Evaluation of Computed Tomography Protocol on Periprosthetic Bone Characterization After Total Hip Arthroplasty: A Cadaveric Study

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INTRODUCTION: While total hip arthroplasty (THA) has proven to be a highly effective and successful procedure, revisions still occur commonly due to wear, infection, and loosening. In these cases, assessment of the periprosthetic region before revision surgery is crucial for timely and appropriate intervention. Computed tomography (CT) imaging plays a pivotal role in these evaluations, offering insights into the implant-bone interface, potential bone loss, and any surrounding tissue changes. While there have been advancements in metal artifact reduction (MAR) and dose optimization in CT, there remains a lack of established and reliable methods for precisely assessing the periprosthetic region. The objective of this study is to evaluate the impact of head material, dose reduction and reconstruction protocols on periprosthetic tissue characterization after THA in a cadaver study.

METHODS: A THA was performed in a cadaver using a size 10 collared stem, a 32mm head (repeated with CoCr and ceramic), a 52mm acetabular cup, and 3 screws. Conventional CT images (120 kVp, 884 slices at slice thickness of 0.5 mm, in plane resolution of 512x512) were acquired at three distinct radiation doses: at clinical dose, at 25% (mid) dose, and at 10% (low) dose, with resulting CTDIvol of 5, 1.2, and 0.5, respectively. Subsequently, the images underwent reconstruction using both a deep learning (AiCE) and standard approach, and each reconstruction method was applied with and without a MAR sequence, for a total of 12 image outputs per scan. The cadaver was scanned three times per head material, with repositioning in between scans to assess repeatability of measurements. For each scan, 3D Slicer (slicer.org) was used to segment regions of interest (ROI) from the image set obtained at clinical dose with standard reconstruction and no MAR. Peri-femoral and peri-acetabular ROIs were defined as 2 mm around the femoral and acetabular components, respectively, achieved using a margin grow tool. The repeatability of segmentations was evaluated by comparing the voxel size of the periprosthetic regions. Signal intensity (measured in Hounsfield Units, HU) was computed in Slicer at the defined ROIs for each scan at each image output. Mean standard deviation (SD) of HUs across the three scans was used as a measure of repeatability. Within both CoCr and ceramic heads, two-way ANOVAs were used to assess the impact of dose and reconstruction technique on the SD of HUs for each ROI. Further, to assess impact of head material, dose was kept constant, and a two-way ANOVA was used to compare CoCr and ceramic material among different reconstruction techniques.

RESULTS: There was < 5% variation in the ROI size of both the peri-femoral and peri-acetabular segmentations across each of the three scans (Figure 1). For each ROI, dose and reconstruction technique had significant impacts on the SD of the HUs (p < 0.001). Notably, for both the deep learning and standard reconstructions, a low dose significantly increased the variability of the signal in the ROIs compared to both mid and clinical doses (Figure 2). With the use of MAR, the variability of the signal at low dose was more comparable to that at clinical dose. There was no difference between deep learning and standard reconstruction techniques when MAR was used in any of the ROIs. When visually comparing images acquired at the clinical dose and at the low dose, minimal observable differences are evident (Figure 3). Head material did not have a significant impact on the variability of signal at each reconstruction technique and at each dose (p > 0.05 in all cases).

DISCUSSION: Both acquisition dose and reconstruction techniques had a significant effect on variability of the signal intensities in the ROIs. Although decreasing the dose increased the artifact, the MAR sequence with both the deep learning and standard reconstructions mitigated the variability in the low dose scan and provided results similar to the conventional clinical dose. Compared to ceramic, the CoCr head did not add a significant amount of metal artifact. Ultimately, this study suggests that both deep learning and standard reconstructions can yield favourable and comparable outcomes at low doses when implementing a MAR sequence, despite the presence of a dense metal implant. This is important for long-term studies that aim to assess changes in periprosthetic tissues (e.g. bone mineral density or texture features) or perform segmentations for computational modelling or CT-based migration analysis.

SIGNIFICANCE/CLINICAL RELEVANCE: Evaluation of the periprosthetic regions can help radiologists and surgeons to accurately diagnose complications and make informed decisions regarding patient care and treatment plans. Low-dose CT scans may be implemented with reliable measurements of periprosthetic tissue densities using modern reconstruction approaches.

FIGURES:
Figure 1: Segmented peri-femoral and peri-acetabular ROIs.
Figure 2: Comparison of SD of HUs between doses and reconstruction techniques for each ROI.
Figure 3: Comparison of clinical vs low dose scans, with deep learning and metal artifact reduction implemented in the image reconstruction.

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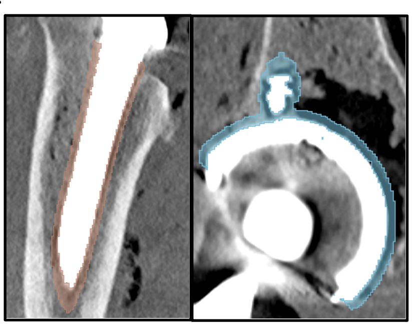

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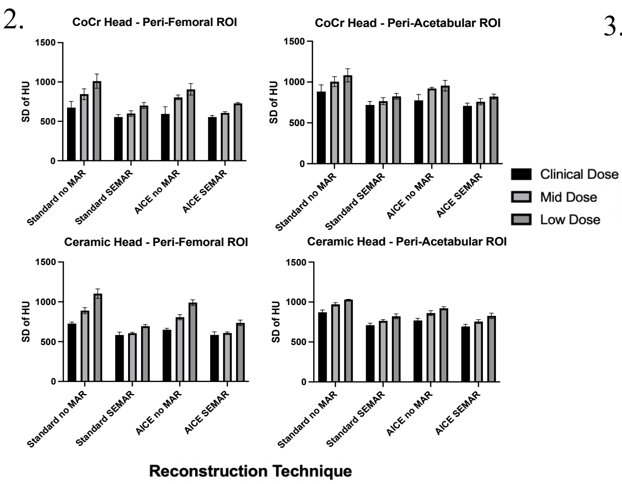

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