Biomechanical Stiffness and Strength of Five Types of Human and Artificial Humeri

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Introduction: The human humerus is the third largest longbone and experiences up to 3% of all fractures. However, few reports provide any intact humerus biomechanical properties. Also, no studies exist comparing fresh-frozen humeri vs. the dried-dehydrated and artificial humeri available from Sawbones (Vashon, WA, USA). The goal of this experimental study was to compare the biomechanical stiffness and strength of “gold standard” fresh-frozen intact humeri vs. 4 other intact humerus models.

Methods: A series of 5 types of intact humeri were used, namely, human fresh-frozen (n=19), human embalmed (n=18), human dried (n=15), artificial “normal” (n=12), and artificial “osteoporotic” (n=12). Humeri were mechanically tested under “real world” clinical loads for shear (Figure 1a), torsional (Figure 1b), and cantilever bending stiffness (Figure 1c), as well as cantilever bending strength (Figure 1c).

Results: Stiffness and strength data are presented as absolute values (Figure 2) and after being normalized by multiplying the ratio of working length / midshaft diameter (Figure 3). Compared to “gold standard” fresh-frozen data, statistical equivalence (p>0.05) was achieved for all 4 test modes (embalmed humeri), 1 of 4 test modes (dried humeri), 2 of 4 test modes (artificial “normal” humeri), and 2 of 4 test modes (artificial “osteoporotic” humeri). Bone mineral density for all human humeri vs. strength was linearly related (R=0.46 to 0.84). Approximately 77% of human humeri failed by a transverse or oblique distal shaft fracture (Figure 4), whereas 88% of artificial humeri failed by a "mixed" fracture that was started transverse on the tensile stress side and then became oblique on the compressive stress side of the humeral shaft (Figure 5).

Discussion: First, only 1 prior study measured shear stiffness of human humeri, yielding a similar value (968 N/mm) to current absolute data [1]. The several previous reports on absolute torsional stiffness (2.01-5.93 Nm/deg)[2-8] showed good overlap with present data for human and artificial humeri. Current absolute cantilever stiffnesses were similar to the only 2 prior studies measuring cantilever stiffness on human humeri (7.5-25 N/mm)[5,6]. No previous studies measured cantilever strength. Second, based on present normalized data, embalmed humeri can fully substitute for "gold standard" fresh-frozen humeri for stiffness and strength measurements in all test modes. Dried humeri can only duplicate fresh-frozen humeri for cantilever shaft fracture load. Artificial humeri, whether with “normal” or “osteoporotic” geometry, only mimic fresh-frozen humeri for cantilever bending stiffness or strength.

Third, current failure modes exhibited by the human humeri, but not artificial humeri, were consistent with clinical classifications by the Orthopaedic Trauma Association of type 12-A3.3 and type 12-A2.3. [9]. Fourth, BMD was a good predictor of intact human humerus strength.

Significance: To date, this is the most comprehensive study on the biomechanical stiffness and strength of intact human and artificial humeri. This information will help biomechanical researchers choose the humerus model which is most suitable for their study on fracture fixation devices and joint replacements.

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