Hydroxyapatite-ceramic-coated femoral stems in revision hip surgery

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We describe the clinical and radiological results of 120 consecutive revision hip replacements in 107 patients, using the JRI Furlong hydroxyapatite-ceramic-coated femoral component. The mean age of the patients at operation was 71 years (36 to 92) and the mean length of follow-up 8.0 years (5.0 to 12.4). We included patients on whom previous revision hip surgery had taken place. The patients were independently reviewed and scored using the Harris hip score, the Western Ontario and McMaster Universities osteoarthritis index (WOMAC) and the Charnley modification of the Merle d’Aubigné and Postel score. Radiographs were assessed by three reviewers for the formation of new bone, osteolysis, osseointegration and radiolucent lines in each Gruen zone.

The mean Harris hip score was 85.8 (42 to 100) at the latest post-operative review. The mean WOMAC and Merle d’Aubigné and Postel scores were 34.5 and 14.8, respectively. The mean visual analogue score for pain (possible range 0 to 10) was 1.2 overall, but 0.5 specifically for mid-thigh pain. There were no revisions of the femoral component for aseptic loosening. There were four re-revisions, three for infection and one for recurrent dislocation. Radiological review of all the femoral components, including the four re-revisions showed stable bony ingrowth and no new radiolucent lines in any zone. Using revision or impending revision for aseptic loosening as an end-point, the cumulative survival of the femoral component at ten years was 100% (95% confidence interval 94 to 100). We present excellent medium- to long-term clinical, radiological and survivorship results with the fully hydroxyapatite-ceramic-coated femoral component in revision hip surgery.

The goals of femoral revision surgery are to regain long-term mechanical stability and to prevent further bone loss. Stable fixation of an implant depends on the design of the component, the surgical technique and pre-existent bone stock. The high incidence of aseptic failure after cemented revision total hip replacement has been well documented.1-4 Cementless revision of the stem with proximally porous-coated implants also has a considerable rate of failure because the implants rely on maximum bone contact in the proximal metaphysis where the bone stock is often deficient.5 An intervening fibrous layer between bone and the implant can prevent complete osseointegration. Fully porous-coated stems aim to reduce the demand on the damaged proximal metaphysis in order to allow reliable biological fixation.6

Hydroxyapatite-ceramic (HAC) coating, first introduced in 1985, encourages the formation of a firm biological bond between bone and the implant. The material has shown promising results in primary hip surgery,7-12 and there has been increasing interest in its use in revision hip arthroplasty.

Our aim was to evaluate the clinical and radiological outcome of a fully HAC-coated femoral component in revision hip surgery.

Patients and Methods
Between 1991 and 1999, we performed 120 consecutive cementless revision hip arthroplasties in 107 patients (43 men, 64 women) with a mean age at surgery of 71 years (36 to 92). The mean length of follow-up was eight years (5.0 to 12.4). Most of the procedures (83 hips, 69%) were performed by the senior author (AJE), the remainder (37 hips, 31%), being undertaken by other consultants in our unit. All patients who received a JRI Furlong HAC-coated femoral component (JRI Instrumentation Ltd, London, UK), with a minimum follow-up of five years, were included irrespective of their primary aetiology. We also included those patients who had already undergone revision hip surgery (Table I).
The indications for revision surgery in 120 hips

<table>
<thead>
<tr>
<th>Indication</th>
<th>Number of hips</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aseptic loosening</td>
<td>99</td>
</tr>
<tr>
<td>Sepsis</td>
<td>10</td>
</tr>
<tr>
<td>Periprosthetic fracture</td>
<td>5</td>
</tr>
<tr>
<td>Recurrent dislocation</td>
<td>3</td>
</tr>
<tr>
<td>Persistent pain</td>
<td>3</td>
</tr>
</tbody>
</table>

* all performed as two-stage procedures

The JRI Furlong HAC stem is a collared implant made from titanium alloy. It is fully-coated with a hydroxyapatite ceramic layer of 150 µm which is more than 90% pure and applied by a plasma-spray process performed in a vacuum. The coating has a crystallinity of 65% and a density of 85%.

We used a standard posterior approach in 82 hips (68.3%), a posterior approach with trochanteric osteotomy (re-attached by cerclage wires) in 15 (12.5%) and an anterolateral approach in 23 (19.2%). We removed all cement as well as the necortex and pedestal and performed sequential reaming in order to achieve good endosteal contact. This was followed by progressive proximal broaching until we achieved satisfactory filling of the canal. A range of diameter of the femoral stem (9 to 18 mm) and two stem lengths were used, a standard 200-mm stem in 102 hips (85%) and a 250-mm stem in 18 (15%) in order to obtain a diaphyseal fit when a proximal metaphyseal fit was impossible.

In 97 reconstructions (81%), we revised both the femoral and acetabular components. In 23 (19%), we revised the femoral component only. We used a cobalt-chrome femoral head in 78 (65%) reconstructions and a ceramic (alumina oxide) femoral head in 42 (35%) for those patients in whom we considered there was a risk of later failure from osteolysis. Of the femoral heads, 108 (90%) were 28 mm, ten (8%) were 32 mm, and two (2%) were 22.225 mm in diameter. All acetabular components had a polyethylene-bearing surface.

The patients were reviewed post-operatively at six weeks, and at one, five and ten years. Clinical examination was performed and the following were recorded: a visual analogue score for pain; the Harris hip score;13 the Western Ontario and McMaster Universities osteoarthritis index (WOMAC);14 Charnley’s modification15 of the score of Merle d’Aubigné and Postel16 for pain, range of movement and function; presence or absence of thigh pain; and the level of physical activity. There were 33 hips in Charnley grade A, 48 in grade B and 39 in grade C.

Three hip surgeons (AJE, JCL, PAM), blinded to the clinical results, undertook an independent radiological evaluation and the consensus was used. The location and extent of femoral defects were classified from both pre-operative radiographs and intra-operative findings, as described by Paprosky, Lawrence and Cameron.17 There were 23 hips with a Paprosky type I defect, 54 with a type II defect, 30 with a type IIIa defect and 13 with a type IIIb defect. Anteroposterior and true lateral radiographs were obtained at each follow-up visit. On sequential radiographs the femoral components were assessed for the presence of new bone, loss of bone, osteolysis and any radiolucent lines in each zone of Gruen, McNeice and Amstutz.18 Peri- and post-operative periprosthetic fractures were noted if present.

The stability of the femoral component was assessed using criteria devised by the senior author and based upon both the criteria of Engh, Massin and Suthers,19 and experience over 15 years of the use of fully HAC-coated femoral components. Radiologically, a femoral component was regarded as osseointegrated when all of the following primary criteria had been met:

1) Evidence of cortical ingrowth of bone into the tip of the stem. This might be on one side only, usually lateral, where the stem is compressed against the femoral cortex (Figs 1 and 2).

2) Bone trabeculae traversing from the cortex to the stem at the cone of the prosthesis.

These are thought to be evidence of formation of bone along new lines of stress and radiate inferiorly from the stem to the cortex on all sides (Figs 1 and 2).

3) The absence of reactive lines around the prosthesis. An area immediately adjacent to the prosthesis and separated from normal bone by a reactive demarcation line suggests that osseointegration has not occurred. Reactive lines are rarely seen in uncomplicated HAC primary total hip replacements and demarcation lines between the prosthesis and normal bone must be viewed with suspicion. They may also be misleading since they can occur as a result of reaming during removal of cement. They may also represent residual cement. However, reactive lines are also seen when
there is deep infection around an HAC-coated femoral component and when bone ongrowth has not occurred.

4) Successive radiographs demonstrating no subsidence. Secondary criteria were also important but they only occurred when the primary criteria were met. These were as follows:

1) Horizontal trabecular bridging between the cortex and stem at 90° to the femoral cortex. This usually occurred on the medial aspect of the stem only, possibly representing formation of bone on the tension side of the prosthesis (Figs 1 and 2).

2) Reconstitution of femoral cortical bone and in-filling of lytic cavities adjacent to the prosthesis. This appeared to depend upon both time and the quality of bone. They occurred more slowly in osteoporotic bone and were most rapid in strong cortical bone in active individuals (Figs 1 and 3).

3) Improvement in the overall bone quality on successive radiographs (Figs 1 and 3).

We performed a survival analysis for the femoral component using a cumulative life-table method with two endpoints. The first was revision or impending revision for...
aseptic loosening and the second re-operations of any kind on the component. We determined the confidence intervals from the effective number at risk using the Rothman equation."20,21

**Results**

Of our 107 patients (120 hips), three (three hips) were lost to follow-up after five years. Therefore, the fate of 117 implants (104 patients) was known at the final review. At the latest review the mean Harris hip score was 86 (42 to 100) with 89 (86%) patients being graded as good or excellent (score of 80 or above). The difference in Harris hip score (mean 87) between the three Charnley groups was not significant (p = 0.63).

The mean Harris hip score was 89 for those with a Paprosky type-I defect, 87 for those with a type-II defect and 85 for those with a type-III defect. Again, this difference was not significant (p = 0.65). The mean WOMAC score at the latest review was 34.5 (24 to 77). For the Charnley modification of the Merle d'Aubigné and Postel score the mean scores were 5.3 for pain, 5.0 for function and 4.5 for range of movement. A return to outdoor activities or sports was possible in 62% of patients. The mean visual analogue score (maximum possible 10) for overall pain was 1.2 (0 to 7) although the mean score specifically for mid-thigh pain was 0.5 (0 to 6). There was no thigh pain in 83 (80%) patients, minimal thigh pain in 19 (18%) and moderate thigh pain in two (2%). No patient experienced severe thigh pain.

There were 12 intra-operative fractures, three perforations of the shaft caused by either cement or removal of the femoral component and three fractures of the greater trochanter and six of the femoral shaft associated with insertion of the component. Four fractures of the shaft were stabilised by cerclage wires during surgery and one requiring a strut allograft supplemented by morcellised bone. All intra-operative fractures healed. Autologous bone graft was used in five other femoral reconstructions to supplement osseointegration.

There were five late (more than one year after revision) traumatic peri-prosthetic fractures. Three were treated non-operatively and two were stabilised by plates. The femoral components were deemed to be secure and left in situ.

Dislocation was seen in nine (7.5%) hips. Two required revision of the acetabular component only, and one required revision of both components, the femoral component being changed to a long, distally-locked HAC-coated design (Cannulok, Orthodesign Ltd, Dorset, UK). Three femoral components were revised for infection, although all were found to be osseointegrated at surgery. A total of four JRI Furlong stems was revised, with no impending revisions.

Wound infections were seen in three hips and were successfully treated by debridement. In all 12 re-operations (six acetabular revisions, one liner change, two peri-prosthetic fractures, three wound debridements) the stem was osseointegrated radiologically at the time of surgery and left in situ.

**Radiological review.** Review of the femoral components revealed that all were stable with evidence of osseointegration and with no radiolucent lines around the stem. No new osteolysis was seen in any zone. In nine hips there was some resorption of bone under the collar of the component. This did not extend below the lesser trochanter and did not appear to threaten fixation of the stem. Bone reconstitution was seen in 51% of the Gruen zones with only 2.3% of zones showing loss of bone, usually in an isolated distribution. Three femoral stems were associated with loss of bone in multiple zones. Two were in hips with deep infection, and the third was in a patient who showed features of marked proximal stress shielding and evidence of transfer of the distal load.

**Survivorship.** We constructed survivorship curves for the HAC-coated femoral component using the information from the cumulative life tables (Table III). Survival analysis ended when the actual number at risk dropped below ten, as suggested by Murray et al.20 With revision or impending revision for aseptic loosening as an end-point, survivorship for the femoral component was 100% at 11 years (95% CI 92 to 100) (Fig. 4). If the three losses to follow-up were counted as failures the survivorship was 92.5% at 11 years (95% CI 81 to 97). With any re-operation on the femoral component as an end-

### Table III. Clinical survivorship for aseptic loosening with revision or impending revision as an end-point

<table>
<thead>
<tr>
<th>Years since operation</th>
<th>Number of hips at start</th>
<th>Failures</th>
<th>Withdrawn</th>
<th>Number at risk</th>
<th>Effective number at risk</th>
<th>Cumulative survival rate (%)</th>
<th>95% confidence interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 to 1</td>
<td>120</td>
<td>0</td>
<td>1</td>
<td>119.5</td>
<td>119.5</td>
<td>100</td>
<td>0.97 to 1.00</td>
</tr>
<tr>
<td>1 to 2</td>
<td>119</td>
<td>0</td>
<td>4</td>
<td>117.0</td>
<td>118.24</td>
<td>100</td>
<td>0.97 to 1.00</td>
</tr>
<tr>
<td>2 to 3</td>
<td>115</td>
<td>0</td>
<td>1</td>
<td>114.5</td>
<td>116.96</td>
<td>100</td>
<td>0.97 to 1.00</td>
</tr>
<tr>
<td>3 to 4</td>
<td>114</td>
<td>0</td>
<td>1</td>
<td>113.5</td>
<td>116.08</td>
<td>100</td>
<td>0.97 to 1.00</td>
</tr>
<tr>
<td>4 to 5</td>
<td>113</td>
<td>0</td>
<td>0</td>
<td>113.0</td>
<td>115.45</td>
<td>100</td>
<td>0.97 to 1.00</td>
</tr>
<tr>
<td>5 to 6</td>
<td>113</td>
<td>0</td>
<td>22</td>
<td>102.0</td>
<td>112.97</td>
<td>100</td>
<td>0.97 to 1.00</td>
</tr>
<tr>
<td>6 to 7</td>
<td>91</td>
<td>0</td>
<td>15</td>
<td>83.5</td>
<td>107.55</td>
<td>100</td>
<td>0.97 to 1.00</td>
</tr>
<tr>
<td>7 to 8</td>
<td>76</td>
<td>0</td>
<td>24</td>
<td>64.0</td>
<td>99.12</td>
<td>100</td>
<td>0.96 to 1.00</td>
</tr>
<tr>
<td>8 to 9</td>
<td>52</td>
<td>0</td>
<td>21</td>
<td>41.5</td>
<td>85.87</td>
<td>100</td>
<td>0.96 to 1.00</td>
</tr>
<tr>
<td>9 to 10</td>
<td>31</td>
<td>0</td>
<td>17</td>
<td>22.5</td>
<td>67.00</td>
<td>100</td>
<td>0.95 to 1.00</td>
</tr>
<tr>
<td>10 to 11</td>
<td>14</td>
<td>0</td>
<td>8</td>
<td>10.0</td>
<td>44.13</td>
<td>100</td>
<td>0.92 to 1.00</td>
</tr>
</tbody>
</table>
point, the survivorship was 84% at 12 years (95% CI 65 to 94) (Fig. 5).

Discussion

There has been no medium- to long-term follow-up of HAC-coated implants in revision hip surgery although their results in primary hip arthroplasty have been excellent.\textsuperscript{7-12}

The results of cemented femoral revision surgery have been disappointing, with rates of failure of approximately 10% to 30% at five years\textsuperscript{1-4} although better cementing techniques have improved this to 10% at ten years.\textsuperscript{22-24} Impaction bone grafting has also become popular, with variable early results.\textsuperscript{25,26} Cementless reconstruction, with porous-coated implants, aims to provide permanent biological fixation between bone and the femoral component. The results with proximally porous-coated implants have been unpredictable in revision surgery because of the demands placed upon compromised proximal femoral bone stock. Berry et al\textsuperscript{5} reviewed 375 proximally porous-coated revision arthroplasties with six different designs of implant. The re-revision rate was 16% with 38% showing radiological evidence of femoral loosening.

Engh et al\textsuperscript{27} using proximally-coated porous implants, reported 127 femoral revisions at a mean of 4.4 years. They graded 107 as optimal, 15 as stable with fibrous encapsulation while five had failure of fixation. Weeden and Paprosky,\textsuperscript{6} using extensively-coated porous implants in 170 hips at a mean follow-up of 14 years, showed that 82% had radiological evidence of bone ingrowth, 14% (24) had a stable fibrous fixation and 4% (seven) were radiologically unstable. All patients with unstable implants had significant thigh pain.

Femoral bone loss is present in most revisions. Our results show that the JRI Furlong HAC-coated implant can form a secure biological bond with the host femur in revision arthroplasty even in the presence of bone loss. Serial review of radiographs revealed reconstitution of femoral cortical bone without the need for bone grafting. The HAC-coating induces the formation of new bone on its surface when in the direct vicinity of living bone.\textsuperscript{28} We deliberately used bone graft sparingly and chose to rely on the osteoconductive properties of hydroxyapatite which has been shown to encourage healing of fractures\textsuperscript{29,30} and all of our 12 intra-operative fractures and/or stem perforations healed.

The low incidence of reported thigh pain was encouraging, indicating clinically that osseointegration of the femoral component had occurred. Possible causes of thigh pain after cementless hip arthroplasty include prosthesis-bone micromovement and/or excessive transfer of stress to the femur. With immediate stability of the implant thigh pain can be reduced.\textsuperscript{31,32} The JRI Furlong stem is made from titanium alloy and is fully coated with HAC, promoting early biological distal fixation and eliminating micromovement at the prosthesis-bone interface.

Infection was the cause of the initial revision in ten hips. Managed in a two-stage procedure, nine had a successful outcome with no recurrence of infection. One patient with a persistent deep infection, despite multiple debridements, underwent a Girdlestone procedure 20 months after implantation although even then we noted some reconstitution of femoral bone stock at surgery. Our results correlate with other studies using uncemented implants in the presence of infection.\textsuperscript{33,34}

There have been concerns about the degradation of HAC leading to third-body wear particles.\textsuperscript{35} However, retrieval studies have failed to detect HAC particles within the joint space.\textsuperscript{36} The theoretical problem of hydroxyapatite third-body wear predisposing to osteolysis was not a feature in our series.

We had no revisions of the femoral component for aseptic loosening and believe that once a biological bond with the host femur has been achieved it is likely to be permanent. Animal studies have confirmed that HAC coating of implants inhibits the peri-implant migration of debris par-
articles by creating a seal of enhanced bone growth. In man this seal may be beneficial, resulting in the complete absence of distal osteolysis in both our study and others. Specifically we saw no evidence of any new osteolysis in any zone around any femoral component. It thus appears that the JRI Furlong HAC-fully-coated implant in revision surgery demonstrates satisfying results in the mid to long term, a low rate of thigh pain, reliable osseointegration, no need for a bone graft and the absence of distal osteolysis.

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

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