The Circle Fit Method is More Reliable for Assessing Bone Quality in the Proximal Humerus than Tingart and Mather Methods: An Analysis in Eight Radiographic Projections

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INTRODUCTION: Proximal humerus fractures are very common among the elderly population and are associated with lower bone mineral density in conditions such as osteoporosis [1,2]. Radiographic measurements are gaining popularity in estimating local bone quality of the proximal humerus, and these include ratios that express the percentage of cortical bone across the transverse breath of the bone (e.g., cortex indices and measures of combined cortical thickness) [3]. These types of simple measurements can be used in helping make decisions for fracture reconstruction and risk stratification for fragility fractures. Simple measurements made on radiographs are popular because of their convenience in both clinical and research settings, especially because they are relatively easy to make and do not require advanced imaging such as CT or MR imaging [4]. Current methods used to make these radiographic measurements, however, can be unreliable and, therefore, their use in clinical or research settings has been questioned [5]. The aim of our study is to introduce and validate the Circle Fit Method (CFM) as a simple, easy method to assess the quality of bone in proximal humerus fractures and show its reliability over several clinically important radiographic views. We compare the inter- and intra-observer reliability of measurements made using the radiograph measurement methods of Tingart [6] and Mather [7] with the CFM [5] (see Fig. 1). We sought to answer these questions using our large sample of radiographic images of human humeri: (1) Is the CFM more reliable than other methods in various rotational views? (2) Which view maximizes reliability for each method? Namely, should other methods be favored over CFM for a particular radiographic view?

METHODS: Thirty fresh-frozen humeri (age range 14-65 yrs, 7 female, 23 male) were digitally radiographed in eight projections spanning from 90° internal rotation (negative values in the table) to 90° external rotation (positive values in the table), and included: (1) epicondyles in the coronal plane, (2-4) internally rotated 30° to 90° in 30° increments from the orientation of #1, (5-7) externally rotated 30° to 90° in 30° increments from the orientation of #1, and (8) true anterior-posterior (AP) view. Using independent sets of randomized unlabeled radiographs, three observers fit a circle to the outer margin of the articular surface of the humeral head and marked the locations of the Tingart Level 1 and Mather Level 1. Inter- and intra-observer variations in the location of each of these levels were measured in terms of millimeters from these landmarks to the upper edge of the humeral head. A semi-automated algorithm was then used to measure distances between these various marked landmarks and the top of the humeral head, as well as mean combined cortical thickness (MCCT) at these two levels (see Figs. 1 and 2).

RESULTS: The results of three representative observers are shown in the table below, which compares three methods for determining bone quality on radiograph (Table 1). 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). Reliability is a measure of agreement.

DISCUSSION: Our results summarized in the Table show that the CFM is more reliable in a majority of the radiographic views. Of the eight radiographic views, the CFM has a higher intraclass correlation (ICC) in five of those projections, and when the ICC was equal to the Tingart level (at 30º and True AP) its confidence interval was higher than that of Tingart in those two projections. In regards to which view was the most reliable for the CFM, several angles (0 º, -60º, -90º, 30º, 90º, and True AP) were above the threshold for excellent intraclass correlation (> 0.90) and that the highest value was found in the radiographic projection of -90º (i.e., fully internally rotated) with an ICC value of .97 [8]. These differences between the CFM vs. the Tingart and Mather methods can be explained by the increased reliability of the CFM. The CFM uses the humeral head as a landmark to establish the distal levels for making the measurements while the Tingart and Mather method use the parallelism in the endosteum (Tingart) and periosteum (Mather) in order establish Tingart and Mather levels respectively [5,6,7]. Determining parallelism incurs greater variation than the CFM and hence the parallelism-based methods introduce more variation in parameters such as MCCT and cortical index that are used to estimate bone quality and strength. Nevertheless, the Tingart method performed well at 30º, 90º, and True AP angles, achieving excellent correlations. In contrast, the Mather method did not have excellent reliability in any angle but had good reliability (ICC values 0.75-0.90) in two projections (0º and 30º). A situation where CFM could not be used is when a proximal humerus fracture, especially when the humeral head is involved. In this situation, another method such as the Tingart method should be used as a substitute.

SIGNIFICANCE/ CLINICAL RELEVANCE: Current methods such as Tingart and Mather are unreliable in determining bone quality in proximal humerus fractures in many cases. Other methods such as Circle Fit Method should be used that are more reliable.

REFERENCES: [1] Jo and Gardner. 2012 Curr Rev Musculoskelet Med. 5(3):192- ; [2] Launonene et al. 2015 Arch Osteoporos. 10:209- ; [3] Skedros et al. 2017 Bone Joint Res. 6:1-; [4] Nho et al. 2007 JBJS 89:44- ; [5] Mears et al. 2017 J Orthop Res. 35:2313- ; [6] Tingart et al. 2003 JBJS 85:611- ; [7] Mather et al. 2013 JSES 22:732- ; [8] Koo and Li. 2016. J. Chiropractic Med,15:155-.

Figure 1: A) Tingart method, B) Mather method, and C) CFM

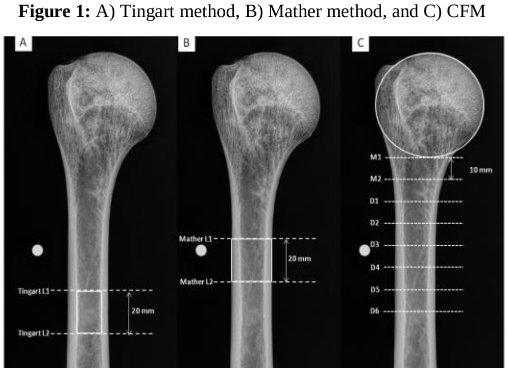

Figure 2: Mean Combined Cortical Thickness (MCCT)

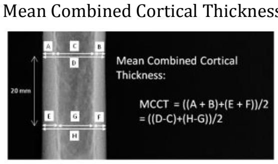

Table 1: Inter-rater reliability (ICC) for MCCT (mean combined cortical thickness) among 3 methods (CFM vs Tingart vs Mather) and among 3 orthopaedic radiographic readers

Radiographic Projection (View)	CFM Levels D4 and D6 ICC* (95% CI**) n***	Tingart Levels 1, 2 ICC* (95% CI**) n***	Mather Levels 1,2 ICC* (95% CI**) n***
0°	.91 (.84 - .95) n = 29	.74 (.58 - .86) n = 29	.88 (.80 - .94) n = 30
-30°	.89 (.81 - .94) n = 29	.54 (.32 - .72) n = 29	.61 (.41 - .77) n = 30
-60°	.96 (.92 - .98) n = 29	.81 (.69 - .90) n = 30	.68 (.50 - .82) n = 30
-90°	.97 (.95 – .98) n = 30	.89 (.81 – .94) n = 30	.74 (.58 – .85) n = 30
30°	.96 (.93 - .98) n = 28	.96 (.92 - .98) n = 29	.89 (.80 - .94) n = 30
60°	.82 (.69 - .90) n = 29	.88 (.78 - .94) n = 29	.43 (.22 - .64) n = 30
90°	.93 (.87 - .96) n = 29	.90 (.83 - .95) n = 29	.70 (.53 - .83) n = 30
True AP#	.95 (.92 - .98) n = 29	.95 (.90 - .97) n = 27	.78 (.64 - .88) n = 30

*ICC = intraclass correlation coefficient (inter-rater reliability); **CI = confidence interval; *** n = number of images that all raters provides values for; # True AP = true AP view, mean±SD: 34.5°±7.2° ; (min , max): (20° , 47°)