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Brief Communication

Elevated Intra-Articular Cobalt and Chromium Levels in Mechanically Assisted Crevice Corrosion in Metal-on-Polyethylene Total Hip Arthroplasty

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ABSTRACT

Background: Failed total hip arthroplasty (THA) caused by mechanically assisted crevice corrosion (MACC) has serious consequences such as adverse local tissue reaction (ALTR). Serum cobalt (Co) and chromium (Cr) ion levels have been used to diagnose taper corrosion, but have not been shown to be an accurate measure of the severity of MACC or associated ALTRs. Additionally, elevated serum ions are not specific in patients with multiple artificial joints.

Methods: We examined the relationship between serum and intra-articular (IA) Co and Cr levels in a cohort of 20 patients undergoing revision THA, 16 who had symptomatic MACC. IA Co and Cr levels in MACC patients were compared with demographic, pre-operative, and operative findings.

Results: Serum and IA metal levels were found to be relatively low in THA patients undergoing revision surgery for isolated instability, aseptic loosening, or infection (average serum Co 0.03 ppb [parts per billion], IA Co 1.4 ppb, serum Cr 0.32 ppb, IA Cr 3.3 ppb). In patients with MACC, average IA Co (940 ppb) was significantly higher than serum Co (5.1 ppb) ($P = .0003$) and IA Cr (491 ppb) was significantly higher than serum Cr (1.3 ppb) ($P = .0003$). IA Co level was associated with shorter time of hip symptoms to revision surgery ($P = .0043$).

Conclusion: Serum levels of Co and Cr correlated with joint levels in the entire cohort, but IA levels of MACC patients were 100 times greater than serum levels. IA Co and Cr levels may be useful in confirming MACC in a specific joint and the striking elevation may explain symptoms and ALTR with relatively low serum values.

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Taper junction corrosion and fretting, also known as mechanically assisted crevice corrosion (MACC), produces cobalt (Co) and chromium (Cr) ions, fretting products, and corrosion debris, which may cause adverse local tissue reactions (ALTRs). ALTRs have been reported in both metal-on-metal (MoM) [1,2] and

metal-on-polyethylene (MoP) bearings [3,4], and are also found to be severe in patients with chromium alloy modular necks [5]. MACC has been shown to result in elevated systemic levels of Co and Cr ions [3,4]. Whether blood concentrations of these ions accurately reflect the levels in the synovial fluid, and hence act as a surrogate marker of failure at the head-neck junction in the symptomatic MoP patient, remains unknown. ALTRs may be difficult to diagnose [1,6], and, in one small cohort, as the time to revision increased, tissue damage was found to worsen [3]. It would therefore be ideal to establish reliable tests to diagnose and ultimately judge when revision is indicated.

Definitive diagnostic criteria for revision in a patient with MACC have not yet been established [7]. The critical serum ion level cut-off proposed for diagnostic cross-sectional imaging in MoM hip failures is approximately 7 parts per billion (ppb or $\mu\text{g/L}$) [8], but other authors have considered a high risk level to be >10 ppb, and a low risk

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level to be <3 ppb [9]. Matharu et al [10] performed a more quantitative evaluation and noted the optimum serum Co threshold for identifying ALTR to be 2.15 ppb for resurfacing implants and 3.57 ppb for MoM THA. Some authors assumed that these criteria apply to MACC in MoP bearings [11] or modular neck failure [12], but others have noted that MACC symptoms occur with lower serum levels [13]. The authors have suggested that debris originating from the taper might be more toxic than that from the bearing surface [14]. It has been previously demonstrated that whole blood ion levels in MoM failures are not a dependable test for assessing tissue damage [15] and whether revision surgery is needed.

Synovial fluid Co and Cr levels may be more representative of prosthetic failure due to MACC. Sampling fluid from the hip joint is more demanding, so its value as a diagnostic investigation must be carefully considered. The relationship between synovial fluid metal ion levels and ALTRs is not completely understood [2], but may give insight into diagnosis and understanding of ALTRs in this subset of patients. The purpose of our study was to analyze the relationship between serum and intra-articular (IA) Co and Cr levels in revision total hip arthroplasty (THA). We hypothesized that IA levels would be elevated in failed THA with MACC but not in revision THA solely for other reasons. Furthermore, we sought to determine if the magnitude of elevated IA ion levels was associated with risk of ALTR as represented by abnormal pre-operative metal artifact repression sequence (MARS) magnetic resonance imaging (MRI) or pathological diagnosis of avascular lymphocytic vasculitis associated lesion (ALVAL).

Methods

Patients

A cohort of 20 consecutive patients whom had revision of a Zimmer (Zimmer, Inc, Warsaw, IN) MoP THA with 12/14 taper was tested for IA Co and Cr levels, in addition to IA cell count, differential, and culture. Each patient also had serum Co and Cr levels tested in addition to serum white blood cell count (WBC), C-reactive protein (CRP), and erythrocyte sedimentation rate (ESR). Creatinine and estimated glomerular filtration rate levels were analyzed to assess patients' renal excretion. The serum and joint samples were collected on average 43 days apart (range 0-119, standard deviation [SD] 35 days) for the MACC patients and 47 days apart (range 21-77, SD 24 days) for the non-MACC revisions. The Institutional Review Board of our hospital approved this study.

The diagnosis of MACC was made with an elevated serum Co of >1.6 ppb and unexplained pain [3,7,16], or an elevated Co of >1.6 ppb in conjunction with another revision diagnosis (2 patients had instability and MACC, a common combination [4,17]). Revision was performed for MACC alone if: (1) there was a pseudotumor or muscle involvement on MRI ($n = 10$); or (2) there were continuous or progressive hip symptoms with a normal finding on cross-sectional imaging, and the patient wanted to undergo revision ($n = 4$). MACC was confirmed in each case with visual evidence of fretting and/or corrosion at the femoral head/neck junction at the time of revision. The trunnion corrosion grade [18] and soft tissue damage grade [19] were noted for all MACC cases.

The 4 patients without MACC underwent revision for instability ($n = 1$), aseptic acetabular loosening ($n = 1$), aseptic femoral loosening ($n = 1$), and periprosthetic bacterial infection ($n = 1$). Lack of any discoloration or corrosion at the femoral head/neck junction was confirmed at the time of revision.

We analyzed these 2 subgroups of patients: 16 patients with MACC and 4 patients with revision for reasons other than MACC. All patients had Zimmer components (Zimmer, Inc) with 12/14 tapers; previous work has demonstrated a high prevalence of MACC in femoral components with this taper [3]. All patients had MoP

Table 1

Demographic Characteristics of Two Groups of Revision Patients.

| | MACC ($n = 16$) | Non-MACC ($n = 4$) |
|------------------------------------|---------------------|----------------------|
| Age at revision (y) | 64.4 (52-76, 7.4) | 63.8 (50-82, 14.1) |
| Age at index (y) | 58.3 (47-72, 7.4) | 53 (41-66, 10.2) |
| Gender, male:female | 9:7 | 1:3 |
| Side, right:left | 11:5 | 2:2 |
| BMI [20] (kg/m ²) | 30 (23-40, 5.2) | 30 (23-37, 6.6) |
| Revision diagnosis | 14 MACC, 2 MACC + I | 1 I, 2 AL, 1 INFX |
| ASA [21] | 1.9 (1-3, 0.96) | 1.8 (1-3, 0.81) |
| UCLA activity [22] | 5.9 (2-9, 1.9) | 6 (5-7, 1.2) |
| Symptoms to revision (d) | 279 (43-868, 246) | 241 (142-351, 87.8) |
| Index to revision (y) ^a | 5.7 (2.9-8.6, 1.9) | 10.1 (3.7-15.2, 5.1) |
| Serum to joint (d) | 42.9 (0-119, 34.9) | 46.5 (21-77, 23.7) |

Results are reported in average (range, standard deviation), unless otherwise specified.

BMI, body mass index; ASA, American Society of Anesthesiologists; UCLA, University of California, Los Angeles; I, Instability; MACC, mechanically assisted crevice corrosion and instability; AL, aseptic loosening; INFX, infection.

^a Only significant difference between groups ($P = .0095$); gender, side, and revision diagnosis categories were not tested, because of very small group sizes.

bearings with a Co-Cr alloy femoral head. All patients with MACC and 3 of the 4 patients with non-MACC revisions had a titanium stem. One patient in the non-MACC group had a Co alloy stem. All the patients had a cross-linked polyethylene countersurface. Twelve of the 20 patients (60%) had one or more joint arthroplasties other than the revised THA (median 1 joint, range 0-3 joints). Two patients with MACC had only a contralateral THA, and that side had a ceramic-on-polyethylene articulation. Demographic information and comparisons are presented in Table 1. With this small cohort, the MACC group was slightly older and the only significant difference was that the MACC patients were revised on average 5.7 years from their original surgery, compared with 10.1 years for the non-MACC group ($P = .0095$). There was no significant difference between the groups in age at index surgery or revision, body mass index [20], American Society of Anesthesiologists score [21], University of California, Los Angeles activity score [22], time between symptom onset and revision surgery, or time from serum metal level to joint metal level.

Revisions and Revision Protocol

A single orthopaedic surgeon performed revisions using the posterior approach. Techniques and implants used in the MACC revision surgeries have been described in detail in our recent publication [23]. In each revision operation, 1-4 samples of synovial and/or pseudotumor tissue were taken for analysis. The primary site of the sample was the pseudotumor capsule, and if not present the hip pseudocapsule. Two cultures were taken on each revision and tested for aerobic and anaerobic bacteria.

Serum and Intra-Articular Samples

Peripheral blood collection was performed per the Mayo Clinic protocol for serum Co and Cr measurement. Blood was collected in a Vacutainer (Becton, Dickinson and Company, Franklin Lakes, NJ) plastic travel element blood collection tube, the specimen was allowed to clot for 30 min, and then centrifuged to separate serum from the cellular fraction. The serum was transferred into a Mayo metal-free, polypropylene vial, and sent to Mayo Clinic (Mayo Laboratories, Rochester, MN) where inductively coupled plasma mass spectrometry was performed. The detection limit for serum Co was 0.1 ppb and serum Cr 0.03 ppb.

Joint fluid was collected either pre-operatively if the serum CRP, ESR, or WBC was abnormal (6/16 MACC patients, 3/4 non-MACC

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