CORROSION AND WEAR AT THE MODULAR INTERFACE OF UNCEMENTED FEMORAL STEMS

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We examined 108 uncremented femoral stems with modular femoral heads which had been retrieved for reasons other than loosening. There were detectable amounts of wear and corrosion in 10 of 29 (34.5%) mixed-alloy components and 7 of 79 (9%) single-alloy components after a mean implantation time of 25 months. We found no correlation between the presence or extent of corrosion or surface damage and any of time in situ, initial diagnosis, reason for removal, age, or weight. Stems with wear and corrosion were less likely to show histological bony ingrowth.

The interface between the head and stem of modular total hip components is a possible source of ion release and wear debris, but wear and corrosion were totally absent in most specimens. This suggests that this problem could be avoided, and that further research is required to develop manufacturing methods which would minimise such changes.

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Modular stems are widely used for total hip replacement since they provide the ability to vary neck length and head size independently of the stem, which reduces the inventory of stock sizes. In addition, modular heads allow the use of mixed-alloy systems such as the combination of a titanium-alloy stem with a cobalt-chrome head. Titanium alloy has been advocated for porous-coated uncemented stems because of its relatively low modulus, while cobalt-chrome is favoured for the head because of its superior wear properties (Skinner 1992). Mears (1975) predicted that cobalt-chrome and titanium alloy could be combined in a modular configuration without significantly enhancing the potential for corrosion, and studies by Lucas, Buchanan and Lemons (1981) predicted no increase in corrosion with such a mixed-alloy system. Kummer and Rose (1983) found that titanium and cobalt-chrome were stable to an electrochemical open-circuit potential, but still felt that caution was needed. More recently, Collier et al (1991, 1992a,b) reported evidence of galvanic corrosion at this interface in retrieved specimens; they concluded that this is time-dependent and may be due to a galvanically-accelerated crevice corrosion.

In addition to corrosion, there is concern that wear debris could be generated from the modular interface (Jacobs, Galante and Sumner 1992). Such metal-wear debris has been linked to the failure of some total hip replacements (Huo, Salvati and Buly 1991). Extensive and early bone lysis has been described in a small number of modular uncemented total hip replacements (Maloney et al 1990), and has been attributed to wear debris secondary to either polyethylene and/or metal particulates (Maloney et al 1990; Skinner 1992). The modular interface has been suggested as one potential source of such particles (Jacobs et al 1992). Fricker and Shivanath (1990), however, predicted no in vivo fretting at a titanium/cobalt-chrome modular interface and Collier et al (1991) reported no evidence of fretting in a number of retrieved specimens in either single-alloy or mixed-alloy uncemented total stems.

Modular components are widely used. Because of concern over possible corrosion and wear at the interface and the disparate findings in other studies, we examined a series of retrieved uncemented femoral stems with modular heads.

MATERIALS AND METHODS

We examined a total of 108 porous-coated uncemented femoral stems, excluding any implants that had been shown to be clinically or radiographically loose at the time of removal. We included 11 stems retrieved at postmortem. The other 97 components had been removed because of malposition, persistent thigh pain, or late infection. Most of them came from other surgeons, with 38 from Tulane University Affiliated Hospitals.

Each stem was sectioned and examined histologically to determine the quantity and type of tissue ingrowth (Cook et al 1991a). Records were made of the manufacturer, the metallic composition of the head and stem, the age of the patient, the time in situ, and the reason for removal. All components were separated, ultrasonically cleaned, and
examined by a stereomicroscope (to 70 x magnification) to identify the extent and distribution of corrosion within each modular head and around the neck of each femoral stem.

We graded wear and corrosion on a scale of zero to three: grade 1 had superficial scratching, burnishing, or localised pitting; grade 2 had larger regions of superficial pitting, significant abrasion or galling which covered less than 25% of the interface; and grade 3 had the same changes involving more than 25% of the interface (Table I). Some selected specimens were also examined by scanning electron microscopy.

RESULTS

There was histological bony ingrowth in 87 of the 108 stems (81%), which had been retrieved from 63 men and 45 women. Since no implant was clinically or radiographically loose at the time of removal, this tends to confirm that the absence of bony ingrowth does not preclude stable fixation. The average time in situ was 20.1 months (2 to 84 months); about 40% of the implants had been in place for over four years, and over 60% for more than three years.

In 91 prostheses (84%) there was no evidence of surface wear or corrosion. The other 17 (16%) showed evidence of wear and corrosion of grade 1 in 14 and grade 2 in three (Table I). There were no cases of grade 3 (severe) wear or corrosion. In all cases in which corrosion was present there was also evidence of a similar degree of surface wear.

A cobalt-chrome head had been mated with a cobalt-chrome stem in 76 cases (Table II). The manufacturers were DePuy (Warsaw, Indiana) in 39, Howmedica (Rutherford, New Jersey) in 22, Osteonics (Allendale, New Jersey) in 6, and Implant Technology (Timonium, Maryland) in 9. Only 5 of these 76 prostheses (7%) showed any evidence of wear or corrosion and it was of grade 1 in every case (Fig. 1). The mean time in situ for those with wear and corrosion was 27.6 months (17 to 46); this was only slightly higher than the mean 19.1 months (2 to 84) for those without corrosion. Some degree of wear or corrosion was seen in at least one specimen from each manufacturer (Table III).

A cobalt-chrome head had been mated with a titanium-alloy stem in 29 modular components (Table II). The manufacturers were Zimmer (Warsaw, Indiana) in 23, Biomet (Warsaw, Indiana) in three, and Osteonics in three. The

<table>
<thead>
<tr>
<th>Grade</th>
<th>Damage</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No abnormality</td>
</tr>
<tr>
<td>1</td>
<td>Superficial scratches, burnishing or localised pitting</td>
</tr>
<tr>
<td>2</td>
<td>Larger regions of superficial pitting or significant abrasion or galling of &lt;25% of the interface</td>
</tr>
<tr>
<td>3</td>
<td>Extensive areas of pitting or surface degradation of &gt;25% of the interface</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Stem</th>
<th>Head</th>
<th>Number</th>
<th>Number</th>
<th>Wear and corrosion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co-Cr-Mo</td>
<td>Co-Cr-Mo</td>
<td>76</td>
<td>5</td>
<td>7.0</td>
</tr>
<tr>
<td>Ti-6Al-4V</td>
<td>Ti-6Al-4V</td>
<td>3</td>
<td>2</td>
<td>66.7</td>
</tr>
<tr>
<td>Ti-6Al-4V</td>
<td>Co-Cr-Mo</td>
<td>29</td>
<td>10</td>
<td>34.5</td>
</tr>
</tbody>
</table>

Fig. 1a
Cobalt-chrome alloy head (a) mated with a cobalt-chrome stem (b) removed at post mortem from a 63.5 kg woman 72 months after implantation. There was little, if any, corrosion or wear at the femoral head/stem junction – grade 0.
mean time in situ was 19.6 months (4 to 53) and there was evidence of wear or corrosion in ten (34.5%). Seven showed grade 1 surface damage. The three with grade 2 damage had been in place for a mean of 38.7 months (26 to 49; Figs 2 to 4).

Only three specimens, all from Biomet, combined a titanium-alloy head with a titanium-alloy stem (Table II). Their mean time in situ was 16.3 months (8 to 32), and two of the three stems had grade 1 corrosion and wear (Table III).

We found no correlation between the presence of corrosion and time in situ: the mean time for all components was 20.1 months, and for corroded components 25.4 months. This difference was not significant (p = 0.53). It should be noted, however, that all three components with grade 2 corrosion and wear had been in place for at least 26 months. We also found no correlation between the reason for removal and the presence of corrosion.

Corrosion and wear, however, were significantly more common in mixed-alloy systems (34.5%) than in all cobalt-

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**Fig. 2a**

Cobalt-chrome alloy head (a) mated with a titanium-alloy stem (b) removed after 41 months from a 370 kg man. There was moderate wear and corrosion on both components – grade 2 (moderate).

**Fig. 2b**

Scanning electron micrograph of a titanium-alloy stem mated with a cobalt-chrome alloy head for 53 months in a 93 kg man. The component showed little or no corrosion and wear – grade 0.

**Fig. 3**

Scanning electron micrograph of a cobalt-chrome alloy head mated with a titanium-alloy stem for 49 months in a 59 kg woman. The head showed a grade 2 (moderate) surface wear and corrosion.

**Fig. 4**

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Corrosion was more common in specimens in which there was no histological bony ingrowth: only 9 of the 17 stems (53%) with corrosion or wear showed bony ingrowth, whereas 78 of 91 components (86%) with no wear had histological bony ingrowth. This difference is statistically significant (p < 0.01).

Surface wear and corrosion were consistently found at the distal portion of the tapered interface between the head and neck, which has been shown to be the highest area of contact stress (Fricker and Shivanath 1990). Fluid from the hip also has direct access to this area. The pattern of surface damage which we found was consistent with the combination of fretting, crevice, and galvanic corrosion.

**DISCUSSION**

Our findings show that the head-neck interface of modular uncemented femoral stems may sometimes be a source of ion release and wear debris. Collier et al (1991, 1992a,b) also found corrosion in a high percentage of prostheses in which a cobalt-chrome head had been mated with a titanium-alloy stem, and considered it to be due to a combination of galvanic and crevice corrosion. Levine and Staehle (1977) have shown that titanium alloy is susceptible to crevice corrosion and that use of a mixed-alloy system would be likely to accelerate this process. Collier et al (1991) found no evidence of fretting, but this disagrees with the view of Sutow, Jones and Milne (1985) who predicted that, in the absence of fretting, crevice corrosion would not occur at an interface between titanium alloy and cobalt-chrome. Our study tends to support the opinion that fretting may lead to breaching of the passive layer of the alloy surfaces, and that this is followed by a combination of crevice and galvanic corrosion. Breakdown of the passive layer increases the corrosion potential from 100 to 500 mV; this must precede the occurrence of crevice corrosion since, as Collier et al (1991) stated, the breakdown potential for the cobalt-chrome to titanium-alloy couple is approximately 400 mV (Devine 1974). In a similar study to ours, Bauer et al (1992) also concluded that the surface damage in these conditions resulted from a combination of fretting and galvanic corrosion.

Contrary to the findings of Collier et al (1991) we also found evidence of surface wear and corrosion when similar alloys were mated. We saw grade 1 changes in two of three titanium-alloy heads on titanium-alloy stems (Fig. 2) and in 5 of 76 cobalt-chrome heads on cobalt-chrome stems (Fig. 3). This agrees with Bauer et al (1992) who also reported that fretting and corrosion were seen in interfaces of the same alloy, although to a significantly less degree than in a mixed cobalt-titanium interface. We had too few all-titanium alloy specimens to draw conclusions other than that changes do occur. In another study of all-titanium alloy modular interfaces in uncemented total hips, we found noteworthy generation of wear debris (Cook et al 1991b). In earlier laboratory studies we have shown that titanium alloy is susceptible to abrasion and fretting corrosion (Cook et al 1983-4).

**Table III.** Details of implants showing surface wear and corrosion

<table>
<thead>
<tr>
<th>Material-combination</th>
<th>Manufacturer</th>
<th>Grade</th>
<th>Bony ingrowth</th>
<th>Time in situ (mth)</th>
<th>Reason for removal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co-Cr/Co-Cr</td>
<td>DePuy</td>
<td>1</td>
<td>Present</td>
<td>18</td>
<td>Component malposition</td>
</tr>
<tr>
<td>Ti-6Al-4V/Ti-6Al-4V</td>
<td>Biomet</td>
<td>1</td>
<td>Absent</td>
<td>21</td>
<td>Malposition</td>
</tr>
<tr>
<td>Ti-6Al-4V/Ti-6Al-4V</td>
<td>Zimmer</td>
<td>2</td>
<td>Present</td>
<td>49</td>
<td>Malposition</td>
</tr>
<tr>
<td>Co-Cr/Co-Cr</td>
<td>Zimmer</td>
<td>2</td>
<td>Absent</td>
<td>26</td>
<td>Pain</td>
</tr>
<tr>
<td>Co-Cr/Co-Cr</td>
<td>Zimmer</td>
<td>1</td>
<td>Absent</td>
<td>32</td>
<td>Malposition</td>
</tr>
<tr>
<td>Co-Cr/Co-Cr</td>
<td>Zimmer</td>
<td>1</td>
<td>Absent</td>
<td>14</td>
<td>Pain</td>
</tr>
<tr>
<td>Co-Cr/Co-Cr</td>
<td>Zimmer</td>
<td>1</td>
<td>Absent</td>
<td>16</td>
<td>Infection</td>
</tr>
<tr>
<td>Co-Cr/Co-Cr</td>
<td>Zimmer</td>
<td>1</td>
<td>Absent</td>
<td>21</td>
<td>Malposition</td>
</tr>
<tr>
<td>Co-Cr/Co-Cr</td>
<td>Zimmer</td>
<td>1</td>
<td>Present</td>
<td>32</td>
<td>Pain</td>
</tr>
<tr>
<td>Co-Cr/Co-Cr</td>
<td>Osteonics</td>
<td>1</td>
<td>Present</td>
<td>16</td>
<td>Unknown</td>
</tr>
<tr>
<td>Co-Cr/Co-Cr</td>
<td>Osteonics</td>
<td>1</td>
<td>Present</td>
<td>8</td>
<td>Infection</td>
</tr>
<tr>
<td>Biomet</td>
<td>2</td>
<td>Present</td>
<td>41 mean 25.4</td>
<td>Malposition</td>
<td></td>
</tr>
</tbody>
</table>

**Fig. 5**

Scanning electron micrograph of a titanium-alloy head mated with a titanium-alloy stem removed after 21 months from a 79.5 kg man. The head showed some areas of corrosion and wear.
Massive wear generation and crevice corrosion have been reported in cobalt-chrome heads on cobalt-chrome stems in Lord uncremented porous-coated prostheses (Svensson et al 1988; Mathiesen et al 1991). In these studies the generation of particulate debris was felt to be secondary to structural imperfections, but the authors warned against the unnecessary use of metal-to-metal interfaces. We found no evidence of structural imperfections in the cobalt-chrome heads on cobalt-chrome stems in the current series, but observed a small degree of surface damage and corrosion in a minority of cases. Kovacs (1992) has shown that galvanic corrosion can occur not only between dissimilar alloys, but also when there is dissimilarity in surface conditions within a single-alloy system.

We found no correlation between factors such as patient age, sex or weight, reason for removal, or time in situ and the presence or degree of corrosion or surface damage. Damaged specimens had been in situ for slightly longer than the others, but not significantly so. All three instances of grade 2 (moderate) damage, however, were in cobalt-chrome to titanium specimens that had been in situ at least 26 months, although a number of mixed-alloy specimens in place for longer periods showed no surface damage or corrosion.

We found a correlation between the absence of bony ingrowth and the presence of surface damage and corrosion. Of the 17 components with interface damage, only 9 had histological confirmation of bony ingrowth while 78 of 91 of those without wear or corrosion had evidence of bony ingrowth (chi-squared test = 7.84; p < 0.01). This finding was largely due to the results for the mixed-alloy Zimmer components with damaged interfaces, of which six of the seven had no evidence of bony ingrowth; it may be that these stems have a propensity to resist ingrowth and to corrode at the head-neck junction. Another explanation may be that failure to achieve bony ingrowth promotes ion and particle release from the stem which affects the interface and promotes corrosion and wear.

Collier et al (1992a) suggested that the greater surface area of a porous-coated implant may accelerate the rate of corrosion by increasing the cathodic to anodic ratio in mixed metal systems. Corrosion, however, has also been observed in smooth metal systems, but our results show that lack of bony ingrowth may be an important variable.

In a minority of cases, a modular interface is a source of ion release and wear debris. The components which we studied had been in situ for a mean of only 25 months; once surface damage and corrosion have been initiated, the passive layer is irreversibly breached, and the process can be expected to progress steadily with time. Uncemented components were developed in hopes of long-term implant survival and the observation of wear and corrosion in over 15% at this early stage may well be of clinical significance. The problem is general: the retrieved components came from six different manufacturers, and used three different alloy combinations. Surface wear and corrosion were seen in at least one case from each manufacturer and in all three alloy combinations, although the combination of a cobalt-chrome head on a titanium alloy stem accounted for most cases. The fact that most of the implants, including mixed-alloy systems, showed no evidence of surface damage implies that this is avoidable, and it is important that manufacturing methods are devised to minimise corrosion and wear at such interfaces.

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.

REFERENCES


Skinner HB. Current biomaterial problems in implants. AAOS Instructional Course Lectures 1992; 41:137-44.
