Pain in the well-fixed, aseptic titanium hip replacement

THE ROLE OF CORROSION

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We have investigated nine patients with cemented Furlong (JRI, London, UK) titanium hip replacements who presented with early pain despite a well-fixed, aseptic prosthesis. All were followed up clinically and radiologically at regular intervals. Pain was located in the thigh and was worse at night. Radiographs showed cortical hypertrophy of the femur around the tip of the stem. Eight of the nine patients subsequently required single-stage revision using an uncemented prosthesis, which relieved the pain. At revision, the pH of the tip of the stem was found to be highly acidic with macroscopic evidence of corrosion consisting of multiple layers of titanium oxides when studied by X-ray dispersive analysis. Cemented titanium implants have a potential for crevice corrosion leading to cortical hypertrophy and intractable pain.

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Titanium has been used extensively for the femoral component of hip prostheses because of its favourable biological and mechanical properties.¹ Although black staining of the tissues surrounding titanium implants²⁻⁴ and galvanic corrosion between modular components such as the head-neck interface⁵⁻¹⁰ have been well documented, corrosion of the titanium alloy stem itself was thought to be very rare because of passivation by a layer of titanium oxide.

We describe the characteristics of nine corroded cemented titanium Furlong (JRI, London, UK) stems with a pattern similar to that reported by Willert et al.⁹ Within 60

months of the initial operation, all patients presented with intractable night pain at the site of a well-fixed, total hip replacement but with no clinical, serological or biopsy evidence of sepsis.

Patients and Methods

Nine patients, three men and six women, with a mean age of 73 years, were identified over a period of three years. All had undergone replacement with Furlong primary cemented femoral components for osteoarthritis using polished titanium-alloy (Ti6Al4V) stems, polyethylene sockets or liners (JRI), polyethylene cement restrictors (Hardinge Cement Restrictor, Cirencester, UK), Palacos R cement (Smith and Nephew, Cambridge, UK) and cobalt-chrome heads (JRI). Second-generation cementing techniques had been used and no intra-operative or post-operative complications had been encountered. All the patients were reviewed clinically and radiologically. The investigations in each case included a full blood count, measurement of the ESR and the level of C-reactive protein, serial radiography and ⁹⁹Tc bone scanning.

Eight of the nine patients subsequently required revision. At operation, as the stem was removed, universal indicator tape dampened with distilled water was placed over the corroded area and the pH recorded. Cultures were then taken from the stem, the surrounding body fluids and local tissues. All stems were revised to uncemented hydroxyapatite or porous-coated prostheses. The stems were invariably well fixed and extremely difficult to remove. An extended trochanteric osteotomy was necessary in two cases.

Four of the retrieved corroded implants and two control prostheses, one of which was off-the-shelf and the other retrieved, not corroded, from another patient, were examined. After a detailed map of the corrosion had been made, representative samples from each implant were examined by SEM and energy-dispersive X-ray analysis (EDXA) to determine the chemical properties of the products of corrosion.

Results

Pain had begun at a mean of 2.9 years (1 to 5) after the initial operation. It was located in the thigh, occurred at rest

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Fig. 1a

Fig. 1b

Radiographs of a cemented Furlong titanium total hip replacement a) two days after implantation and b) two years after implantation showing a florid swelling of the femur around the level of the tip of the stem.

and was typically worse at night. It was often relieved by exercise. Patients reported that their symptoms were considerably worse than the arthritis which had led to the need for the hip replacement. After a bone scan one patient obtained long-term relief and another for two years. We have been unable to explain this.

In all cases the haematological investigations were normal.

The immediate post-operative radiographs appeared to be satisfactory but from 18 months to two years cortical hypertrophy was seen at the tips of the femoral components (Fig. 1). This reaction was always centred within either Gruen zones 3, 4 or 5¹¹ and was often associated with a cement mantle of less than 1 mm. The hypertrophy progressed insidiously for up to 36 months before stabilising. The ⁹⁹Tc bone scans showed a marked increase in uptake around the prosthesis and in the region of the cortical hypertrophy (Fig. 2). In all but one case, the symptoms persisted even when the periosteal reaction appeared to be static.

Eight of the nine patients subsequently required a single-stage revision operation. In the other patient, the pain reached a stable level after three years and the cortical hypertrophy settled. The prostheses were revised to uncemented implants. The stems were very well fixed at the time of surgery but there was obvious corrosion at their tips with debris visible on their surface (Fig. 3). The mean pH at the

Fig. 2

A ⁹⁹Tc bone scan showing increased uptake around the affected prosthesis.

Fig. 3

Photograph of a cemented Furlong femoral component showing distal corrosion.

Fig. 4

Photograph showing immediate pH testing of a corroded cemented Furling stem at revision. The distal end has caused the universal indicator tape to turn a pink colour indicating a highly acidic pH. It becomes natural proximally.

site of the corrosion was 2.5 but became normal more proximally (Fig. 4).

Electron microscopy of the implants showed gross corrosion which covered two-thirds of the stems distally (Fig. 5). The fourth implant showed scratching of the surface and minor corrosion pits at its distal end. Extensive surface roughening and pitting were seen on either side of the layers of corrosion (Fig. 6). The EDXA spectrum showed that the corrosion products consisted of multiple layers of titanium oxides.

Discussion

The cultures obtained at revision were sterile in all cases and there was no serological evidence of infection, making this an unlikely cause of the patient's symptoms. None of the revisions became infected and in all patients the symptoms improved after this procedure.

Although cortical hypertrophy around other types of stem has been described, it is usually asymptomatic.¹²⁻¹⁵ When seen with titanium Müller stems it was also associated with corrosion.⁹ Although this latter study reports nine cases, no other patients with the same implant developed cortical hypertrophy. When it did occur it was always symptomatic and the implants were always corroded when seen at revision. If the cortical hypertrophy was due to other

Fig. 5

SEM of a retrieved specimen showing gross corrosion covering two-thirds of the stem distally.

Fig. 6

High-power electron radiograph showing pitting of a retrieved stem.

reasons, such as a design fault in the stem or a flexural mismatch, it would have been seen more often.

Galvanic corrosion can take place in modular systems in which different metals are in contact.^{5-8,10} However, in these examples, corrosion was only seen at the head-neck junction. It therefore, seems unlikely that the corrosion at the tips of the stems in our series was due to a galvanic reaction between the cobalt heads and titanium stems. Titanium is used mostly in its alloy form of Ti6Al4V. Its stability comes from the ability to form a protective oxide layer when it comes into contact with water or air, which provides

a barrier to electrolytes. To be protective, however, the layer must cover the implant fully and must remain on the surface even when it is stressed. In the presence of movement, the passivating oxide layer may be abraded leaving base metal exposed, which can lead to fretting and/or crevice corrosion. In a steady state, the oxide layer will be replaced by consumption of oxygen but this cannot happen in a crevice. The cathodic reaction (oxygen reduction) and the anodic reaction (metal dissolution) then become separated and an electrical cell is set up. This reaction produces an excess of positive ions which is balanced by an influx of negative ions. In bodily fluids these are usually the smaller, more mobile chloride ions which result in the formation of titanium chloride products. These then hydrolyse, reducing the pH which further accentuates the dissolution of titanium.¹⁶

Crevice corrosion of Ti6Al4V alloy, although less than in the stainless steel, has been demonstrated *in vitro*¹⁷ and experimentally in dogs.¹⁸ Until recently it has not been described as occurring away from the Morse taper of modular implants. In cases already reported the symptoms, radiological signs and laboratory findings were similar to those of our patients.^{9,19-21} The exact mechanism is unclear but it may start by micromovement between the stem and cement which initiates a progressive abrasion of the protective oxidised layer.^{22,23} Any breach of this layer in the proximal portion of a stem will be reversed quickly because of the plentiful supply of oxygen from fluid in the false capsule, but further distally there may not be sufficient oxygen to allow a stable oxide layer to re-accumulate. This phenomenon also explains why the corrosion was centered at the tip of the stem and not in Gruen zones 1, 2, 6 and 7. Partial states of oxidation then develop which lead to corrosion and the build-up of the resultant products. These hydrolyse to form protons which act as an acidic irritant, causing pain and stimulating bone growth. The reason why uncemented titanium stems do not undergo the same process may be because oxygen is freely available from the bone, which perhaps explains why revision to uncemented stems alleviated the symptoms in our patients.⁹

We no longer implant cemented titanium stems because of the problems described. Other authors have also experienced problems with such implants,^{9,19-21} although the exact mechanism of failure is unclear. It seems that crevice corrosion may be at least one of the reasons for failure. We still use uncemented titanium stems since these do not undergo the same processes and have been shown to give excellent long-term clinical results.¹

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