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Correlation of Corrosion and Biomechanics in the Retrieval of a Single Modular Neck Total Hip Arthroplasty Design
Modular Neck Total Hip Arthroplasty System

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ABSTRACT

Increased modularity of total hip arthroplasty components has occurred, with theoretical advantages and disadvantages. Recent literature indicates the potential for elevated revision rates of modular neck systems and the potential for local pseudotumor and metallosis formation at the modular neck/stem site. Retrieval analysis of one modular neck implant design including SEM (SCANNING ELECTRON MICROSCOPY) assessment was done and correlated with FEA (finite element analysis) as well as clinical features of patient demographics, implant and laboratory analysis. Correlation of the consistent corrosion locations to FEA indicates that the material and design features of this system may result in a biomechanical reason for failure. The stem aspect of the modular neck/stem junction may be at particular risk.

Total hip arthroplasty (THA) is a common procedure, with excellent longevity and patient satisfaction. However, advances continue to be proposed to improve implant longevity, patient satisfaction, and surgical technique. Implant innovations have led to increasing modularity from monoblock femoral components to hip systems with modular heads. In addition to modularity of the prosthetic head, several manufacturers have proposed modularity of the femoral neck. Modularity at this level was proposed to allow changes in version, length, offset and neck – shaft angle. This was theorized to be an attractive design innovation as it potentially allowed for better recreation of the patients' anatomy. Increased modularity also had surgical technique advantages, such as allowing increased opportunities for soft tissue balancing and leg length optimization, thereby potentially allowing for reduced surgical time.

However, modular necks have been cause for some concern clinically, and there are reports of corrosion, metallosis [1] and modular neck fracture [2]. There have also been reports of higher revision rates, with pseudotumor and catastrophic mechanical failure being implicated in registry data [3]. This has led to the market withdrawal or recall of some implants. However, other products continue to be available. The purpose of this retrieval study was to examine modes of failure of a single implant design with a modular femoral neck. Visual classification of damage, scanning electron microscopy (SEM) assessment to assess for corrosion and metal transfer, and biomechanical assessment of the prosthesis using finite element (FE) modeling were performed.

Methods

Study Population

All modular neck implants in our institutional implant retrieval lab were retrospectively reviewed. Approval for review of patient charts and implant retrieval analysis was obtained from the internal review board. A total of nineteen implants were identified to be of the same design of a dual taper Ti–Al–V (TMZF) femoral component, and a Co–Cr–Mo (Vitallium) modular femoral neck (Rejuvenate, Stryker, Mahwah, New Jersey) and examined after retrieval. All retrieved hips had Co–Cr heads (forged Vitallium) articulating on a highly cross-linked polyethylene liner. Details with regard to patient characteristics (Table 1), implant (Table 2), and laboratory analysis (Table 3) were collected. These implants were retrieved from fourteen females and five males, with a mean age of 65 years (range, 41 to 81 years) and a mean body mass index of 33.5 (range, 26.7 to 49.1 years). The diagnosis leading to the THA was avascular necrosis in two patients and osteoarthritis in the remainder of the patients. Ten of the twelve magnetic resonance imaging scans conducted prior to revision revealed cystic pseudotumors, with an average size of 8.2 × 5 × 2.7 cm (range, 12.7–1.8 cm). The implants were in situ for an average of 1.7 years (range, 0.8 to 3.1 years), and three of the retrieved implants were

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Table 1
Patient Demographics and Results of Cross Sectional Imaging of All Revised Implants.

Case	Age	BMI	Time In Situ	Symptoms	Reason	MRI
1	81.0	32.4	1.3	Pain	metallosis	ALVAL
2	57.6	33.8	1.8	Pain	metallosis	N/A
3	60.1	33.9	2.2	Weakness	metallosis	ALVAL
4	64.5	26.0	1.2	Pain/Neurology	metallosis	ALVAL
5	66.7	33.7	2.4	Weakness	metallosis	ALVAL
6	78.3	30.8	3.1	Pain	metallosis	ALVAL
7	81.1	34.0	1.9	Weakness	metallosis	ALVAL
8	75.2	26.1	2.0	Pain	metallosis	ALVAL
9	60.8	52.0	2.1	Weakness	metallosis	ALVAL
10	68.9	28.2	1.8	Pain/Weakness	metallosis	ALVAL
11	60.3	43.1	2.0	Weakness	metallosis	ALVAL
12	65.9	26.7	1.5	Pain/Weakness	metallosis	N/A
13	41.4	32.1	1.6	Pain/Neurology	Pain	Neg
14	60.5	49.1	1.1	Drainage	Infection	N/A
15	41.1	31.1	1.0	Pain	Infection	Neg
16	71.3	30.7	1.3	Infection	Infection	N/A
17	72.6	38.1	1.1	Pain	Subsidence	N/A
18	66.6	34.9	0.8	Pain	Subsidence	N/A
19	60.8	31.4	3.0	Pain	Subsidence	N/A
Average	65.0	34.1	1.7		Infection: 3 metallosis: 12 Subsidence: 2 Pain: 1	

Table 3
Laboratory Analysis of All Patients Prior to Revision.

Case ID	ESR (mm/h)	CRP (mg/L)	Chromium (μg/L)	Cobalt (μg/L)	Titanium (μg/L)	Ratio (Chr/Co)
1	34.0	13.3	0.4	3.2	1.6	0.1
2	38.0	5.7	0.2	2.8	2.3	0.1
3	25.0	7.2	1.0	2.7	5.0	0.4
4	90.0	28.2	N/A	N/A	N/A	N/A
5	9.0	2.9	1.9	5.7	3.8	0.3
6	16.0	1.7	0.8	15.7	2.3	0.1
7	32.0	8.1	0.9	9.5	3.2	0.1
8	6.0	6.4	1.3	9.9	4.3	0.1
9	14.0	10.1	1.0	6.3	5.8	0.2
10	1.0	9.0	0.4	9.8	1.9	0.0
11	20.0	6.0	1.2	4.6	2.2	0.3
12	7.0	1.2	N/A	N/A	N/A	N/A
13	5.0	1.2	0.4	2.4	2.5	0.2
14	38.0	54.4	N/A	N/A	N/A	N/A
15	27.0	16.0	0.9	4.2	1.7	0.2
16	44.0	35.8	0.6	3.6	3.5	0.2
17	16.0	4.3	0.3	0.5	1.9	0.6
18	28.0	4.9	N/A	N/A	N/A	N/A
19	7.0	2.6	0.4	2.4	3.5	0.2
AVERAGE	24.1	11.5	0.8	5.5	3.0	0.2

revised for infection. The average ESR was 25, CRP 12, chromium level of 0.7, cobalt 5.5, and titanium 3.1, with an average ratio of chromium to cobalt of 0.2:1.

Visual Damage Scoring

Each modular neck was examined visually using the method of Goldberg et al [4] for signs of corrosion and fretting by two of the authors (M.G.T. and B.A.L.). The necks were divided into four zones, corresponding to the superior, anterior, inferior, and posterior sides of the neck (Fig. 1). The marking arrow on the face of the trunion was taken as pointing to the superior zone, and all other zones followed in a consistent clockwise pattern. For each zone, corrosion and fretting were graded as none (grade 1), mild (grade 2), moderate (grade 3), or severe (grade 4) under stereomicroscope visualization (SZ-CTV, Olympus, Tokyo, Japan). Where differences in grading occurred, consensus was achieved after further discussion and evaluation.

Table 2
Implant Specifications for All Retrieved Implants.

Case ID	Acetabular Size (mm)	Head Size (length) (mm)	Stem Size	Neck Length (mm)	Version (°)
1	58	36	9	30	0
2	52	36	7	30	0
3	52	36 (−5)	8	34	8
4	54	36	7	30	16
5	52	36 (−5)	9	30	0
6	56	32	7	34	8
7	50	32 (−4)	7	30	0
8	56	36	9	34	0
9	54	36 (−5)	9	30	8
10	50	32	7	34	8
11	5	32 (+4)	8	30	0
12	50	32 (+0)	7	30	0
13	58	40	8	34	0
14	50	32	7	30	8
15	62	36	8	34	0
16	48	32 (−4)	7	34	0
17	52	36 (+5)	7	34	0
18	56[a]	36 (+5)	7	34	8
19	58	40 (+4)	8	34	0
		Size 32: 7 Size 36: 10 Size 40: 1	Size 7: 10 Size 8: 5 Size 9: 4	Length 34: 10 Length 30: 10	0°: 12 8°: 6 16°: 1

[a] Porous 273 acetabular component.

Scanning Electron Microscopy

The first six consecutively retrieved implants, along with two never-implanted reference specimens, were further analyzed with scanning electron microscopy (LEO 440 SEM, Carl Zeiss SMT Inc., Peabody, Massachusetts) and energy dispersive x-ray (Quartz Xone EDX system, Quartz Imaging Corporation, Vancouver, British Columbia) analysis (SEM/EDX). All six modular necks were examined using SEM/EDX for evidence of corrosion, fretting, and material transfer. In addition, one stem was sectioned in two planes at the neck–stem interface, and these sections also underwent SEM/EDX analysis.

Finite Element Analysis

The never-implanted reference specimens (size 7 and size 12 stems, 0 and 8 degree 30 mm necks, and 32 mm head) were laser scanned to generate 3D models for finite element analysis (FEA). The models were appropriately meshed and assembled in the FEA software (Abaqus, Dassault Systemes, Waltham, Massachusetts). The material properties applied to the components were a Poisson's ratio of 0.32 for the TMZF stems, and a Poisson's ratio of 0.30 for the Vitallium® necks and head [5–7]. The elastic moduli for TMZF and Vitallium vary in the literature, therefore we ran multiple models across these different moduli. These were 79 500, 100 000, and 110 000 MPa for the TMZF stem, and 200 000 and 240 000 MPa for the Vitallium neck and head [5,6,8]. The outer surface of the stem was fixed, and the coefficient of friction between the head and neck, and neck and stem was set as 1.00 to model zero motion between them. Simulating one body weight of an 80 kg person crossing the joint, an 800 N load was applied to the femoral head as a concentrated force, as has been done in other studies [7,9,10]. Von mises stress was measured from the simulations, virtual cross-sections between the segments were taken, and the regions of highest stress were probed for maximum values.

Statistics

Descriptive statistics (mean ± SD) were calculated for the corrosion and fretting damage scores. A D'Agostino and Pearson omnibus test for normality was used. As the scores were not normally distributed, Wilcoxon matched-pairs signed rank tests were used to compare the damage between zones.