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ORIGINAL ARTICLE

Spatial mapping of humeral head bone density

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Background: Short-stem humeral replacements achieve fixation by anchoring to the metaphyseal trabecular bone. Fixing the implant in high-density bone can provide strong fixation and reduce the risk of loosening. However, there is a lack of data mapping the bone density distribution in the proximal humerus. The aim of the study was to investigate the bone density in proximal humerus.
Methods: Eight computed tomography scans of healthy cadaveric humeri were used to map bone density distribution in the humeral head. The proximal humeral head was divided into 12 slices parallel to the humeral anatomic neck. Each slice was then divided into 4 concentric circles. The slices below the anatomic neck, where short-stem implants have their fixation features, were further divided into radial sectors. The average bone density for each of these regions was calculated, and regions of interest were compared using a repeated-measures analysis of variance with significance set at $P < .05$.
Results: Average apparent bone density was found to decrease from proximal to distal regions, with the majority of higher bone density proximal to the anatomic neck of the humerus ($P < .05$). Below the anatomic neck, bone density increases from central to peripheral regions, where cortical bone eventually occupies the space ($P < .05$). In distal slices below the anatomic neck, a higher bone density distribution in the medial calcar region was also observed.
Conclusion: This study indicates that it is advantageous with respect to implant fixation to preserve some bone above the anatomic neck and epiphyseal plate and to use the denser bone at the periphery.
Level of evidence: Basic Science; Anatomy Study; Imaging

Keywords: Shoulder arthroplasty; humeral bone density; short-stem devices; implant fixation; humeral component; implant design; implant loosening

Short-stem humeral component designs have been introduced by several manufacturers in the past few years.[6,8] The benefits of this type of design (Fig. 1) include decreased bone resection compared with conventional stemmed implants and the ability to replicate the native humeral head center without compensating for a patient's variable humeral shaft offset.[2] A drawback of such designs is that they rely on a smaller proximal region for fixation with a less advantageous lever arm, which is not located as far down the shaft of the humerus, compared with traditional stemmed designs. Currently available short-stem designs resect the humeral head and achieve fixation in bone distal to the resection plane in the trabecular metaphyseal region. The density of the bone in this region is therefore important for achieving adequate component

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This study has been conducted according to the ethics approval (REC reference: 13/LO/1839, IRAS project ID: 132972) from National Research Ethics Service.

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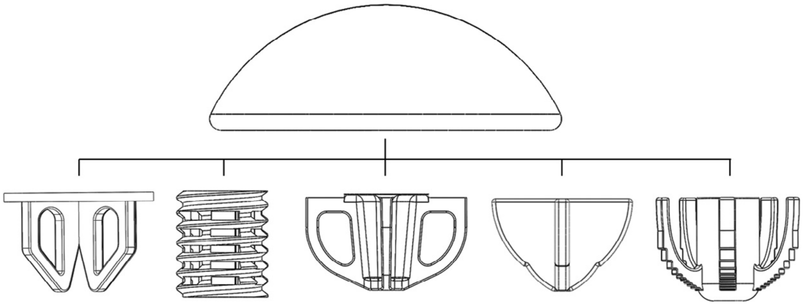

Figure 1 Diagram of the most common short-stem humeral components. The hemispherical head is assembled to a variety of stem designs shown in the figure using a taper fit mechanism. The stem is press fitted into the cancellous bone beneath the anatomic neck cut.

fixation. In fact, Favre et al,[3] using cadaveric humeri, showed that in a short-stem device, micromotion between bone and implant may increase significantly with decreased apparent bone density. They showed that when bone density is lower than 0.1 $g \cdot cm^{-3}$, an implant may experience micromotions above the 150-µm threshold accepted to result in bone growth.[7,12]

A number of studies have investigated the bone density distribution in the proximal humerus. A summary of their methodologies and findings is shown in Table I. In a study on dissected proximal humeri using bone mineral densitometry and an indentation test, Saitoh et al[14] showed that the proximal part of the humeral head exhibited the greatest amount of bone mineral density and the humeral neck had approximately half the bone mineral density of the humeral head. In addition, they also showed that the cancellous bone of the neck had only one-third the mechanical strength of the humeral head in the indentation test. In a volumetric bone mineral density assessment of 20 cadaveric bones, Tingart et al[16] showed that trabecular bone has significantly higher density in the proximal posterior portion of the articular surface. Yamada et al[21] performed a computed tomography (CT) study of 40 patients and found that bone density was higher on the medial side of the humeral head, especially near the articular region. Hepp et al[5] investigated bone strength rather than density by slicing 24 cadaveric humeri and measuring bone strength by indentation. They showed that medial and posterior aspects of the proximal humerus had the highest bone strength. In addition, they found that the greater and lesser tuberosities and the central area of the proximal head had the lowest bone strength. Barvencik et al[1] studied age-related changes in bone density in 60 cadaveric proximal humeri. They investigated bone density using x-rays and found that the most superior and medially located part of the humerus had highest bone density independent from age. They also found that the most prominent decrease in bone density due to age was observed in the region of the greater tuberosity.

These studies provide valuable information on the spatial distribution of bone in the proximal humerus for screw fixation, rotator cuff repair suture anchors, or conventional stemmed humeral devices. However, they report data in the transverse plane (more appropriate for conventional stemmed humeral devices) or with limited data resolution in this volume of interest. Hepp et al[5] reported strength from 5 points in 4 transverse slices in the proximal humerus, Yamada et al[21] divided the CT data into 2 areas (medial and lateral) for transverse slices of the proximal humerus, and Barvencik et al[1] assessed a single coronal slice of the proximal humerus. Tingart et al[16] did report their data relative to the humeral neck, but only in 1 slice that was perpendicular to the long axis of the shaft. A summary of the measurement location of these studies is shown in Table I. As a result, the data provided by these studies are of limited use in relation to short, proximally fixed humeral designs that are orientated in the plane of the head-neck junction, with fixation features protruding around 20 to 40 mm perpendicular to that plane. For such devices, the spatial density map therefore needs to be reported in a reference frame relative to the anatomic neck and to provide high-resolution density mapping in the volume of bone proximal to this plane and 20 to 40 mm distal to this plane.

A spatial map of humeral bone density in the volume of bone where devices with proximal fixation achieve fixation would therefore be useful to surgeons by providing a guide for the positioning of anchoring features of existing implants and could prove to be a critical resource for implant designers seeking to improve the fixation features of future humeral components by using denser regions of the bone. Therefore, this study aimed to provide a detailed map of bone density in the proximal humerus, specifically in the bone distal to the humeral neck where these devices achieve fixation. The null hypothesis is that there is no statistically significant relationship between the bone density and the spatial location in proximal to distal, central to peripheral, and radial directions in the humeral head.

Method

Eight CT scans of independent cadaveric humeri specimens with mean ± standard deviation age of 71 ± 10 years (range, 59-83 years; 4 male) were used. There was no evidence of degenerative joint disease or osteoporosis in the specimens. The CT scans were carried out using a Toshiba (Tokyo, Japan) Aquilion 32 machine. Standard phantoms of Delrin, nylon, and polypropylene provided by the manufacturer were used to calibrate the machine for bone, soft tissue,