

# Characterization of the Asymmetric Bone Envelope of the Proximal Humeral Metaphysis for Stemless Shoulder Implants

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## Introduction

Stemless humeral implants in anatomic total shoulder arthroplasty (TSA) are increasingly favored for preserving bone stock, relying on the bony structures of the proximal humeral metaphysis for mechanical stability. In many current stemless shoulder systems, the sizing of the implant is performed purely based on the dimension of the humeral head resection, whereas the humeral head resection may be performed following the anatomic articular margin or using fixed angle resection with predefined inclination and retroversion angles. An inadequate sizing or placement of a stemless humeral implant may lead to cortical impingement or periprosthetic fractures<sup>1</sup>. For the intra-operative sizing and/or stemless implant design, it is therefore imperative to understand the morphology and bone envelope of the humeral metaphysis and as it relates to different humeral head resections. Several studies<sup>2-5</sup> have previously highlighted the large variability in the humeral morphology in terms of humeral head diameter, head offset, or neck inclination and retroversion angles. Reeves et al.<sup>5</sup> characterized the bone envelope of the humeral metaphysis with respect to the native neck resection using fitted circles without considering the variability of the resection angles or the highly asymmetric morphology of the proximal humerus. This study aimed to develop a statistical model that characterizes the bony envelope (“safe zone”) for implant placement/design to reduce the risk of cortical impingement, accounting for common surgical variations in humeral head resection.

## Methods

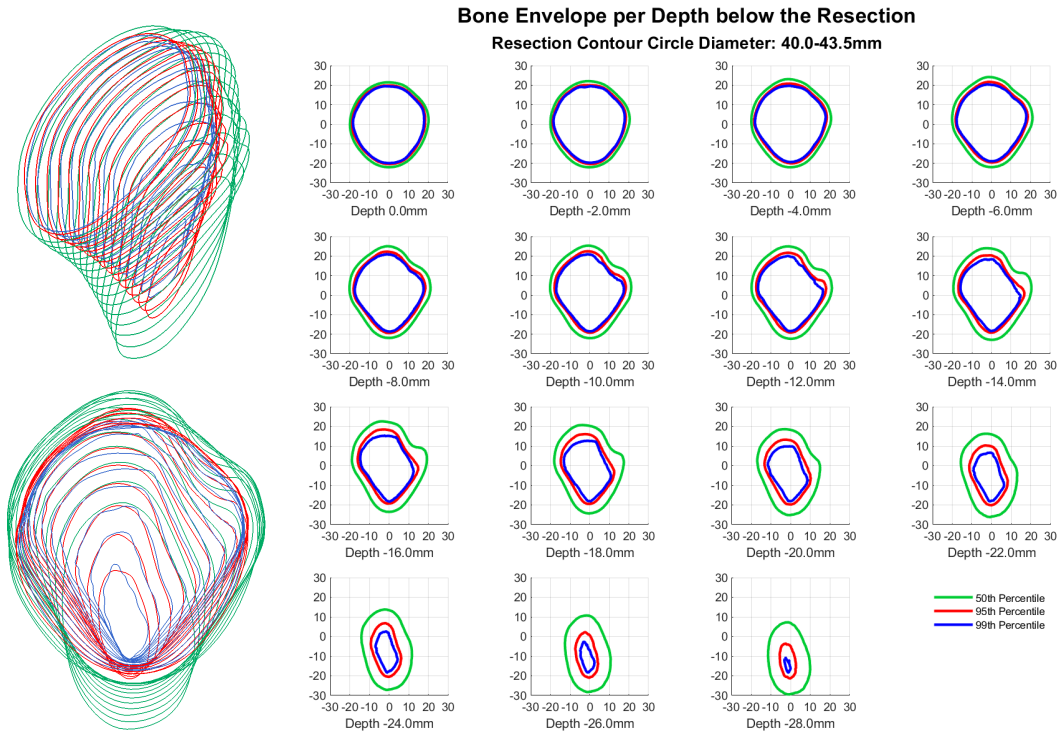
For this study, 220 humeral bone models (reconstructed from CT scans using threshold-based segmentation) derived from various ethnicities (61% Caucasian, 22% Asian, 17% unknown) and both genders (52% female, 42% male, 5% unknown) were analyzed. For each bone model, several humeral resection planes were virtually identified accounting for the surgical variations (i.e. anatomic head resection or fixed angle with an inclination angle of  $135^{\circ} \pm 5^{\circ}$  and a retroversion angle of  $30^{\circ} \pm 10^{\circ}$  (based

on the trans-epicondylar axis) or the native retroversion angle  $\pm 10^{\circ}$ ). For each virtual resection, the size of the resection contour was measured as the largest inscribed circle diameter and a local coordinate system was defined at the contour centroid, with the z-axis perpendicular to the resection plane, and the y-axis pointing superior/lateral to the greater tubercle and the x-axis anteriorly (note, right bones were mirrored). The contour of the outer cortical bone was extracted at the humeral resection level as well as at 14 parallel slices with 2 mm spacing distal to the resection in the resection-based coordinate system. Each outer bone contour was inset by 2 mm to account for the cortical thickness. All bone contours were then grouped based on size of the resection. For each slice, all contours were overlaid, and the statistical bone envelope was identified as the median (50<sup>th</sup>), 95<sup>th</sup>, and 99<sup>th</sup> percentile coverage, where the latter two define the “safe zone” with no cortical impingement in 95% or 99% of the cases.

## Results

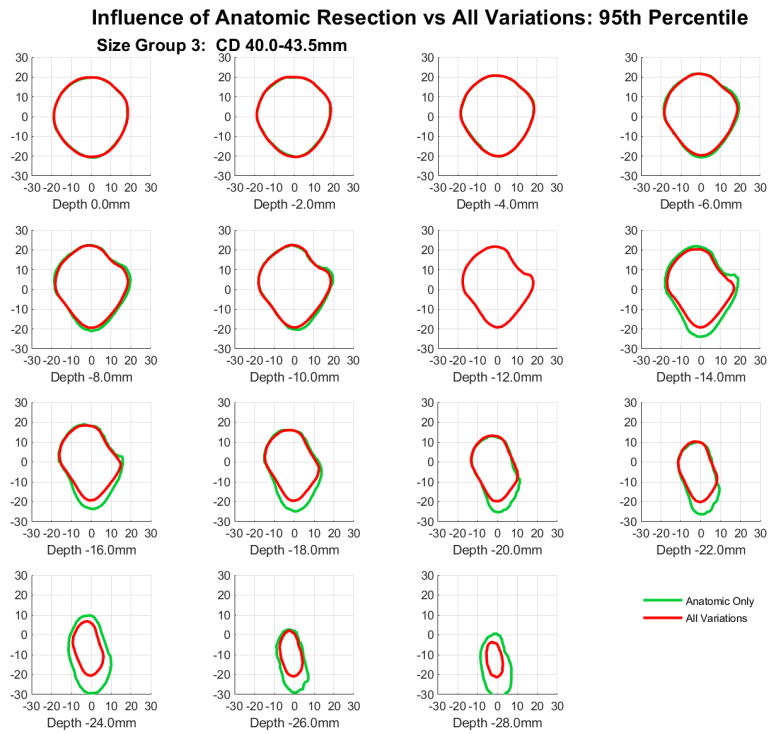
The statistical bone envelope shows that the humeral metaphysis is highly asymmetric due to the shape of the greater and lesser tubercle and the bicipital groove and only the proximal slices directly below the humeral resection can reasonably be described with circular measurements (Figure 1). Considering the morphological and surgical variability, the average bone envelope remains relatively wide, however the safe zone envelope narrows down with depth below the resection in the anterior-posterior directions with the widest envelope in medial-lateral (y-) direction and the centroid of the bone envelope translates inferiorly. Considering only anatomic head resections, a wider safe zone envelope was observed for the distal slices whereas no difference was seen in the 0 to -12 mm slices compared to the safe zone including all resection variations (Figure 2).

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**Figure 1**

Statistical bone envelope showing the median (green), 95<sup>th</sup> (red) and 99<sup>th</sup> (blue) safe zones for 15 slices (spaced at 2 mm) distal to the humeral resection, accounting for cortex thickness and common surgical variability (shown for the group with resection diameters between 40 and 43.5 mm).



**Figure 2**

Influence of surgical resection variation (green: anatomic resection only, red: all resection variations) on 95<sup>th</sup> percentile safe zone for the 15 slices.

## Discussion

These results highlight the highly asymmetrical nature of the proximal humeral bone and highlight the challenge for stemless shoulder implant design, for both implant sizing and placement. There is limited space to place circular or symmetric implants without risking cortical impingement or periprosthetic fractures. The centroid of the bone envelope translates inferiorly with increasing depth below the resection, which is consistent with previous findings<sup>5</sup>. The impact of surgical variability was more pronounced as the depth increases. Therefore, surgical flexibility to accommodate patient functional requirements comes at the expense of a smaller design envelope. Non-circular, asymmetric stemless anchor designs may optimally fit within the asymmetric bone envelope and could be designed to reach the periphery of the metaphysis, where the bone density is typically higher compared to the central region<sup>6,7</sup>.

## Conclusion

This study underscores the importance of considering morphological and surgical variability when evaluating the asymmetrical nature of the proximal humeral bone, not only for stemless implant design but also for intraoperative sizing and placement of stemless anchors. Often, the metaphyseal cavity for the stemless implant is prepared for a certain size that is solely defined based on the size of the resection. To minimize the risk for cortical impingement or periprosthetic fracture, surgeons may choose to downsize the stemless implant below what the resection surface indicates, which may compromise optimal fixation stability as the implant may engage with less dense bone in the center of the metaphysis<sup>6,7</sup>. An asymmetric, non-circular stemless implant design could address these limitations, while still reaching the periphery of the metaphysis and denser bone.

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