Flexural Rigidity of THAs is Associated with MRI and Histological findings

Sara E. Sacher[1], Elexis Baral[1], John P. Neri[1], Timothy Wright[1], Thomas W. Bauer[1], Michael Parides[1], Douglas Padgett[1], Hollis G. Potter[1], Matthew F. Koff[1]
[1]Hospital for Special Surgery, New York, NY
sachers@hss.edu

Disclosures: Sara E. Sacher (N), Elexis Baral (N), John Neri (N), Timothy Wright (N), Thomas W. Bauer (N), Michael Parides (N), Douglas Padgett (1; DJO. 3B; DJO, Navbit Pty, Parvisi. 8; J Arthroplasty. 9; Hip Society), Hollis G. Potter (5, GE Healthcare), Matthew F. Koff (N)

INTRODUCTION: Adverse local tissue reactions (ALTRs) after total hip arthroplasty (THA) due to implant wear debris and corrosion may necessitate premature revision surgery[1]. Micromotion at the head-neck junction of modular THAs has been implicated as a source of fretting and corrosion[2]. Most studies have focused on the evaluation of metal-on-metal (MOM) THA or hip resurfacing arthroplasty (HRA) designs[3], but more traditional THA designs such as metal-on-polyethylene (MOP) and ceramic-on-polyethylene (COP) bearing surfaces have also been associated with the development of ALTRs[4,5]. Although the formation of wear debris and corrosion products is multifactorial, lower implant stiffness as measured by flexural rigidity (FR) is associated with increased fretting and corrosion[6,7], suggesting that implant material composition and geometry may be an important factor in the generation of ALTRs. While previous studies reported a negative correlation between FR with implant corrosion and fretting[6,7], none examined the relationship between FR and clinical imaging outcomes. Magnetic resonance imaging (MRI) and histopathology have been associated with the presence and detection of ALTRs[8], but how MRI outcomes relate to FR of failed THAs is unknown. Therefore, the objective of this study was to determine if differing implant FR's are associated with unique MRI imaging metrics and histopathological outcomes.

METHODS: This study had IRB approval and informed written consent was obtained. The types of THAs meeting inclusion were MOM, MOP, COP, and ceramic-on-ceramic (COC). To date, a total of 320 patients undergoing revision THA surgery were sequentially recruited, of whom complete data was available for 84 patients. MRIs were obtained prior to revision surgery and were acquired on clinical 1.5T scanners using an 8-channel phased array cardiac coil. 2D-FSE images were acquired in the axial, sagittal, and coronal planes[9]; coronal 3D MAVRIC-SL and MAVRIC-SL STIR images[10] were also acquired. MR images were evaluated for the presence (y/n) and type of synovitis (fluid, solid, mixed), impression of synovium (normal, ALTR, infection, metallosis, polymeric, or abnormal), synovial thickness, ALTR severity (none, mild, moderate, severe), and presence (y/n) and location of osteolysis (femoral/acetabular)[8]. Tissue samples at the inferomedial aspect of the head-neck junction were acquired during revision surgery and scored using Campbell's aseptic lymphocyte-dominated vasculitis-associated lesion (ALVAL) score[11], as well as the Natu[12] and Fujishiro[13] grading methods which semi-quantitatively evaluate the presence of histiocytes, tissue particle type and load, inflammation, and necrosis. Geomagic software (Morrisville, NC, USA) was used to calculate FR of retrieved implants as: $Flexural\ Rigidity = E_Y \cdot \pi \cdot \frac{(Engagement\ Diameter)^4}{64}$, where E_Y is the Young's modulus of the femoral stem and the engagement diameter is defined as the distal end of the male taper. Regression models were used to determine relationships between variables of interest and flexural rigidity, controlling for age, BMI, sex, and length of implantation.

RESULTS: The mean FR of the 84 retrieved stems was 227.69 Nm^2, with the most flexible and rigid stems having FRs of 86.8 Nm^2 and 489.2 Nm^2, respectively. FR was associated with the presence of osteolysis on MRI and synovitis type. Increased stem FR was observed in individuals with geographic osteolysis on MRI (+54.9 Nm^2, $p = 0.038$). When evaluated by region, the presence of femoral osteolysis was associated with higher FR (+61.9 Nm^2, $p = 0.022$) and the presence of periacetabular osteolysis was associated with higher FR (+64.2 Nm^2, $p = 0.018$). Further, FR was higher for subjects with no synovitis present on MRI as compared subjects with fluid synovitis present (-166.1 Nm^2, $p = 0.0026$), or mixed synovitis present (-119.2 Nm^2, $p = 0.020$). Regarding histological findings, FR was related to the presence of granuloma and the severity of necrosis. Lower FR was observed in individuals with granuloma (-87.8 Nm^2, $p = 0.030$). Further, individuals with the most severe grading of necrosis (grade 4) had stems with lower FR compared to those with the second most severe necrosis grading (grade 3) (-97.0 Nm^2, $p = 0.038$).

DISCUSSION: In this study of patients undergoing revision THA surgery, an increase of femoral stem FR was associated with the presence of osteolysis and a reduced synovial response while a decrease of FR was associated with the presence of granulomas, different synovitis types, and tissue necrosis. The association between decreased FR with the presence of granulomas and necrosis severity is aligned with previous findings that THAs with lower stem and neck FR resulted in higher corrosion[6,7]. Our results demonstrate that macrophage responses to corrosion debris may be generated by micromotion from more flexible stems. Similarly, the lower FR observed in individuals with synovitis present compared to those without may indicate an inflammatory response to particulate debris. The positive relationship between FR and osteolysis indicates that a highly rigid femoral stem may alter the natural strain distribution in the femoral and acetabular bones and subsequently alters the biomechanically induced bone remodeling process[14,15].

CLINICAL RELEVANCE: The biologic impact of varying implant stiffness in THA manifests with differing MRI and histologic features, and imaging can serve as a useful biomarker of the local response.

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Figure 1. (A) Coronal MAVRIC image of a MOP THA (81 F, Length of implantation: 17.8 years, FR=489.2 Nm^2) displaying periacetabular and femoral osteolysis (arrows). (B) Coronal MAVRIC image of a MOP THA (56 M, Length of implantation: 0.58 years, FR=182.0 Nm^2) demonstrating the synovial reaction of an ALTR (arrow).

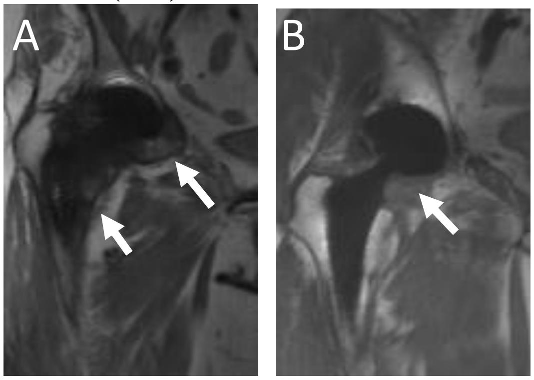

Figure 2. A higher FR is associated with the presence of osteolysis on MRI