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Mechanical Testing Data Favor Modification of Humerus Fracture Treatment Algorithms

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Introduction: Algorithms have been devised that facilitate decision making for the operative and non-operative treatment of proximal humerus fractures. These algorithms are useful for making specific decisions with regards to techniques and operative hardware used in fracture reconstruction. This reflects the fact that 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. A popular and very useful treatment algorithm is that of Nho and co-workers [1] (Fig. 1). The aspects of their algorithm that are the focus of this investigation are the branch points where cortical thickness measurements are made using an anterior-posterior (AP) radiograph. These branch points are based on the combined cortical thickness measured at the medial and lateral cortices of the proximal metaphysis/diaphysis. If this measurement is <4mm then the recommendation is typically that the surgeon should avoid open reduction and internal fixation (ORIF); for example, hemi-endoprosthetic replacement is the recommendation for these fracture types: AO/ASIF B (Bifocal) and AO/ASIF C (Anatomic Neck). A problem with the 4mm cutoff is that it is not based on data derived from mechanical testing. In fact, the 4mm cutoff is based only on DEXA measurements from a sample of cadaveric proximal humeri [2]. In our recent prior study we had preliminary data suggesting that the 4mm cutoff was not a mechanically distinct threshold for distinguishing the ultimate fracture load of cadaveric humeri [3]. In the present investigation we sought to determine if the 4mm threshold should be modified as the definition of the branch points in the fracture treatment algorithm of Nho et al. (2007). In general, we not aware of prior studies that analyzed the relative strengths of correlations of this simple radiographic morphometric measurement 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 threshold when defined as a value greater than 4mm is better than the "cortical index" (defined below) for determining if ORIF should be used instead of hemi-endoprosthetic replacement for osteoporotic proximal humerus fractures.
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 (AP) radiographs were taken of each bone in neutral rotation next to an aluminum (Al) step wedge (one mm/step; 2-12 mm of Al) (Fig. 2). Cortical thickness measurements were made from the radiographs. Thicknesses of the medial and lateral cortices were measured in proximal locations of each bone, 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. 2). Cortical index (C.I.) was also measured at specific locations of the bone shaft in AP 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). Bone mineral density (BMD) was determined for each proximal humerus using DEXA scans [2]. Each humerus was loaded in a manner that simulated a backwards fall (2mm/sec, 30 degrees off axis) (Fig. 3). Test data, recorded on load-deformation curves, included: (1) UFL (N), and (2) area under the load-deformation curve (i.e., energy absorbed to fracture; N-m). A power analysis performed prior to this study indicated that twenty specimens provided 90% power ($\beta = 0.1$) to detect a significant difference ($\alpha \leq 0.05$) in the BMD between the proximal metaphyseal locations and a 40 N reduction in UFL. Differences between fracture loads and among the other parameters were evaluated using Fisher's PLSD test (ANOVA).
Results: Results are summarized in the table. These results show that the 6mm combined (medial + lateral) cortical thickness cutoff consistently distinguished the data from the 34 tested bones in terms of donor age, BMD (derived from DEXA scans), UFL (N), and energy absorbed to fracture. The clear distinction between the 6mm cutoff and the other two cutoffs (4mm and 5mm) is shown by the fact that all cells in the 6mm p-value matrix at the right in the table are statistically significant (all cells are grayed for the 6mm value). It is important to also emphasize that in contrast to [2] where a 4mm threshold showed a significant difference in proximal humerus BMD (they did not determine UFL), we found no statistically significant difference in the sample of tested bones in terms or UFL and energy absorption when using the 4mm cutoff. The data also showed that the 6mm combined cortical thickness cutoff is also more consistent in distinguishing age and energy absorption data than C.I. measurements that were taken at the same locations (Part B of the Table).
Discussion: Results of this study support modifying the main branch points in the algorithm of Nho et al (2007) [1] (Fig. 1). Consideration should be given for changing the 4mm cutoff that defines the main branch points to 6mm. Data from the present study and our prior study [3] also show that morphological characteristics made using AP 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 [4,5]. Consequently, we maintain opinion stated in our prior study that 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.

Significance: A recent algorithm for treating proximal humerus fractures is based on DEXA-derived data to define its major branch points. Results of the present study use data from mechanical tests that suggest that the definitions of these branch points need modification.

Acknowledgments:

References: [1] Nho et al. 2007 J Bone Joint Surg 89:44-; [2] Tingart et al. 2003 J Bone Joint Surg Br 85:611-; [3] Skedros et al. 2013 Trans Ann ORS 59, abstract 376; [4] McCreadie and Goldstein 2000 J Bone Miner Res 15:2305-; [5] Dawson-Hughes et al. 2008 Osteoporos Int 19:449-.

Figure 1

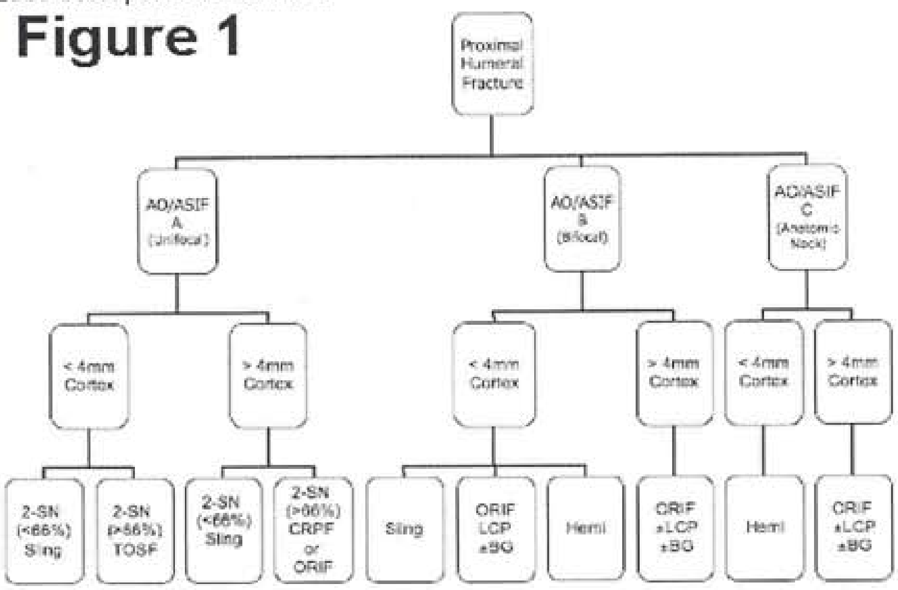
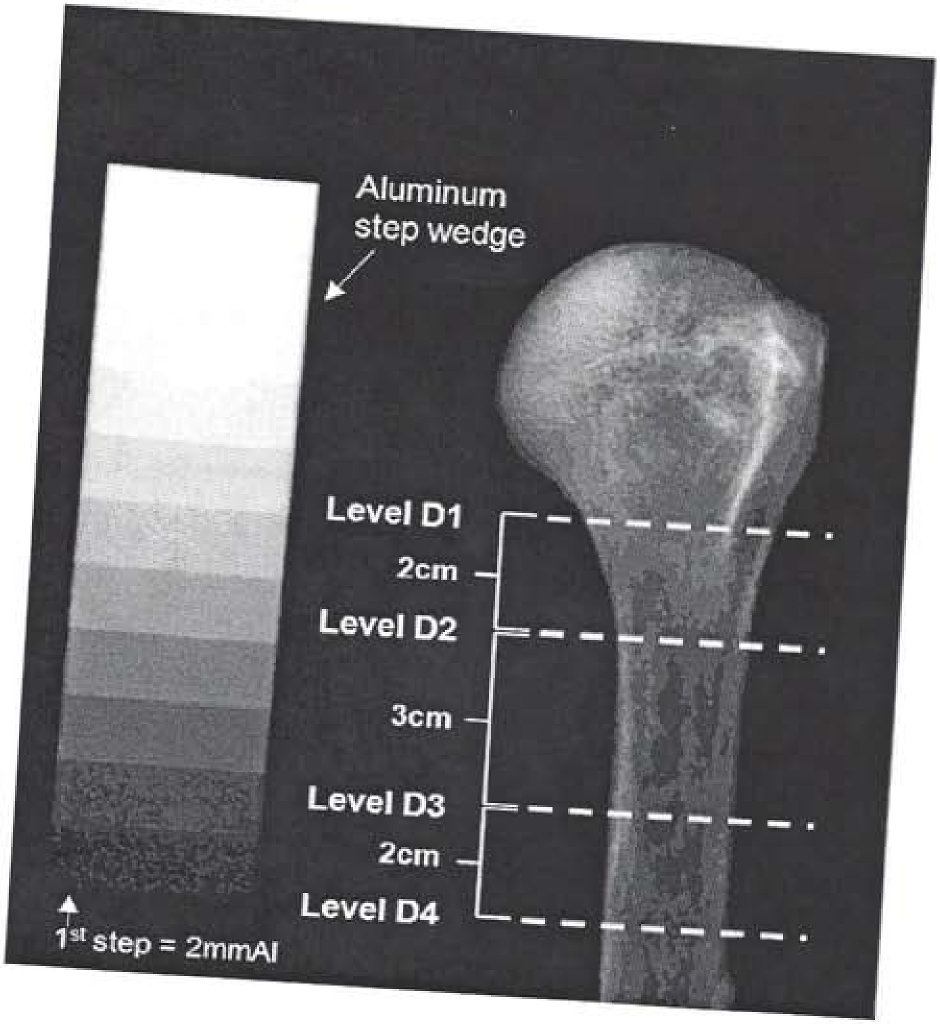


Figure 2



Aluminum step wedge
Level D1
2cm
Level D2
3cm
Level D3
2cm
Level D4
1st step = 2mmAl

Figure 3

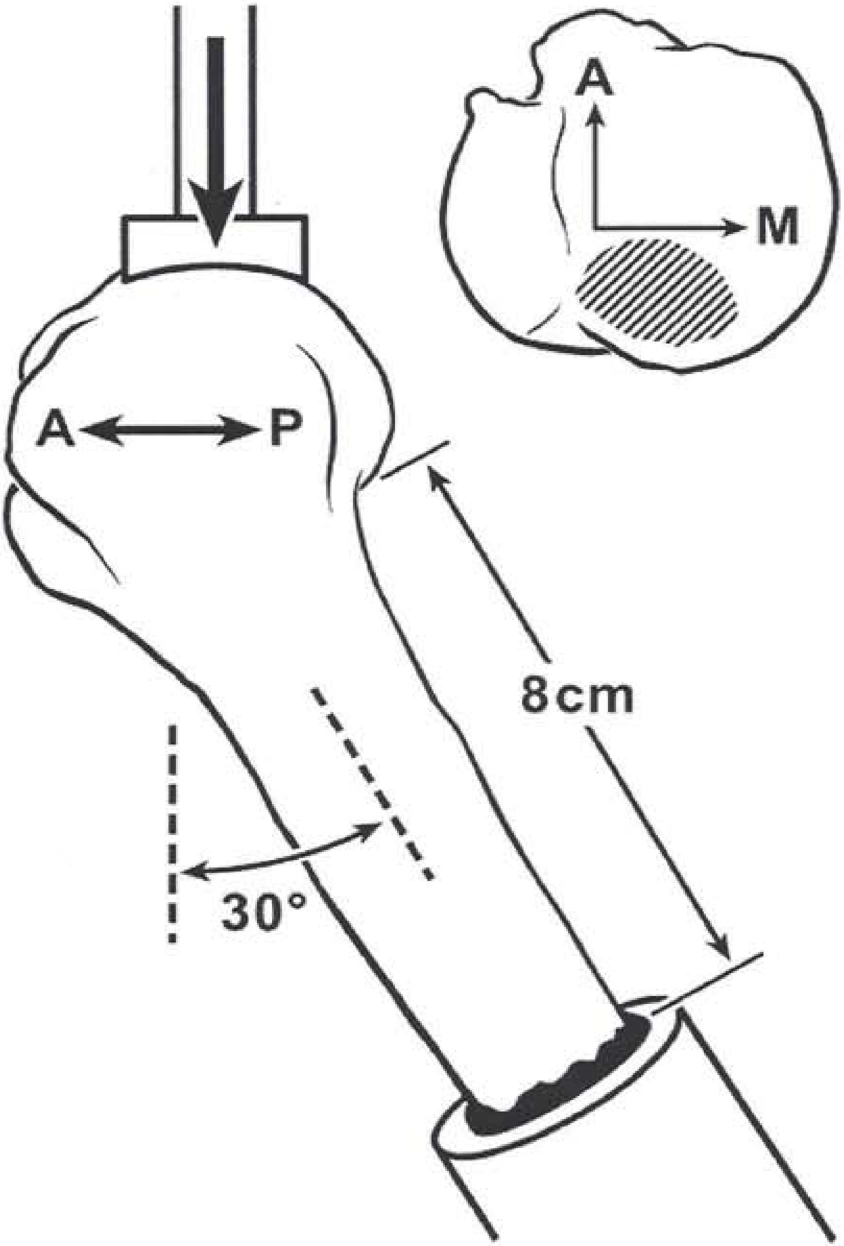


TABLE. COMPARISONS OF AGE, BMD, UFL (N), AND ENERGY ABSORPTION (N-m) FOR MEAN CORTICAL THICKNESS (A) AND CORTICAL INDEX (B) CUTOFFS

A. Cortical Thickness

4 mm	Mean Age		n		P values: Age	BMD	N	N-m
	<4mm	>4mm	<4mm	>4mm				
D1	63.1	58.8	12	21	0.1	0.6	0.2	0.9
D2	68.0	56.7	7	26	0.01	0.006	0.04	0.05
D3	68.5	57.8	4	29	0.07	0.008	0.08	0.1
D4	75.0	58.0	2	31	0.03	0.01	0.1	0.3
D1-3	73.4	56.5	5	28	<0.001	<0.001	0.01	0.04
D3-4	75.0	58.0	2	31	0.03	0.01	0.1	0.3
D1-4	73.0	57.7	3	30	0.02	0.001	0.04	0.2

5 mm	Mean Age		n		Age	BMD	N	N-m
	<5mm	>5mm	<5mm	>5mm				
D1	59.9	46.5	31	2	0.1	0.4	0.5	0.4
D2	67.5	54.2	12	21	<0.001	0.02	0.1	0.2
D3	66.4	56.7	8	25	0.03	0.002	0.01	0.06
D4	72.0	57.3	4	29	0.01	<0.001	0.01	0.07
D1-3	66.5	55.4	11	22	0.005	0.004	<0.001	0.005
D3-4	70.2	56.6	6	27	0.005	<0.001	0.007	0.03
D1-4	71.0	55.8	7	26	<0.001	<0.001	0.002	0.009

6 mm	Mean Age		n		Age	BMD	N	N-m
	<6mm	>6mm	<6mm	>6mm				
D1	All D1 data <6mm				All D1 data <6mm			
D2	65.4	49.4	20	13	<0.001	0.006	<0.001	0.006
D3	67.3	54.3	12	21	<0.001	0.004	0.001	0.009
D4	71.0	55.8	7	26	<0.001	<0.001	0.002	0.009
D1-3	64.9	48.9	21	12	<0.001	0.006	<0.001	0.003
D3-4	69.0	55.8	8	25	0.002	<0.001	0.003	0.008
D1-4	65.1	53.4	16	17	0.001	0.003	<0.001	0.005

B. Cortical Index (CI)

0.4 CI	Mean Age		n		Age	BMD	N	N-m
	<0.4 CI	>0.4 CI	<0.4 CI	>0.4 CI				
D1	All D1 data <0.4 CI				All D1 data <0.4 CI			
D2	All D2 data <0.4 CI				All D2 data <0.4 CI			
D3	60.0	50.0	30	3	0.1	0.008	0.04	0.07
D4	62.4	54.0	20	13	0.03	0.003	0.05	0.6

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