation in clinically successful and secure femoral prostheses. Radin et al. (1982) in their studies of the bone-cement interface after experimental total hip replacement in sheep, also reported similar histological appearances in animals killed at 12 months. The incidence of a radiolucent line on sequential radiographs was 100%; the line completely surrounded the femoral component in all but one of the specimens.

We believe that the fibrocartilaginous zone accommodates the different strains which inevitably develop when a rigid implant transmits load to a relatively flexible bone. A compliant layer seems to be a universal
requirement at such an interface, independent of the method of fixation. It has been reported to develop in similar quantity and type in both cemented and uncemented experimental implants (Hori and Lewis 1982), and such layers have been reported, albeit with varying frequency, under both components of hip and knee arthroplasties in man. Although our study was limited to the tibial component, very similar radiolucent changes were frequently observed on the femoral side; usually these completely surrounded the implant.

Roentgen stereophotogrammetric analysis has actually demonstrated micromotion at the bone-cement interface in patients with clinically successful total condylar prostheses in which there was a radiolucent zone under the tibial components (Selvik et al. 1983). The mean maximum rotation was 0.7°, corresponding to a mean maximum deformation of 0.4 mm at the interface. These micromovements can be explained on the basis of the elastic properties of the fibrocartilaginous material at the interface which acts as a buffer between materials with different Young’s moduli.

The static nature of the radiolucent line in clinically asymptomatic patients implies a state of equilibrium between the mechanics and the biology. Of course the presence or absence of a radiolucent zone cannot be seen when a radiolucent implant is used without cement. Nor may it be possible to detect its presence beneath a radiodense implant if the surfaces of the prosthesis are non-planar. Thus the irregular surfaces of some metal prostheses designed for cementless fixation would obscure the fibrocartilaginous zone in their corrugations, were it present.

CONCLUSIONS

Our observations add weight to the increasing body of experimental and clinical evidence that the interface between living bone and a load-bearing prosthesis is usually filled by a layer of relatively compliant fibrocartilaginous material. There are good mechanical reasons for its presence.

Once it has healed, the restructured bone end can resume its load-bearing function and remain in equilibrium with the prosthesis for long periods. Since the remodelling process which produces the radiolucent zone and the radiodense line is not complete for many months, it may be wise whenever possible to restrict the load applied to prosthetic implants during this period.

We draw attention to the importance of the radiodense line which may constitute positive evidence that healing is complete and that the equilibrium is established. Absence of a radiodense line at a mature interface may indicate disequilibrium and impending failure.

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REFERENCES


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