Current Methods for Measuring Proximal Humerus Morphology from Clinical Radiographs are Unreliable: Establishing a Reproducible Method for Measuring the Proximal Humerus for Clinical and Biomechanical Studies

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INTRODUCTION: Routine radiographs are being used to predict bone quality of the proximal humerus [1-7]. Cortical index (CI) is the most common measurement and is obtained from anterior-posterior (AP) radiographs. CI is the difference between the outer (OD) and inner diameters (ID) divided by the OD [(OD-ID)/OD] (lower CI values = weaker bone). Mean combined cortical thickness (MCCT = (OD-ID)) also strongly correlates with bone quality [1,2,5,8]. These measurements are clinically relevant: (1) surgeons can evaluate radiographs of the fractured humerus and the non-fractured side, (2) age-related changes in these simple measurements correlate with reduced bone quality and fracture strength [1-2], and (3) age-related changes can result in complications of shoulder arthroplasty and fracture fixation [1]. This study introduces a new anatomical orientation system for evaluating these measurements for cadaveric and clinical studies, which is an advance over other current popular methods because they lack a defined/reproducible proximal reference point/location.

METHODS: Digitized radiographs of 33 proximal humeri from a prior study (mean age: 59.5; 15 males and 18 females) [9] were obtained in neutral rotation (i.e., true AP view) [10]. The bones ranged from robust cortices (i.e., "good quality") to osteoporotic (i.e., "poor quality") as established by radiographic inspection and DXA analysis. The soft tissues had been dissected prior to being radiographed. Five observers analyzed the digitized radiographs and made CI and MCCT measurements in accordance with: (1) methods of Tingart et al. (2003) [2], (2) methods of Tingart as modified by Mather et al. (2013) [8], and (3) our new method. **Tingart method:** "The lateral and medial cortical thickness of the proximal humeral diaphysis was measured at two different levels. Level 1 was the most proximal level of the humeral diaphysis where the endosteal borders of the lateral and medial cortices were parallel to each other. Level 2 was 20 mm distal to level 1." (We only used Level 1.) **Mather method:** "The first level was the most proximal point on the humerus where the outer medial and lateral cortical borders become parallel, as previously described by Tingart et al. (2003) [Note, this is an error; Tingart et al. used the endosteal cortical borders]. A perpendicular line was drawn from the medial outer cortex of the humerus to the lateral outer cortex of the humerus and measured with a digital caliper to provide the thickness of the entire bone (M1) [This is different from the "M1" used in the present abstract]. At the same level, the width of the intramedullary canal was obtained (M2). **Tingart and Mather:** These methods lack a defined/reproducible proximal reference point/location. **New method:** Our new method establishes a reference location for all subsequent measurements. This employs a circle that is best fit to the curvature of the articular surface of the humeral head on AP radiographs (Fig. 1). The circle was placed and all subsequent measurements were made using the ImageJ program. The lower-most edge of the circle was defined as the proximal reference level (or "M1"; M = metaphysis = surgical neck region). Then seven successive "levels" (locations) were defined, and each was below the M1 level, and each were separated by 10 mm. There were two "M" (metaphyseal levels) and six "D" (diaphyseal) levels: M1, M2, D1, D2, D3, D4, D5 and D6. **All methods:** Center points of D1 and D6 were used to define the longitudinal axis for each measurement method. CI and MCCT were measured at each of our D levels and at the L1 levels of Tingart and Mather methods.

RESULTS: There was relatively minimal observer variation (inter and intra) in establishing the surgical neck (M1) location using our method. The magnitude of the errors in the M1 locations was also significantly lower ($p<0.001$) when compared to the Tingart and Mather methods (Fig. 2) to establish their L1 locations. The errors when using the Tingart and Mather methods were not significantly different ($p=0.2$). The CI and MCCT data obtained using our method also showed minimal variation at each of the D levels. There was also substantial variation in which of our D levels were in closest proximity to the Tingart or Mather L1 levels (reflecting the high variations in establishing the L1 locations of these two methods). Finally, the measurements made using our method could be done nearly 50% faster than the Tingart et al. and Mather et al. methods.

DISCUSSION: This study shows poor reliability in using the methods of Tingart et al. and Mather et al. in defining the location for measuring CI or MCCT in the proximal humerus of clinical AP radiographs. The new method described here not only reduces the errors to acceptably low levels, but it is also easy to perform and can be accomplished using in modern digital radiographic programs used in the clinical setting. We are now conducting studies on a much larger sample of bones (teenage to 90s) that will be subsequently correlated with fracture data from the bones obtained in a simulated ground-level fall [11].

SIGNIFICANCE: For making clinically relevant morphological measurements on anterior-posterior radiographs of the proximal humerus, the method described here is more reliable, accurate, and efficient than the popular method of Tingart et al. and the modified method of Mather et al.

REFERENCES: [1] Skedros et al. 2013 ORS Abstract no. 376; [2] Tingart et al. 2003 JBJS 85:611-; [3] Hepp et al. 2009 Arch Orthop Trauma Surg 129:1251-; [4] Osterhoff et al. 2012 Arch Orthop Trauma Surg 132: 509-; [5] Namdari et al. 2012 J Shoulder Elbow Surg 21:1787-; [6] Giannotti et al. 2012 Clin Cases Miner Bone Metab 9:37-; [7] Spross et al. 2015 Clin Ortho Rel Res 473:3038-; [8] Mather et al. 2013 J Shoulder Elbow Surg 22:732-; [9] Skedros et al. 2014 Biores Open Access 3:250-; [10] Tillett et al. 1993 J Shoulder Elbow Surg 2:255-; [11] Skedros et al. 2015 J Orthop Res, in press.

Figure 1

Ti = Tingart; Ma = Mather; L1 = Level 1; M1 = our first metaphyseal level at the lower-most (transversely tangental) edge of the circle.