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ORIGINAL ARTICLE

An assessment of proximal humerus density with reference to stemless implants

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Background: Shoulder arthroplasty humeral components have undergone several generational changes, with systems now offering shorter stems and stemless options. The stemless humeral implants obtain fixation in the trabecular bone of the proximal humerus through elaborate fixation features. To optimize implant design, the regional variations in bone density within the proximal humerus should be determined. As such, the purpose of this computed tomography–based study was to map the regional variations in bone density of the proximal humerus.

Methods: The trabecular-canal of the proximal humerus was extracted from computed tomography scans of 98 subjects and divided into 13 slices and 5 subsections (central, anterior, posterior, medial, and lateral). The average apparent density (ρ_{AVG}) was then quantified in each subsection of the trabecular-canal.

Results: Slice depth, subsection, and gender were all significant main effects, with additional significant interactions between slice depth, subsection, and osteoarthritic condition. The slices above the resection plane had the greatest ρ_{AVG}, with densities decreasing down the canal. The central subsection had significantly lower ρ_{AVG} than the peripheral sections, and the medial subsection tended to have the highest ρ_{AVG} ($P < .001$). Furthermore, the ρ_{AVG} of male subjects was significantly greater than that of female subjects ($P < .001$).

Conclusions: The apparent density of the proximal humerus' trabecular-canal is nonuniform. This has implications for the design of stemless implants, indicating that implants seeking purchase in higher density bone should take advantage of the peripheral regions of the trabecular-canal within the first 15-20 mm beneath the humeral head resection plane.

Level of evidence: Anatomy Study; Imaging

Keywords: Shoulder arthroplasty; stemless; canal sparing; osteoarthritis; bone density; proximal humerus

Shoulder arthroplasty is an effective surgical treatment for osteoarthritis (OA), fracture, inflammatory arthritis, and cuff tear arthropathy. Implant manufacturers have recently designed shorter stem and stemless implants, which are less invasive and preserve bone, in the hope of decreasing stress shielding and bone remodeling.

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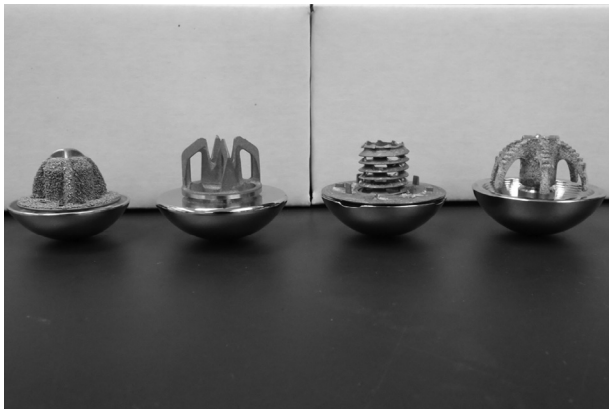

Figure 1 A selection of currently available stemless implants are shown to demonstrate the variability present in metaphyseal designs for attaining fixation in the trabecular bone of the proximal humerus.

Wolff's law states that bone is resorbed and remodeled in part because of the loads that it is subjected to, which suggests that when the loads acting on a section of bone are diminished beyond some strain energy density threshold,[26] the bone will be resorbed in response.[18,41] In a reconstructed joint, the implant stem or fins share some of the load that was initially borne solely by the bone.[24] This load sharing can reduce bone stimulus, leading to the phenomenon termed stress shielding,[4,36,37] which is a cause of bone resorption and can contribute to implant loosening.[4,5,8] A radiographic study by Nagels et al reported evidence of stress shielding surrounding proximal humeral implants in 9% of the cases investigated (n = 70); but they pose that the true incidence may be higher because they were unable to account for changes in the trabecular bone density.[25]

With the concern of stress shielding in mind, implant manufacturers have gradually reduced the length of traditional stemmed implants to maintain as much of the natural loading conditions and bone as possible. Most recently, ultrashort shoulder implants, termed stemless, have been released by several implant manufacturers.[9,10,13,14,17,30,35] Whereas these stemless implants all seek to maintain implant fixation through establishing purchase in the trabecular bone of the proximal humerus, their designs vary from simple pegs to elaborate branching structures (Fig. 1). This disparity in the metaphyseal fixation features suggests that the optimal design for stemless shoulder implants (that will reduce stress shielding while maintaining adequate implant fixation) has yet to be quantified, perhaps because there has not been a thorough investigation of the morphology of the underlying trabecular bone.

Whereas much is known about the overall structural morphology of the proximal humerus,[3,6,11,16,19-21,28,29,32-34,43,44] few investigations have focused on how that morphology may have an impact on arthroplasty.[6,33] Studies suggest that morphologic variability is an important factor that should influence implant selection and design.[31,33] As such, variation in the quality of subarticular trabecular bone, in which stemless implants seek fixation, may be of interest. This is supported by

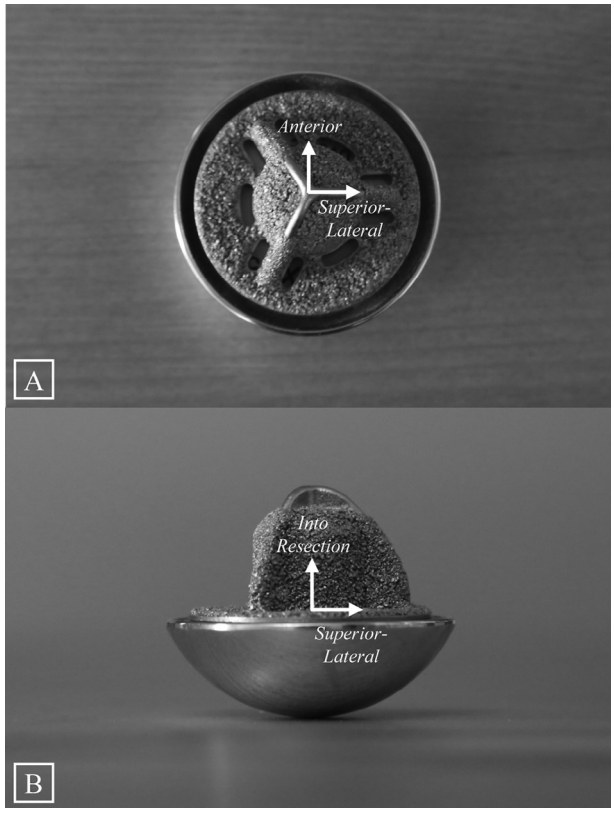

Figure 2 As an example, the Tornier Simpliciti implant is presented to demonstrate that a stemless implant–relevant Cartesian coordinate system should be constructed with axes directed (**A**) superior-laterally, anteriorly, and (**B**) perpendicular to the underside of the implant.

studies of hip arthroplasty, which demonstrate that bone density at the time of surgery is an important factor inversely correlated to peri-implant bone loss after arthroplasty.[4,12,22,38] Accordingly, proximal humerus implants should seek fixation in denser regions of trabecular bone.

A few studies have investigated the regional variation of trabecular bone quality in the proximal humerus as it pertains to arthroplasty.[1,15,23,39,42,45] Although there seems to be some consensus that the medial and dorsal regions of the proximal humerus consist of the highest density bone,[15,42] only 1 study has begun to assess the regional variations in trabecular bone density in a 3-dimensional coordinate system that is relevant to stemless shoulder arthroplasty (Fig. 2); however, this study had a small sample size (n = 8) and did not include osteoarthritic humeri.[1] The purpose of this anatomic study was to quantify regional variations in trabecular bone apparent density (ρ_{AVG}) in a 3-dimensional, stemless implant–relevant, coordinate system. To do so appropriately, gender and OA condition were accounted for as between-subject factors.

Materials and methods

Shoulder computed tomography (CT) scans from 98 subjects were obtained and classified into 3 categories per their OA condition by