

3D Analysis of the Proximal Radial Shaft Morphology

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INTRODUCTION: The proximal radial (PR) and its intramedullary canal (IC), spanning from the radial neck to the bicipital tuberosity (BT), have a complex morphology. This morphology presents a significant challenge when designing radial head (RH) implant stems, which are housed in the IC. Accurate descriptions of the shaft and canal are necessary to develop better fitting implants. Special attention must be given to the narrowest point of the PR as well as the start and maximum width of the BT. Numerous studies have attempted to describe this morphology. However, much of the existing work relies on simplifications such as circular radial neck and tuberosity shape, the exclusion of the IC from analysis, and reliance on two-dimensional (2D) imaging information. These contribute to an incomplete understanding of radial morphology in the context of RH arthroplasty. This study aims to improve the accuracy of PR and IC specifications.

METHODS: 52 three-dimensional (3D) models of the PR and the corresponding IC were created from high resolution CT-scans from the New Mexico Decedent Image Database. The study was regarded as exempt by the institutional review board. 26 average sized females (160-165 cm) and males (173-178 cm) divided in two equally sized age group (25-30 and 40-45 years) were used (4 groups total). The radii and canals were algorithmically aligned with the z-axis, and 0.1 mm thick axial slices were created for a length of 60 mm starting from the end of the RH. Axial slices were then fitted using an ellipse. From each fit, minor axis, major axis, midpoint coordinates, and the root mean squared error (RMSE) of both the PR and IC were extracted (see Figure 1). Additionally, axial slices were fitted with a circle, and RMS was measured for comparison. Utilizing this dataset, distance to the RH, width of the IC and outer PR, eccentricity of the narrowest point of the PR, start of the BT, maximum extent of the BT, canal width increase of the BT, and other morphological properties were extracted. BT origin was determined with the aid of the second derivative of a polynomial-fit over the region of interest. The Mann-Whitney U test was used to evaluate statistically significant differences in the sex and age groups as well as differences in the RMSE between the elliptical and circular fitted models. P-values less than 0.001 were regarded as significant to account for multiple hypothesis testing.

RESULTS SECTION: The narrowest part of the PR was positioned between 12.6 to 20.0 mm from the RH (females: 14.9±1.5 mm (mean ±standard deviation) males: 17.9±1.4 mm), with a minimum canal width range of 5.2 to 10.6 (female: 6.9±1.2 mm, male: 8.0±1.3 mm) and a minimum cortex width between 9.8 to 15.7 mm (female: 11.7±0.9 mm male: 13.7±1.0 mm). The start of the BT was between 15.6 to 25.3 mm (female: 18.8±2.0 mm male: 22.0±2.1 mm) away from the RH. The maximum width of the BT varied between 8.3 to 17.1 mm (female: 11.3±1.3mm, male: 13.5±1.7 mm). The BT was 1.4 to 7.4 mm (female: 4.4±1.3 mm male: 5.5±1.2 mm) wider than the narrowest slice of the PR. The mean eccentricity of the PR was between 0.32 and 5.4 (female: 0.42±0.07 male: 0.42±0.05) and for the IC between 0.48 and 0.67 (female: 0.54±0.05 male: 0.56±0.05). All positional and width differences were significantly larger for the male population. For the BT the canal width increases significantly more for older females (25-30: 3.7±1.4 mm 40-45: 5.1±0.8 mm, $p < 0.001$), all other age and eccentricity differences are not significant. The RMSE for the elliptical fit (canal: 0.11±0.02 mm cortex: 0.19±0.15 mm) is significantly lower than the circular-fit error (canal: 0.39±0.09 mm cortex: 0.76±0.52 mm).

DISCUSSION: Results showed high variance within the patient groups despite similar heights. Significant differences between sexes were found, but these may potentially result from differences in height. The study only included subjects with average height, reducing variance within the subject population. Further research needs to be done to determine the true spread of radial stem morphology in the general population. Results show a high spread of the relevant landmarks within the sample which must be considered when designing implants. Significant age-related enlargement of the tuberosity width in women indicates that age consideration must play a more significant role in RH arthroplasty. The elliptical fitting of the radial anatomy demonstrated significantly less error than circular fitting, suggesting that previous studies conducted with this assumption are flawed. Furthermore, the reported eccentricity shows that the PR and IC are not simply circular, while implant stems and their corresponding surgical tools are primarily circular. The orientation of the axial slices might not be perpendicular to the radial axis, changing eccentricity of the fitted ellipsis. The algorithm used for alignment was constructed to minimize this error, but the corresponding inaccuracy remains to be quantified.

SIGNIFICANCE/CLINICAL RELEVANCE: This study provides accurate morphological data on the radial neck and the bicipital tuberosity. Important data to improve the design of currently complication prone radial head implants.

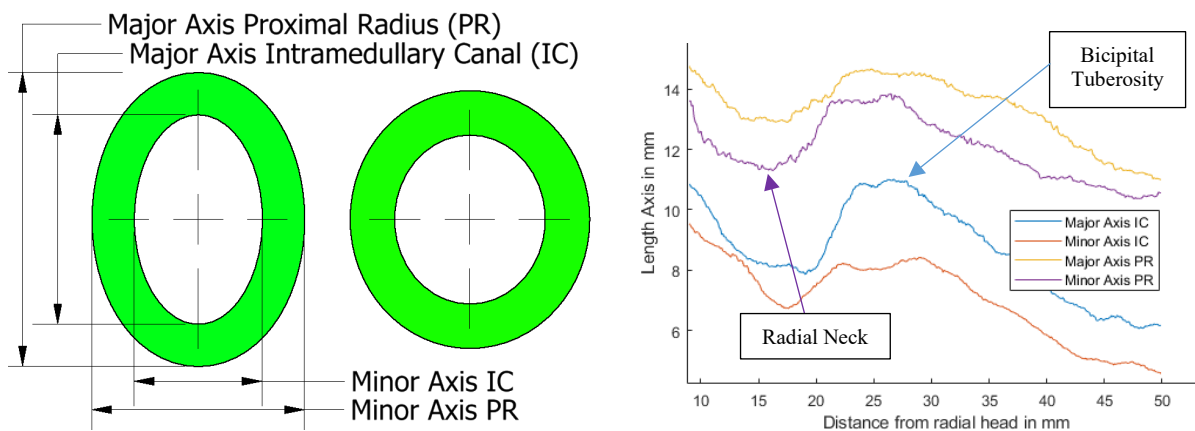


Figure 1: Each slice of the proximal radius (PR) cortex is classified by two ellipses. One representing the outside boundary of the PR the other the outline of the intermedullary canal (IC). Each ellipses size and shape are specified by a major and minor axis. Plotting these axes for each slice yields a graph describing the morphology of the PR and IC and allows to get positional and width data on each important landmark, such as the narrowest part of the PR and the full extent of the bicipital tuberosity. Equal minor and major axis mean the ellipsis is circular, else it is eccentric. The PR and IC are mostly eccentric.