A Longitudinal Analysis of MRI Texture of Trabecular Bone Surrounding Total Hip Arthroplasty

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Introduction: Total hip arthroplasty (THA) is the standard clinical treatment for end-stage osteoarthritis. The number of revision THA surgeries continues to increase[1] even as failure of primary THA is relatively low[2]. Aseptic loosening is the most common reason for THA revision[3], which may be associated with previously existing and/or post-surgical-induced osteoporosis in the proximal Gruen zones[4,5]. Reduction of bone mineral density, assessed using dual energy x-ray absorptiometry (DEXA), has been associated with implant loosening in patients with THA[6], however a DEXA scan is a 2D representation of a complex 3D structure, and most patients with THA do not receive DEXA[7]. Magnetic resonance imaging (MRI) is a fully 3D imaging modality capable of displaying structures with high contrast near implanted hardware, and the signal intensity of trabecular bone may be used to assess radiomic features (image texture)[8]. MR image texture analysis has discriminated healthy from osteoporotic fractures of vertebral bodies[9] and emphasizes the potential of radiomic analyses to aid in clinical diagnosis. How texture features of trabecular bone in MRI change in the post-operative setting is unknown. Therefore, the objective of this study was to quantify the trabecular bone texture in patients with THA and determine: 1) if longitudinal changes in MRI image texture and volume exist and 2) if textural and volumetric differences exist between Gruen zones.

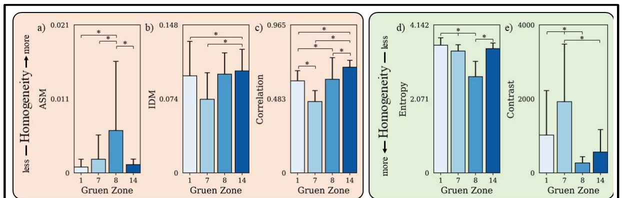

Figure 1: Differences in (a) ASM (image homogeneity), (b) IDM (local homogeneity), and (c) Correlation (linearity of neighboring pixel intensity), (d) Entropy (image disorder), and (e) Contrast (image variability) between the proximal Gruen zones 1, 7, 8, and 14. Statistical differences ($p<0.05$) between zones indicated by a "*".

Methods: Following IRB approval with informed consent, self-reported asymptomatic primary THA patients underwent MRIs annually for four years. All scanning was performed on clinical 1.5T scanners (GE Healthcare) with an 8-channel cardiac coil (Invivo). Morphologic[10] and susceptibility reduced images (MAVRIC)[11] were acquired. Femoral trabecular bone surrounding the implant was automatically segmented from the MAVRIC images, and separated into Gruen zones (Mathworks). Manual editing was performed as needed (ITK-Snap[12]). Image texture analysis (maZda[13] V18.07), was performed to calculate the gray level co-occurrence matrix (GLCM) for each subject at each time point. Intensity data was normalized to a range defined by the 1st and 99th percentiles of voxel intensity within the region of interest. Derived texture features included: angular second moment (ASM, image homogeneity), contrast (image variability), correlation (interdependence of intensities between neighboring voxels), inverse difference moment (IDM, local homogeneity), and entropy (image disorder)[8]. A mixed effects model was performed to detect differences of textural features and volume between Gruen zones and overtime. Post-hoc testing with the Tukey-Kramer test evaluated significant differences within fixed effects (SAS).

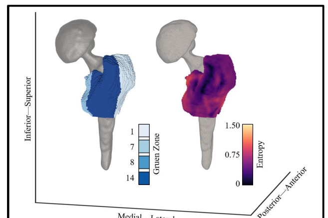

Figure 2: Labeled Gruen zones and entropy texture distribution of the trabecular bone surrounding a femoral prothesis (69 y.o. M) at their baseline MRI. Entropy in Gruen zones 1 and 14 are greater than zones 7 and 8.

Results: The data from 20 hips (6 male; Age: 69.7 ± 8.4 y.o.; BMI: 30.9 ± 2.1, 14 female; Age: 76.5 ± 9.2 y.o.; BMI: 23.9 ± 3.1) across 4 timepoints have been evaluated to date. Gruen Zones: Significant differences in all texture features were found among the Gruen zones (Figure 1, $p<0.0014$). Gruen zone 8 displayed the greatest homogeneity for ASM, Entropy, Contrast and the second greatest homogeneity for IDM and Correlation. Gruen zone 7 displayed the greatest measure of heterogeneity for 3 of 5 texture features (IDM, Correlation, and Contrast). Longitudinal Changes: No differences were observed in trabecular bone texture ($p\geq0.09$) or volume overtime ($p=0.8$). Gruen Zone Texture & Volume: All zones had significantly different volumes, $p<0.0001$, except for zones 1 and 14 which had the largest volumes.

Discussion: This study evaluated image texture features of trabecular bone in subjects with THA. Notable asymmetry in trabecular bone texture exists between the anterior (Gruen zone 8) and medial (Gruen zone 7) regions, having the most and least homogeneous texture, respectively, and differing for 3 of 5 texture features evaluated. The differences in texture may are likely a product of stress distribution and subsequent trabecular remodeling following prothesis implantation[14–16]. In most THA surgeries, the femoral stem is implanted more anterior-medially (zones 7 and 8) to be in-line with the acetabulum. Reduced anterior and medial stress shielding likely prompt asymmetric remodeling of trabeculae, potentially appearing in MR texture as zonal signal intensity differences. A similar investigation of 2D radiographic image texture in THA patients showed discrimination of healthy individuals from patients with femoral periprosthetic osteolysis[17], suggesting texture may be capable of distinguishing differences in zonal trabecular remodeling associated with aseptic loosening. While documented correlations between 2D and 3D radiograph texture features further support this conclusion[18], 3D texture results are known to be impacted by region of interest volume[8,9], and may have influenced the current results. This study had several limitations. First, susceptibility reduction techniques minimize the presence of metal artifact in MR images, but subtle residual artifact may still exist within MAVRIC images[19], particularly around the prosthetic-bone interface. Second, the relationship between image texture heterogeneity and trabecular bone loss cannot be directly made as no pre-operative or follow-up BMD measurements were recorded. However, by correlating the current findings with clinical assessment of implant integration from the morphologic images, an association of texture heterogeneity with integration status may be possible. Third, as texture calculations may be influenced by region of interest size, focusing on regions of uniform size in close proximity to the bone-implant interface rather than the full volume of visualized trabecular bone may facilitate statistical comparisons. Continued evaluation of additional asymptomatic subjects as well as subjects who have undergone revision THA surgery will further elucidate if zonal textural differences are indicative of pathological mechanical asymmetry or are product of zonal volume differences.

Significance/Clinical Relevance: Image texture analysis may aid in identifying trabecular bone health which can indicate an individual's risk of aseptic loosening and potential requirement for revision surgery.

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References: (1) Singh et al., J Rheum 2019 (2) Maradit Kremers et al., JBJS 2015 (3) Feng et al., Am J transl Res 2022 (4) Gruen et al. Clin Orthopa Relat Res 1979 (5) Bernatz et al. J. Arthroplasty 2019 (6) Venesmaa et al. J Orthop Sci 2000 (7) Delsmann et al., Osteoporos Int 2021 (8) Hall-Beyer M Calgary Press 2017 (9) Zaworksi J Clin Endocrinol Metab 2021 (10) Nawabi et al., J Bone Joint Surg Am 2013 (11) Koch et al., Magn Reson Med 2009 (12) Yushkevich et al., Neuroimage 2006 (13) Szczypinski et al. Comp Meth Prog Biomed 2009 (14) Oba et al. Bone Joint Res 2016 (15) Skinner et al. Clin Orthop Relat Res 1994 (16) Noble et al. Clin Orthopa Relat Res 1988 (17) Wilkie et al. Acad Radiol 2008 (18) Almhdie-Imjabbar et al. Arthritis Res Ther 2021. (19) Koff et al., JMRI 2013.