Comprehensive Analysis of a Recalled Modular Total Hip System and Recommendations for Management

Danyal H. Nawabi, MD, FRCS(Orth), Huong T. Do, MS, Allison Ruel, BA, Brett Lurie, MBBS, Marcella E. Elpers, BS, Timothy Wright, PhD, Hollis G. Potter, MD, and Geoffrey H. Westrich, MD

Investigation performed at the Adult Reconstruction and Joint Replacement Service, Department of Orthopaedic Surgery, Hospital for Special Surgery, New York, NY

Background: Recent total hip arthroplasty designs have introduced modularity at the neck-stem junction. There are reports of failure of this class of designs due to corrosion at the modular junction. The purpose of this study was to evaluate patients implanted with a recently recalled modular total hip arthroplasty system.

Methods: This was a prospective study of 216 total hip arthroplasties in 195 patients performed by a single surgeon. All hips had a titanium-alloy stem, but 199 had a modular cobalt-chromium neck and seventeen were monolithic. The mean patient age was 65.4 years (range, twenty to eighty-eight years); seventy-nine were men and 116 were women. Patients were evaluated for infection and with metal ion assays and MRI (magnetic resonance imaging). Intraoperative tissue samples were graded, and retrieved implants were examined.

Results: At a mean follow-up of 19.3 months, eighty (37%) of 216 hips had been revised. An adverse local tissue reaction (ALTR) was the cause for revision in seventy-three of these eighty hips; all had the modular neck design. Assay results for the patients requiring revision showed higher levels of cobalt (mean, 8.6 ng/mL) than chromium (mean, 1.8 ng/mL). MRI showed moderate to severe levels of synovial response in sixty-three of 166 hips. The mean ALVAL (aseptic lymphocytodominated vasculitis-associated lesion) score for the revised hips was 8.1. Corrosion was visible on all tapers at the neck-stem junction but not the head-neck junction.

Conclusions: Early failures of modular total hip arthroplasty occur due to fretting and corrosion at the neck-stem junction, resulting in ALTR. Surveillance utilizing metal ion levels and MRI may be indicated for all patients regardless of symptoms, as the early survivorship is poor and the ultimate failure rate may be catastrophically high.

Level of Evidence: Therapeutic Level II. See Instructions for Authors for a complete description of levels of evidence.

Peer Review: This article was reviewed by the Editor-in-Chief and one Deputy Editor, and it underwent blinded review by two or more outside experts. The Deputy Editor reviewed each revision of the article, and it underwent a final review by the Editor-in-Chief prior to publication. Final corrections and clarifications occurred during one or more exchanges between the author(s) and copyeditors.

The evolution of modularity in total hip arthroplasty started at the head-neck junction, gaining popularity in the 1980s for providing versatility in adjusting neck length and offset. Despite early concerns about fretting and crevice corrosion, design and manufacturing improvements resulted in universal adoption of head-neck modularity in total hip arthroplasty, with an excellent safety profile.

Following the success of modular heads, an additional interface at the neck-stem junction was introduced to enable the surgeon to alter version. Modular necks initially had breakage and neck-stem dissociation. One feature common to these cases was the coupling of titanium alloy on the neck and stem. The next modification was manufacture of the modular neck with cobalt-chromium alloy, which resulted in fretting and crevice corrosion. Recent reports of modular total hip arthroplasty failures have shown corrosion at the neck-stem junction and a severe adverse local tissue reaction (ALTR), similar to that seen in failed metal-on-metal arthroplasties. In June 2012, one

Disclosure: One or more of the authors received payments or services, either directly or indirectly (i.e., via his or her institution), from a third party in support of an aspect of this work. In addition, one or more of the authors, or his or her institution, has had a financial relationship, in the thirty-six months prior to submission of this work, with an entity in the biomedical arena that could be perceived to influence or have the potential to influence what is written in this work. No author has had any other relationships, or has engaged in any other activities, that could be perceived to influence or have the potential to influence what is written in this work. The complete Disclosures of Potential Conflicts of Interest submitted by authors are always provided with the online version of the article.

with a modular-neck total hip arthroplasty were offered MRI using a protocol to reduce metallic susceptibility artifacts. The presence and extent of ALTR on MRI were taken into consideration when deciding whether to perform revision surgery. An ultrasound-guided biopsy was performed for select patients suspected of having ALTR on the basis of the MRI.

**MRI Acquisition and Analysis**

MRI was performed on 151 patients (166 hips). Of the forty-four patients (fifty hips) who did not undergo imaging, fifteen had a non-modular total hip arthroplasty, eight had claustrophobia, five declined because of the absence of symptoms, four were lost to follow-up, three had a pacemaker, four had a fracture, three had died, and two underwent imaging elsewhere.

Scanning was performed with 1.5-T clinical scanners (GE Healthcare) using either a three-channel shoulder coil or an eight-channel cardiac coil, depending on the specific scanner. The specific pulse sequence parameters have been previously described. Two-dimensional fast-spin-echo proton-density-weighted images were obtained in three planes. The MAVRIC (multiaquisation variable-rezontance image combination) sequence was used in the coronal plane to reduce susceptibility artifacts. This prototype pulse sequence has previously been used to measure the volume of an adverse synovial response, which is elevated in patients with ALTR, and the thickness of the synovial lining, which is predictive of ALVAL (aseptic lymphocyte-dominated vasculitis-associated lesion). Magnetic resonance images were evaluated independently by two musculoskeletal radiologists and then reported by consensus. Synovial response was graded as mădă, moderate, or severe. Synovitis was defined as the presence of material with fluid signal intensity or solid debris, either contained by the pseudocapsule or communicating with a disrupted pseudocapsule. The synovitis was characterized as solid, fluid, or mixed (solid and fluid). The volume of synovitis (in mm³) was calculated using a validated segmentation method. The thickness of the synovial lining (in mm) was measured digitally on the coronal MAVRIC images where it was noted to be greatest.

**Tissue Damage Assessment**

Intraoperative tissue damage was graded subjectively by the operating surgeon using a previously described four-point scale (see Appendix).

**Histologic Assessment**

Tissue samples were excised on the basis of the areas of damage seen on MRI. All histologic analyses were performed by the same experienced musculoskeletal pathologist. On average, ten tissue blocks were processed per site. Tissue was cut at a thickness of 5μm and stained with hematoxylin and eosin. Microscopic examination was performed twice within a one-week interval to minimize intraobserver variability. The synovial lining, macrophagic and lymphocytic infiltrate, and tissue organization were graded to yield an ALVAL score. A score of 5 of 10 was considered to indicate a moderate to high probability for ALVAL. Histologic evaluation included analyses of inflammatory cells (including plasma cells and eosinophils) and of intracellular and extracellular material (metallic debris and corrosion products).

**Retrieval Analysis**

The retrieved necks were examined for evidence of fretting and corrosion. All components were cleaned in a mild 10% bleach solution and allowed to dry overnight. After cleaning, they were examined macroscopically for fretting and corrosion at both taper surfaces using light microscopy at >5 to ×10 magnification. Scanning electron microscopy and energy-dispersive x-ray analysis (EDAX) were used to evaluate black debris at the interface.

**Statistical Methods**

Continuous data were evaluated using the Wilcoxon rank-sum test, and categorical data were analyzed using the Fisher exact test. Spearman rank correlation coefficients were calculated to assess the relationship between histologic findings and MRI characteristics. Kaplan-Meier survivorship curves were generated for failures. All confirmed cases of ALTR were further analyzed using a regression

---

**Table I: Neck Characteristics for Total Hip Arthroplasties with the Modular-Neck Rejuvenate Design**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>No. of Arthroplasties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neck length in mm</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>71</td>
</tr>
<tr>
<td>34</td>
<td>94</td>
</tr>
<tr>
<td>38</td>
<td>29</td>
</tr>
<tr>
<td>42</td>
<td>5</td>
</tr>
<tr>
<td>Neck angle in deg</td>
<td></td>
</tr>
<tr>
<td>127</td>
<td>131</td>
</tr>
<tr>
<td>132</td>
<td>68</td>
</tr>
<tr>
<td>Neck version</td>
<td></td>
</tr>
<tr>
<td>Neutral</td>
<td>177</td>
</tr>
<tr>
<td>8° antverted</td>
<td>18</td>
</tr>
<tr>
<td>8° retroverted</td>
<td>4</td>
</tr>
</tbody>
</table>

---

**Materials and Methods**

This was a prospective study of 216 consecutive primary total hip arthroplasties in 195 patients performed by a single surgeon between April 2010 and March 2012. The mean age of the patients was 65.4 years (range, twenty to eighty-eight years); seventy-nine were men and 116 were women. Study approval was obtained from our institutional review board.

All primary total hip arthroplasties were performed via a posterolateral approach by the senior author (G.H.W.). There were 199 modular and seventeen monolithic stems. The monolithic stems were used for smaller femora for which modular stems were unavailable. Neck length, angle, and version distributions are given in Table I, and implant details are described in the Appendix.

Clinical outcome scores were available for all patients preoperatively and at six weeks, three months, six months, one year, and yearly thereafter. These included the Harris hip score (HHS), Western Ontario and McMaster Universities (WOMAC) osteoarthritis index, 12-item Short-Form Health Survey (SF-12), and University of California Los Angeles (UCLA) activity score.

Diagnostic Work-up

All patients were contacted to undergo radiography followed by measurement of inflammatory markers, including serum C-reactive protein (CRP) and erythrocyte sedimentation rate (ESR). Patients with raised markers underwent hip aspiration for microbiological culture. Serum metal ion levels were measured for all patients by a single laboratory. As part of an institutional initiative, all patients...
model to identify patient and implant-related predictors of this mode of failure. Significance was set at p < 0.05. All analyses were performed using SAS software (version 9.2; SAS Institute).

**Source of Funding**
Stryker Orthopaedics (Mahwah, New Jersey) provided funding for the investigations of the patients who were called back for assessment as part of the recall but had no other involvement in the writing of this paper.

**Results**

**Clinical Follow-up and Survivorship**

At a mean follow-up of 19.3 months (range, nine to forty-two months), eighty (37.0%) of the 216 hips, in seventy-five (38.5%) of the 195 patients, had been revised and an additional eleven hips in nine (4.6%) of the patients were awaiting revision. Of the remainder, 117 hips in 104 (53.3%) of the patients were asymptomatic at that time, with a benign appearance on MRI and/or low metal ion levels (cobalt, <5 ng/mL), and had not been revised. They continue to be followed at six-month intervals. Four (2.1%) of the 195 patients were lost to follow-up, and three had died of unrelated causes.

The mean time from primary total hip arthroplasty to symptom onset was 21.0 months (range, one to thirty-six months). ALTR was the cause for revision in seventy-three of the eighty revised hips. Five hips were revised for periprosthetic fracture and the remaining two, for pain that was unexplained (no evidence of infection, a benign MRI appearance, and normal metal ion levels). The latter two patients had subtle changes on MRI suggestive of ALTR; however, minimal taper corrosion was seen when surgery was performed and the final pathologic examination yielded an ALVAL score of 3, indicating a low probability of ALVAL. These two cases perhaps represented early-stage development of corrosion-induced ALTR. All cases of ALTR occurred in the modular-neck group, with no revisions for ALTR or any other reason in the monolithic group.

The Kaplan-Meier survivorship of the Rejuvenate stem, with failure due to all causes as the end point, was 69.3% at two years of follow-up (Fig. 1) and dropped to 30.3% at three years. A failed hip arthroplasty was defined as any hip undergoing revision or scheduled for revision surgery at the time of writing of this manuscript. The Kaplan-Meier survivorship of the Rejuvenate stem with ALTR as the cause of failure was 73.9% at two years and dropped to 35.4% by three years (Fig. 2). A regression model did not reveal any patient-related predictors of failure. A preliminary univariate analysis identified neck angle and neck version as possible predictors of revision surgery, as both had a p value of <0.2 and thus met our criterion for inclusion in a multivariate analysis. Subsequently, however, a definitive Cox proportional-hazards model demonstrated that neither neck angle nor version was a significant predictor in this particular population.

The HHS improved from a mean of 50.7 (range, 3 to 89) to 81.8 (range, 17 to 100) at the latest follow-up prior to any revision surgery. The HHS at the latest follow-up was significantly (p < 0.001) higher in the asymptomatic hips (mean [and standard deviation], 85.1 ± 19.2) than in the hips requiring revision before the revision surgery (mean, 77.4 ± 19.2) (Table II).

**Diagnostic Work-up**

The mean ESR for the seventy-five patients who had undergone revision was 19.8 mm/hr (range, 1 to 86 mm/hr). Twenty of these patients had values above the normal range (i.e., >27 mm/hr). The mean CRP value for these seventy-five revised patients was 1.5 mg/dL (range, 0.1 to 14.1 mg/dL), with twenty-eight having abnormally elevated levels (i.e., >1.0 mg/dL). Both markers were elevated in fifteen of the seventy-five revised patients. These fifteen patients underwent hip aspiration. The synovial fluid cell count could be measured for only six of fifteen samples because of large amounts of amorphous material. The mean synovial fluid white blood-cell (WBC) count was 130 cells/μL (range, 0 to 1675 cells/μL), and no organisms were grown in any of the fifteen samples after microbiological culture.
Serum metal ion levels were obtained in 144 of the 195 patients. The mean serum cobalt was 6.1 ng/mL (range, 0.5 to 37.7 ng/mL; normal, ≤1 ng/mL), and the mean serum chromium was 1.3 ng/mL (range, 0.2 to 5.3 ng/mL; normal, ≤5 ng/mL). Patients who had undergone or were awaiting revision had significantly (p < 0.001) higher serum cobalt ion levels (mean, 8.6 ng/mL; range, 1 to 28 ng/mL) compared with patients who were asymptomatic (mean, 6.6 ng/mL; range, 0.5 to 37.7 ng/mL) (Fig. 3). Patients who had undergone or were awaiting revision also had significantly (p = 0.04) higher serum chromium ion levels (mean, 1.8 ng/mL; range, 0.2 to 5.2 ng/mL) compared with patients who were asymptomatic (mean, 1.3 ng/mL; range, 0.5 to 5.3 ng/mL) (Fig. 3).

Ultrasound-guided biopsy results were positive for ALTR in sixteen of thirty-one hips with suspected ALTR, with a 100% specificity and positive predictive value. However, there were fourteen false negatives and only one true negative, giving a sensitivity of only 53% and a negative predictive value of 6.7%.

**MRI Analysis**

Of the 166 hips in 151 patients that had undergone MRI, seventy-eight hips had been revised or were awaiting revision and eighty-eight hips were asymptomatic. Synovitis was detected in ninety-six (57.8%) of the 166 imaged hips.

A moderate to severe synovial response was observed in fifty-eight (74.4%) of the seventy-eight imaged hips that had been revised or were awaiting revision; no to mild synovial response was observed in the remaining twenty (25.6%). The latter hips were revised on the basis of raised metal ion levels and the presence of pain and/or functional impairment in the affected hip. A moderate to severe synovial response was observed in five (5.7%) of the eighty-eight imaged hips that were asymptomatic; no to mild synovial response was observed in the remaining eighty-three (94.3%).

The mean volume of synovitis was 91 cm³ (range, 5 to 537 cm³), and the mean synovial thickness was 10.3 mm (range, 3 to 22 mm). The mean volume of synovitis was significantly greater in the hips that required revision (121 cm³) compared with the asymptomatic cases (33 cm³; p < 0.001). The synovial thickness was significantly higher in the hips that required revision (11.6 mm) compared with the asymptomatic hips (7.5 mm; p < 0.001).

**Surgical Findings**

The mean time from symptom onset to revision surgery was 2.2 months (range, 0 to 16.4 months). All cases of ALTR demonstrated...
large, thick soft-tissue masses in the peritrochanteric region. The modular necks were all well-fixed; the surgeon opted to disengage them from the stem using the crowbar device designed by the manufacturer for that purpose. The femoral components were typically well-fixed but were revised without the need for an extended trochanteric osteotomy. A needle-tipped Midas Rex drill (Medtronic) and flexible osteotomes were used to disrupt the implant-bone interface. An extraction device was attached to the female taper of the femoral stem, which was then backslapped to remove the stem with minimal bone loss. All ADM (anatomic dual mobility) components were revised to a titanium socket with screw augmentation and a highly cross-linked polyethylene liner. The mean tissue damage score was 2.2 (range, 0 to 3).

**Histologic Findings**

Histologic sections of satisfactory quality were available for seventy (88%) of the eighty revised hips. Widespread necrosis was evident in all hips except the five revised because of fracture and the two revised because of unexplained pain. The mean ALVAL score for the seventy revised hips was 8.1 (range, 4 to 10). Intracytoplasmic green corrosion products (Fig. 4) were observed in forty-seven (67%) of the seventy hips, and metallic debris was

---

**Fig. 5-A** Fretting (arrow) and corrosion observed on the distal taper junction of retrieved modular necks. The head-neck taper on the left side of the image displayed little, if any, corrosion or fretting. **Fig. 5-B** Magnified photograph of the distal taper junction of a retrieved modular neck showing corrosive pitting (×20).

**Fig. 6** Backscatter scanning electron microscope image of the surface of the modular neck-stem junction, with a cross indicating the location of the corresponding EDAX trace on the right demonstrating evidence of corrosion products.
seen in four hips. The ALVAL score correlated with the synovial thickness on MRI ($r = 0.46; p = 0.007$) and with the tissue damage score ($r = 0.46; p = 0.006$).

Retrieval Analysis
Fretting (mechanical wear) and corrosion (chemical dissolution) were visible on all tapers at the neck–stem junction, but not at the head–neck junction (Figs. 5-A and 5-B). EDAX of debris on the neck portion of the neck-stem junction revealed that the debris was composed of chromium with traces of titanium, cobalt, and molybdenum, consistent with the debris being a by-product of corrosion (Fig. 6).

Discussion
Corrosion at the neck-stem junction in total hip arthroplasty has been reported as a cause of ALTR. This has resulted in the voluntary recall of many modular-neck total hip arthroplasty designs, including the specific design analyzed in this study. Because of the lack of a prospective analysis of a large cohort of modular total hip arthroplasties, the scale of the problem has remained unknown. The current study has shown that the failure rate of a recalled modular-neck total hip arthroplasty design is catastrophically high in the first two years after implantation, and that failure is typically preceded by soft-tissue destruction but with relatively well-preserved clinical function.

Eighty of the 216 hips in our cohort had been revised at a mean follow-up of 19.3 months, and ALTR was present in seventy-three of those eighty hips. There were no failures in the monolithic cohort. Although the clinical scores were worse in the group requiring revision than in the well-functioning group, the differences were limited by a false-negative rate of 45% and a negative predictive value of 6.7%. Although all biopsies were performed by an experienced radiologist, sampling error remains a problem and may have contributed to the high false-negative rate. We do not recommend performing biopsies for diagnosing corrosion-induced ALTR.

The necrosis and ALVAL seen in the current study are consistent with the recent literature for failures of modular-neck and metal-on-metal total hip arthroplasties. The etiology of these reactions has been attributed to an adverse response to a metallic burden or to a hypersensitivity response. The source of metal in modular total hip arthroplasty failures is mechanically assisted crevice corrosion, during which fluid ingress at the modular junction causes repassivation of the titanium alloy. The release of hydrogen ions during repassivation produces hydrochloric acid, which can dissolve titanium or cobalt alloys. The evidence for corrosion in the current study was observed histologically as reported by Huber et al.

Retrieval analysis of the modular necks showed evidence of fretting and corrosion at the neck-stem junction but not at the head-neck junction. This phenomenon has been reported by other authors, who observed corrosion at both junctions. The greater damage seen at the neck-stem junction could be explained by the difference in taper design between the two junctions. Also, the neck-stem junction experiences an increased moment arm, and therefore higher bending and torsional stresses, compared with the head-neck junction.

We acknowledge limitations to this study. Although our findings may only apply to a particular modular design, there have been reports of failure of other modular neck-stem designs. Despite the observation of corrosion products in the histologic analysis, we did not perform EDAX on tissue retrieved during the
surgery to confirm the presence of chromium orthophosphate as reported by other authors. However, our retrieval analysis confirmed the presence of a corrosion etiology.

In conclusion, this particular modular neck-stem total hip arthroplasty design, involving cobalt-chromium on titanium alloys, showed a survivorship of 69.3% at two years. The majority of failures were due to ALTR, secondary to corrosion at the neck-stem junction. Patients with the Rejuvenate stem should first undergo ESR and CRP measurements to rule out infection and then be evaluated for ALTR with serum metal ion levels and MRI. Because of the high early failure rate, we recommend screening all patients, regardless of symptoms. In asymptomatic patients with positive findings on metal ion testing or MRI, we recommend surveillance every six months and revision surgery if the patient becomes symptomatic or if repeat investigations demonstrate progression of ALTR. We caution against use of modular-neck designs for total hip arthroplasty until the advantages of neck modularity can be utilized without consequences of implant corrosion and subsequent ALTR.

Appendix

Component Details

The implanted acetabular components included 207 Anatomic Dual Mobility (ADM) cups, eight Trident shells, and one Titan shell (all by Stryker). The median cup size was 50 mm (range, 46 to 62 mm). The bearing couple was cobalt-chromium alloy on highly cross-linked polyethylene; 211 articulations were dual-modality and five were standard. The head size was 28 mm in 212, 32 mm in one, and 36 mm in three. All femoral components were of the Rejuvenate design (Stryker), made from a titanium-molybdenum-zirconium-iron alloy; 199 had a modular cobalt-chromium-alloy neck and seventeen were monolithic. During the study period, patients with morbid obesity (body mass index, >40 kg/m²) were implanted with Stryker Secure-Fit Advanced monolithic stems rather than Reju- venate stems, and these are therefore not included in this study.

Tissue Damage Grading

Grade 0 indicated normal tissue; Grade 1, fluid collection with or without mild synovial reaction and with or without pseudocapsular dehiscence; Grade 2, Grade 1 plus moderate to severe synovial reaction with or without metallosis; and Grade 3, Grade 2 plus abductor damage and/or bone loss. A damage score of ≥2 was considered indicative of severe soft-tissue damage.

Note: We thank Dr. Giorgio Perino (musculoskeletal pathologist) for analyzing the pathology specimens reported in this study and for providing Figure 4.

References

21. Harris WH. Traumatic arthritis of the hip after dislocation and acerbata frac-


