Radiograph-Based Radiomics Trained on MSI-MRI Evaluation of Femoral Loosening in Patients with Total Hip Arthroplasty Improves Sensitivity of Standard Radiographical Assessments of Implant Integration

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Introduction: Aseptic loosening is among the most common post-operative complications for patients with total hip arthroplasty (THA), often requiring revision surgery [1–3]. THA revision surgery increases mortality risk [4–6], re-revision rate [7–9] and reduces postoperative mobility [9]. Radiography is standard for postoperative monitoring and has high specificity for detection of loosening (100%), but poor sensitivity (26%) [10,11]. Three-dimensional multi-spectral magnetic resonance imaging (MSI-MRI) demonstrates high sensitivity (75%) and specificity (100%) for detecting loosening [11], and may address the limitations of radiography, but MSI-MRI is not routinely performed at follow-up [12]. Radiomic features provide quantitative evaluations of local and global signal intensity changes within an image [13–15], and have been extracted from radiographs to evaluate bony architecture following THA [16] and the presence of periprosthetic osteolysis [17]. We propose leveraging the high diagnostic accuracy of implant loosening on MSI-MRI to a radiograph-based radiomic model of implant loosening. We hypothesized that radiograph-based radiomic models would be capable of classifying loose from non-loose implants.

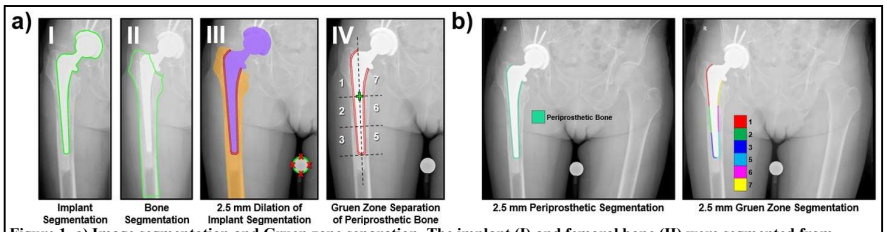

Figure 1. a) Image segmentation and Gruen zone separation. The implant (I) and femoral bone (II) were segmented from which the mutual exclusion of (I) from (II) resulted in separate segmentations (III). The image segmentation was dilated 2.5mm (III), based on a 25mm diameter calibration marker (green/red markings). The bone within the 2.5mm region was separated into three lateral (1, 2, and 3) and three medial (5, 6, 7) Gruen zones (IV) and b) used for radiomic analysis.

Methods: Following IRB approval with informed consent, symptomatic patients undergoing revision surgery underwent an MRI scan prior to surgery and femoral component loosening was confirmed. A second cohort of asymptomatic primary THA patients received MRIs. MRI scanning was performed on clinical 1.5T scanners. Morphologic [18] and MSI-MRI [19] images were acquired as were standard anterior-posterior (AP) pelvis radiographs. A 2.5 mm periprosthetic region was segmented from radiographs and divided into six Gruen zones for further analysis [20]. The full combined periprosthetic region was also assessed. Radiographs were subdivided into overlapping square patches (10–150 mm²) for radiomic analysis, and the PyRadiomics [15] package was used to compute 96 texture features per patch. Z-score normalization was applied to the extracted radiomic features. Cross-validated binary classification models were created [21] to identify loose implants. Prior to model training, the feature space was reduced through principal component analysis while maintaining 95% of explained variance. Logistic regression with L2 regularization was implemented as the primary classification algorithm. Hyperparameters were optimized through stratified five-fold cross-validation, maintaining class balance and strict training/test set independence. Model performance was summarized as mean ± standard deviation of area under the receiver operating characteristic (ROC) curve (AUC) across folds.

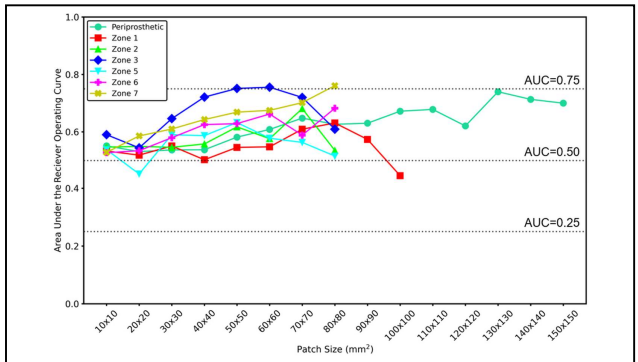

Figure 2. Display of average area under the receiver operator characteristic (ROC) curve (AUC) for six Gruen zones and full periprosthetic bone by patch size.

Results: Image data from 40 asymptomatic (Age: 65.4 ± 9.3 years [mean±SD], Length of Implantation [LOI]: 4.3 ± 3.2 years, 20 male) and 38 symptomatic patients with confirmed femoral loosening (Age: 67.0 ± 10.0 years, LOI: 9.8 ± 10.2 years, 20 male) were evaluated. No significant differences in age or LOI were present (p=0.06). Sixty-four models were trained across zones and patch sizes. Gruen zones 3 (distal, lateral) and 7 (proximal, medial) achieved the highest performance (AUC = 0.76). The full periprosthetic model reached an AUC of 0.74 at 130x130 mm^2.

Discussion: This study found that radiograph-based radiomics can classify MSI-MRI confirmed femoral component loosening in subjects with THA. The maximum AUC values of 0.74 (full bone) and 0.76 (Gruen zones 3 and 7) indicate that radiomic classification outperformed reported conventional radiograph interpretation [10,11]. Improved performance of individual Gruen zones underscores the anatomical specificity of loosening as migration of the femoral stem, which frequently accompanies loosening, may have altered the distal lateral and proximal medial bone, detected by radiomics as changes in signal intensity. This study had several limitations. First, patch extraction was constrained by the narrow geometry of Gruen zones, limiting maximum patch sizes in zonal models. Second, square patches were utilized whereas vertically oriented patches aligned with the femoral anatomy may better capture length-related texture features. Third, inclusion of cortical bone, attributed to implant migration, could have influenced textural measurements in certain zones. Fourth, acetabular component loosening was not evaluated, as standardized segmentation of the spherical cup is more challenging than femoral Gruen zones [11]. Fifth, although the cohort was balanced, the modest sample size limits generalizability. Future studies with larger datasets, refined segmentation strategies, and evaluation of implant design factors may improve performance and clinical applicability. In summary, this investigation provides a feasible method for quantitatively enhancing the qualitative assessment of implant integration using standard-of-care radiographs. Such models could support earlier detection of loosening, guide postoperative management, and improve patient mobility, particularly in settings where advanced imaging modalities such as MSI-MRI are unavailable.

Clinical Relevance: Radiograph-based radiomics enables assessment of femoral implant loosening using radiographs acquired during routine post-operative follow-up. This approach leverages the established high diagnostic sensitivity and specificity of MSI-MRI as a reference standard while utilizing the widespread availability of standard radiographs in routine post-operative care.

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