Ultimate Fracture Load of Cadaveric Proximal Humeri Correlates More Strongly With Mean Combined Cortical Thickness than Cortical Index, DEXA Density, or CC Ratio

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Introduction: Age-related decreases in bone quality (e.g., osteopenia/osteoporosis) of the proximal humerus can result in complications of fracture fixation such as poor screw purchase and post-operative loosening of the implant. In fact, more than 70% of proximal humeral fractures occur in patients older than 60 years. Since the 1970s, various radiographic measures, such as cortical index (C.I.), have been used to predict the strength of bones. For example, C.I. continues to be used in these contexts to assess bone strength/quality in studies of fracture fixation and endoprosthetic replacement of the proximal humerus and femur in bones ranging from healthy to severely osteoporotic [1-5]. C.I. was originally defined at specific locations of the bone shaft in A-P radiographs as the difference between the outer (OD) and inner diameters (ID) of the bone divided by the OD [(OD-ID)/OD] (lower C.I. values resent weaker bone). Recent studies, however, have expressed C.I. in terms of area measurements of larger regions of the shaft on A-P radiographs [2,4]. The goals of this study are to determine: (1) if areal C.I. is a stronger correlate of ultimate fracture load (UFL) than linear C.I., and (2) if other radiographic- or DEXA-based measures are stronger correlates of UFL than C.I. The additional measurements for assessing bone strength/quality included regional density measurements (e.g., DEXA), humeral head diameter and volume, and the canal-to-calcar (CC) ratio (extrapolated from its use in the proximal femoral shaft where a larger value indicates weaker/poor quality bone). We are unaware of prior studies that analyzed the relative strengths of correlations of these radiographic and densitometric data in terms of humerus fracture load using a biomechanical model simulating a ground-level fall. In this perspective we also sought to determine if the 4mm threshold is valid for determining if open reduction and internal fixation should be used instead of hemi-endoprosthetic replacement for osteoporotic proximal humerus fractures [3,5]. This is important because this cutoff was based on DEXA data and not on fracture tests [5].

Methods: 34 fresh-frozen cadaveric humeri (mean 59 yrs; range 39-78; 18 F, 16 M) were used. 24 bones were from a prior study that tested simulated rotator cuff repairs at a low load rate where suture rupture was the primary failure mode. An additional 10 bones were added. Data from the two groups were combined when it was demonstrated that there were no significant differences between them in terms of ultimate fracture load (UFL) or energy absorbed to fracture. Anterior-posterior (A-P) radiographs were taken of each bone in neutral rotation next to an aluminum (Al) step wedge (one mm/step; 2-12 mm of Al). mmAl was determined in four 1.0x1.0 cm regions of interest (ROIs) from the digitized radiographs (Fig.). Cortical thickness, linear and areal C.I., and diameter measurements (including the humeral head) were made from the radiographs. Thicknesses of the medial and lateral cortices were measured in the diaphysis, including the surgical neck (D1), and at three locations at these distances below D1: two cm (D2), five cm (D3), and seven cm (D4) (Fig. 1). The C-C ratio was measured with respect to D2 and D4 [5]. Bone mineral density (BMD) was determined for each proximal humerus using DEXA scans [6]. Each humerus was loaded in a manner that simulated a backwards fall (2mm/sec, 30 degrees off axis). Test data, recorded on load-deformation curves, included: (1) UFL (N), and (2) area under the load-deformation curve (i.e., energy absorbed; N-m).

Results: Results summarized in the table show that areal C.I. does not correlate more strongly with UFL or energy absorption than does linear C.I. However, C.I. is a weaker correlate (r values typically <0.6) of UFL when compared to mineral density in the central humeral head (H2 mmAl) and mean-combined cortical thickness averaged at D3-D4 (r values ~0.7). Notably, age, DEXA and C-C ratio values were even weaker correlates of UFL than were the areal or linear C.I. values. An additional analysis of mean combined (medial + lateral) cortical thickness thresholds with respect to UFL was also conducted. In contrast to [6] where a 4mm threshold showed a significant difference in proximal humerus BMD (they did not determine UFL), we found no statistically significant difference in UFL and energy absorption using the 4mm cutoff. By contrast, significant differences were found using a 6mm cutoff.

Discussion: Although our results show that linearly measured C.I. is a stronger correlate with UFL, it is still rather weak when compared to mean combined cortical thickness or central humeral-head density. It is suggested that these rather simple measurements be used in experimental and clinical studies where C.I. may have previously been the top choice. Our data also show that morphological and densitometric characteristics made using A-P radiographs of cadaveric humeri are stronger predictors of UFL and energy absorbed to fracture when compared to chronological age, C.I., and DEXA-derived density values. These findings are consistent with studies showing that DEXA scans do not correlate strongly with fracture risk in a substantial percentage of patients [7,8]. Consequently, the use of DEXA scans to estimate proximal humerus quality/strength must be questioned, especially in view of the fact that DEXA measurements are becoming more common in biomechanical studies using proximal humeri. The strongest correlates that were found in this study should help in identifying poorer quality bones for fracture studies. Similar methods for segregating bones into 'quality categories', though not based on fracture data, have been described for the humerus [6] and proximal femur [9]. Finally, the 4mm cutoff used in the fracture-treatment algorithm described by [3] may need to be revised to 6mm.

Significance: Relative differences in the strength/quality of cadaveric humeri are less reliably predicted by DEXA BMD, and linear and areal C.I when compared to mean combined cortical thickness of the proximal shaft and mineral content of the central humeral head. Consequently, these less conventional measurements should be used in clinical and biomechanical studies of proximal humerus aging and fracture fixation.

References: [1] Giannotti et al. 2012 Clin Cases Miner Bone Metab 9:37-; [2] Hepp et al. 2009 Arch Orthop Trauma Surg 129:1251-; [3] Nho et al. 2007 J Bone Joint Surg 89:44-; [4] Osterhoff et al. 2012 Arch Orthop Trauma Surg 132:509-; [5] Dorr et al. 1993 Bone 14:231-; [6] Tingart et al. 2003 J Bone Joint Surg Br 85:611-; [7] McCreadie and Goldstein 2000 J Bone Miner Res 15:2305-; [8] Dawson-Hughes et al. 2008 Osteoporos Int 19:449-; [9] Bloebaum et al. 1993 J Arthroplasty 8:347-.

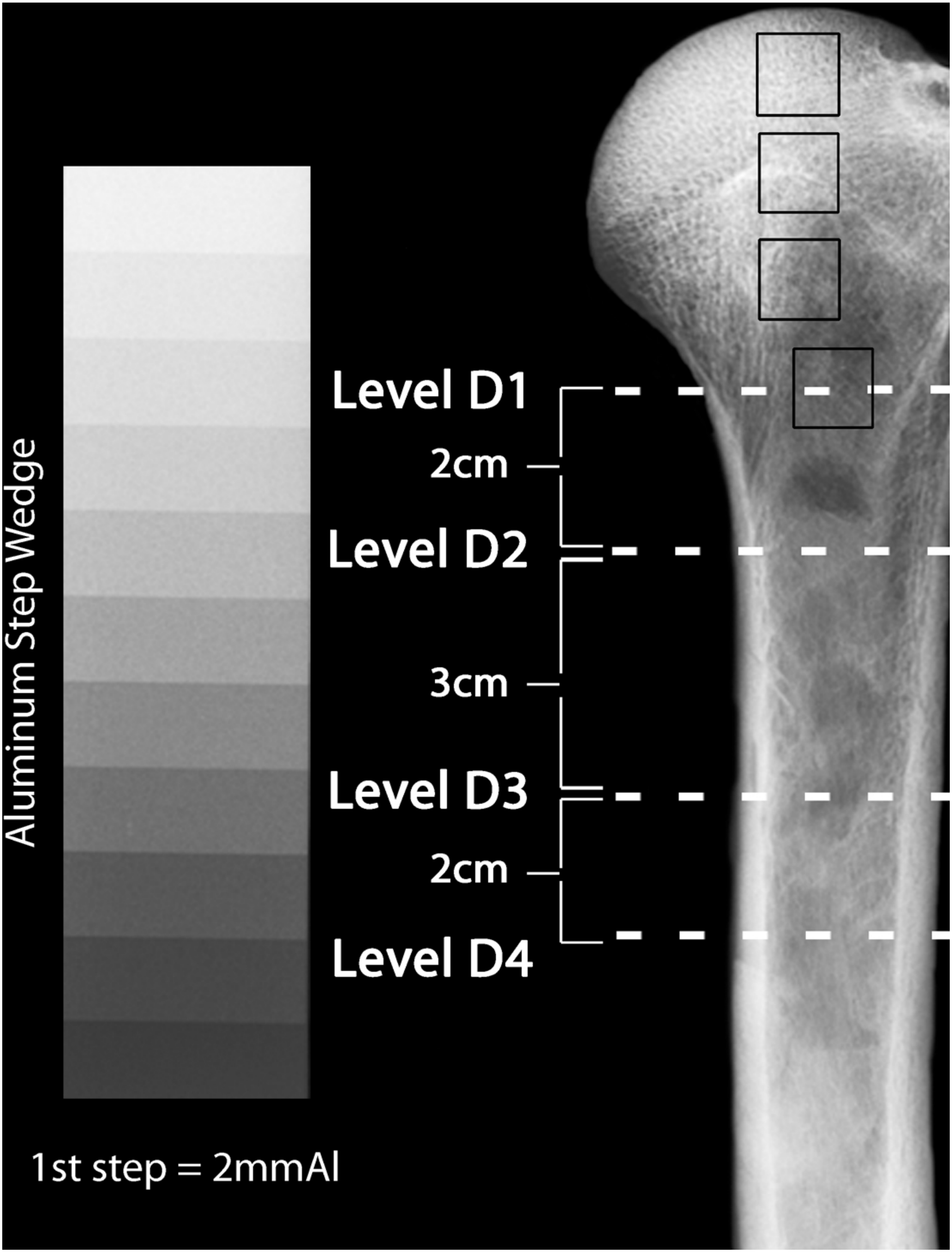
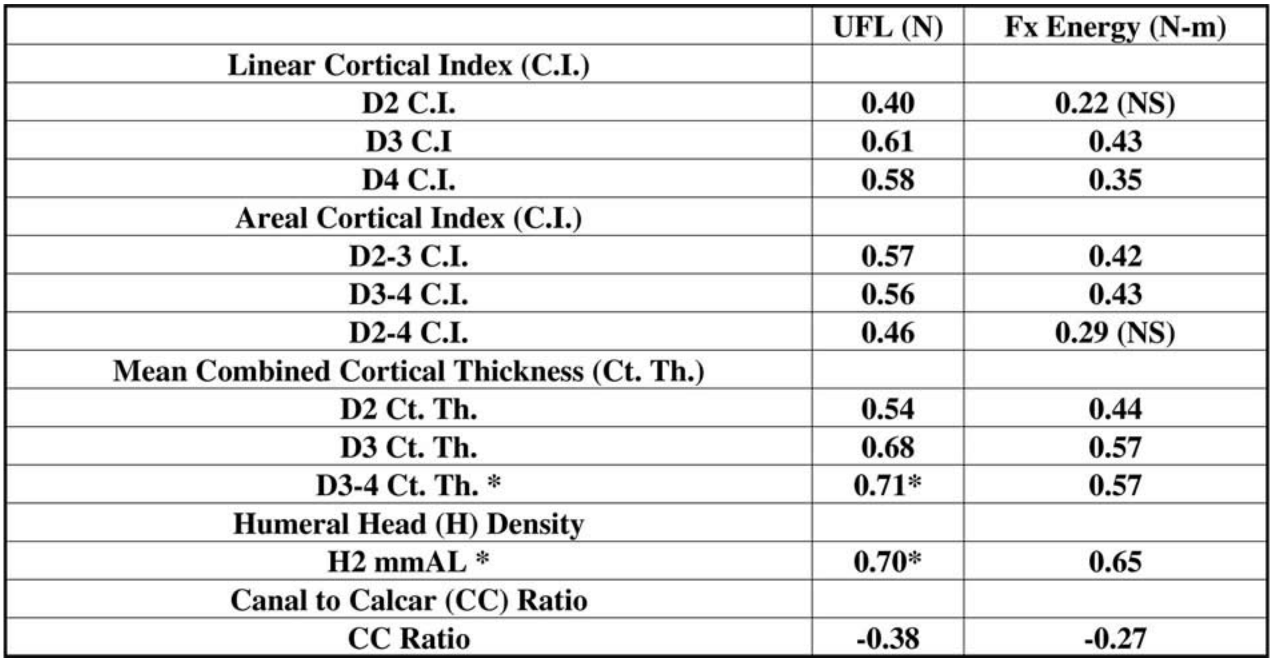


Table of Most Important Correlation Results (r values)



	UFL (N)	Fx Energy (N-m)
Linear Cortical Index (C.I.)		
D2 C.I.	**0.40**	**0.22 (NS)**
D3 C.I	**0.61**	**0.43**
D4 C.I.	**0.58**	**0.35**
Areal Cortical Index (C.I.)		
D2-3 C.I.	**0.57**	**0.42**
D3-4 C.I.	**0.56**	**0.43**
D2-4 C.I.	**0.46**	**0.29 (NS)**
Mean Combined Cortical Thickness (Ct. Th.)		
D2 Ct. Th.	**0.54**	**0.44**
D3 Ct. Th.	**0.68**	**0.57**
D3-4 Ct. Th. *	**0.71***	**0.57**
Humeral Head (H) Density		
H2 mmAL *	**0.70***	**0.65**
Canal to Calcar (CC) Ratio		
CC Ratio	**-0.38**	**-0.27**

* = THE STRONGEST OF ALL CORRELATES;
UFL= ultimate fracture load, Fx= fracture, N= Newtons, C.I.= cortical index, Ct. Th.= mean combined cortical thickness, D= diaphysis, NS= not significant