The Deltoid Tuberosity Index is an Unreliable Measure of Local Bone Quality in the Proximal Humerus

Brody W. King, B.S.[1,2], Nathan W. Camp, B.S.[2,3], Casey J. Kiser, M.D.[2], James H. Marshall[4], Kent N. Bachus, Ph.D.[5,6], John G. Skedros, M.D.[2,5]
[1]University of Utah School of Medicine, Salt Lake City, UT, USA, [2]Utah Orthopaedic Specialists, Salt Lake City, UT, USA , [3]University of Nevada, Reno School of Medicine, Reno, NV, USA, [4]Brigham Young University, Provo, UT, USA, [5]University of Utah Dept. of Orthopaedic Surgery, Salt Lake City, UT, USA, [6]Dept. of Veterans Affairs Medical Center, Salt Lake City, UT, USA
Email of Presenting Author: jskedrosmd@uosmd.com

DISCLOSURE: The authors have nothing to disclose.

INTRODUCTION: Anterior-posterior (AP) radiographs of the proximal humerus can be used to assess local bone quality and mass [1-4], and simple radiographic measures can be used to estimate the load-carrying capacity of this region and help determine the most optimal method of fracture fixation [3,5]. Spross et al. (2015) [4] introduced the "deltoid tuberosity index" (DTI), which is a ratio between the outer diameter (OD) and inner diameter (ID) measured at "the proximal aspect of the deltoid tuberosity where the outer cortical borders become parallel" (DTI = OD/ID). They found that the DTI was superior when compared to the Tingart method [1] in terms of correlating with BMD of the proximal humerus measured using pQCT. They also concluded that the DTI is an accurate and efficient method when evaluating clinical AP radiographs of patients with fractured proximal humeri (i.e., internally rotated because of the use of a sling). However, in our studies of morphological measurements made from standard AP radiographs of cadaveric humeri [3], we observed that the deltoid tuberosity is an unreliable landmark due to its variable presence and/or prominence in both gross specimens and radiographs. If our observations are correct, then use of this landmark is inappropriate. The "circle fit method" (CFM) is an alternative method that uses diaphyseal "D" levels based on 10 mm increments from the bottom of the transverse tangent line of a circle that is fit to the outer margin of the humeral head. Radiographic measurements using the CFM correlate strongly with ultimate fracture load, and the CFM is more reliable than other methods for measuring clinically relevant indices [3,6]. However, these prior studies have only examined AP views. We sought to answer: (1) Is the deltoid tuberosity a reliable landmark in one or more radiographic views spanning from 90° internal rotation to 90° external rotation? (2) How is visualization of the deltoid tuberosity affected by radiographic projections across the 180° range? (3) Does the CFM assess bone quality measurements more reliably across the 180° range?

METHODS: Thirty fresh-frozen humeri (age range 14-65 yrs, 7 female, 23 male) were grossly examined and given a deltoid tuberosity score (DTS) from 0-3 (0 = flat/smooth, 3 = most prominent). The proximal-most aspect of the deltoid tuberosities (PDT) were grossly identified and a mark was made where the PDT merged into the cortex. The humeri were then digitally radiographed in 15 projections spanning from 90° internal rotation to 90° external rotation: (1) epicondyles in the coronal plane, (2-7) internally rotated 15° to 90° (negative signs in tables) in 15° increments from the orientation of #1, (8-13) externally rotated 15° to 90° (positive signs) in 15° increments from the orientation of #1, (14) true AP view (label N in tables), and (15) rotated such that the deltoid tuberosity was the most obvious along the edge of the humeri (label O in tables). Angles at which projections 14 and 15 were taken with respect to #1 were recorded. Using independent sets of randomized unlabeled radiographs, three observers digitally marked the PDT and also digitally fit a circle to the humeral head margin. Inter- (shown below) and intra-observer variations in the location of the PDT were measured in terms of millimeters from this landmark to the upper edge of the circle [6], and the OD/ID measurements were made at PDT locations (DTI method) (see Fig. below) or D4, which is 60 mm below the circle (CFM). Inter-rater reliability was measured with the intraclass correlation coefficient (ICC), based on a two-way random-effects model, with both bone specimen and rater as random effects (random sample of bones, random sample of raters), using absolute agreement (raters attempting to achieve exact same values) and individual measure (intended use is a single reading for clinical practice, rather than the mean of the three raters which might be used in research study). Accuracy was estimated using measurements made directly on the bones from the top of the humeral head to the marked PDT.

RESULTS: As shown in the two tables below, the DTI is a highly unreliable method. Our results clearly show that regardless of the radiographic view the deltoid tuberosity was unclear and not easily visualized in many cases. This was especially true in the internal rotation view that would most likely mirror that of a typically sized patient in a sling (i.e., 60° internal rotation) because of a proximal humerus fracture. The ICCs show the superiority of the CFM.

DISCUSSION: Mack et al. (1989) [7] reported similar results of the variable presence of the deltoid tuberosity by also showing that only 29-46% of patients showed any radiographic evidence of this landmark, which also varied with age. Observer bias may have also been involved in the Spross et al. study, as the radiographs of the non-fracture group were evaluated only by the principal investigator/first author (Spross) and the radiographs of the fractured humerus were evaluated by Spross and co-author EB, and the principal investigator/lead author was likely not blinded to the hypothesis of the study.

SIGNIFICANCE/CLINICAL RELEVANCE: Use of the deltoid tuberosity index (DTI) is problematic for basic and applied applications because it is based on an unreliable landmark for its measurement. Other methods should be used that are more reliable and accurate, including the CFM.

REFERENCES: [1] Tingart et al. 2003 JBJS 85:611-; [2] Mather et al. 2013 JSES 22:732-; [3] Skedros et al. 2016 J Orthop Res 34:331-; [4] Spross et al. 2015 Clin Orthop Rel Res 473:3038-; [5] Nho et al. 2007 JBJS 89:44; [6] Mears et al. 2017 J Orthop Res 35:2313- ;[7] Mack et al. (1989) Nucl. Med. Biol. 16: 469-.

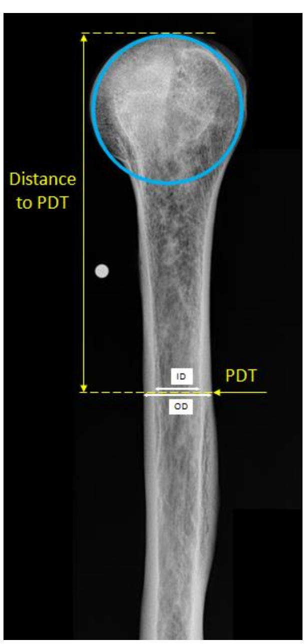

Table 1: Inter-rater reliability (ICC) for PDT DTI among orthopaedic radiographic readers

Label	Radiographic Projection (View)	3 raters ICC* (95% CI**) n***	2 raters omit King ICC (95% CI)	2 raters omit Kiser ICC (95% CI)	2 raters omit Skedros ICC (95% CI)
A	0°	.30 (.01 - .62) n = 17	.45 (.01 - .76) n = 17	.11 (0 - .52) n = 20	.14 (0 - .54) n = 18
B	-15°	.28 (0 - .61) n = 16	.37 (0 - .73) n = 16	.22 (0 - .59) n = 19	.20 (0 - .61) n = 18
C	-30°	0 (0 - .38) n = 10	0 (0 - .30) n = 10	.19 (0 - .66) n = 13	.10 (0 - .65) n = 11
D	-45°	.67 (.22 - .92) n = 7	.99 (.89 - 1) n = 7	0 (0 - .67) n = 8	.55 (0 - .88) n = 9
E	-60°	.44 (0 - .95) n = 4	.88 (.11 – .99) n = 4	.74 (0 - .97) n = 5	.06 (0 - .91) n = 4
F	-75°	0 (0 - .82) n = 3	0 (0 – 1) n = 3	.66 (0 – .93) n = 7	0 (0 – .59) n = 4
G	-90°	.80 (.08 – 1) n = 2	.69 (0 – 1) n = 2	.63 (0 – .95) n = 5	.86 (0 - 1) n = 2
H	15°	.75 (.52 - .90) n = 14	.85 (.61 - .95) n = 14	.70 (.33 - .89) n = 15	.66 (.23 - .87) n = 15
I	30°	.66 (.40 - .86) n = 15	.64 (.23 - .86) n = 15	.80 (.52 - .93) n = 16	0 (0 - .37) n = 20
J	45°	.10 (0 - .57) n = 10	0 (0 - .52) n = 10	.36 (0 - .74) n = 14	.21 (0 - .69) n = 12
K	60°	0 (0 - .73) n = 5	0 (0 – .77) n = 5	0 (0 - .72) n = 6	.74 (.14 - .95) n = 7
L	75°	.30 (0 – 1) n = 2	.22 (0 – 1) n = 2	.55 (0 – .94) n = 5	.21 (0 – .97) n = 3
M	90°	-- n = 1	-- n = 1	.04 (0 - .85) n = 5	0 (0 - 1) n = 2
N	mean±SD: 34.5±7.2 min , max: 20, 47	.26 (0 - .65) n = 12	.14 (0 - .66) n = 12	.21 (0 - .63) n = 16	.45 (0 - .78) n = 14
O	mean±SD: -17.6±11.3 min , max:-38, 20	.46 (.17 - .74) n = 16	.69 (.33 - .88) n = 16	.44 (.02 - .74) n =19	.31 (0 - .66) n =19

*ICC = intraclass correlation coefficient (inter-rater reliability)
**CI = confidence interval
*** n = number of images that all raters provides values for

Table 2. Inter-rater reliability (ICC) for D4 DTI among orthopaedic radiographic readers

Label	Radiographic Projection (View)	3 raters ICC* (95% CI**) n***	2 raters omit King ICC (95% CI)	2 raters omit Kiser ICC (95% CI)	2 raters omit Skedros ICC (95% CI)
A	0°	.87 (.78 - .93) n = 29	.84 (.70 - .93) n = 29	.96 (.91 - .98) n = 29	.82 (.65 - .91) n = 29
B	-15°	.89 (.82 - .95) n = 29	.88 (.77 - .94) n = 29	.89 (.79 - .95) n = 29	.91 (.82 - .96) n = 29
C	-30°	.86 (.76 - .92) n = 29	.82 (.65 - .91) n = 29	.86 (.72 - .93) n = 29	.92 (.82 - .96) n = 29
D	-45°	.94 (.88 - .97) n = 29	.92 (.84 - .96) n = 29	.92 (.82 - .96) n = 29	.96 (.92 - .98) n = 29
E	-60°	.91 (.85 - .95) n = 29	.94 (.87 – .97) n = 29	.92 (.83 - .96) n = 29	.88 (.77 - .94) n = 29
F	-75°	.92 (.86 - .96) n = 30	.92 (.85 – .96) n = 30	.94 (.89 – .97) n = 30	.88 (.77 –.94) n = 30
G	-90°	.92 (.86 –.96) n = 30	.92 (.83 – .96) n = 30	.95 (.89 – .98) n = 30	.90 (.78 - .95) n = 30
H	15°	.92 (.86 - .96) n = 29	.88 (.76 - .94) n = 29	.96 (.92 - .98) n = 29	.92 (.84 - .96) n = 29
I	30°	.84 (.72 - .91) n = 28	.79 (.60 - .90) n = 28	.94 (.88 - .97) n = 28	.77 (.57 - .89) n = 28
J	45°	.96 (.92 - .98) n = 28	.96 (.91 - .98) n = 29	.97 (.93 - .98) n = 28	.95 (.90 - .98) n = 28
K	60°	.96 (.92 - .98) n = 28	.95 (.85 – .98) n = 29	.95 (.90 - .98) n = 28	.98 (.95 - .99) n = 28
L	75°	.91 (.85 –.96) n = 28	.87 (.74 – .94) n = 29	.93 (.86 – .97) n = 28	.91 (.81 –.96) n = 28
M	90°	.86 (.75 - .92) n = 29	.85 (.71 - .93) n = 29	.93 (.86 - .97) n = 29	.81 (.62 - .90) n = 29
N	mean±SD: 34.5±7.2 min , max: 20 , 47	.87 (.77 - .93) n = 29	.87 (.75 - .94) n = 29	.90 (.79 - .95) n = 29	.84 (.68 - .92) n = 29
O	mean±SD: -17.6±11.3 min , max: -38 , 20	.93 (.87 - .96) n = 30	.91 (.82 - .95) n = 30	.97 (.94 - .99) n =30	.90 (.79 - .94) n =30

*ICC = intraclass correlation coefficient (inter-rater reliability)
**CI = confidence interval
*** n = number of images that all raters provides values for