

Estimation of Radiographic Joint Space of the Trapeziometacarpal Joint with Computed Tomographic Validation

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INTRODUCTION: The trapeziometacarpal (TMC) joint exists at the base of the thumb and is defined by the articulation between the first metacarpal and trapezium. X-ray radiography is commonly used to evaluate the joint with respect to the presence of musculoskeletal disorders [1], such as osteoarthritis, for which the TMC joint is the most commonly affected isolated joint of the hand [2]. Evaluation metrics are primarily qualitative. Quantitative determination of structural features, including joint space, can be challenging due to the visual complexities of the two-dimensional radiographic projection of the joint, which may arise due to the complex curvature of the joint structure [3], rendering the identification of reference features from which to quantify the joint space difficult to determine. The purpose of this study was to formulate a methodology for measuring the radiographic joint space of the TMC joint using computed tomographic (CT) measurement for validation. The hypothesis was that radiographically measured TMC joint space can closely approximate CT-measured TMC joint space for standardized regions of radiographic analysis.

METHODS: Fifteen arm cadaveric specimens (7 female, 8 male) were placed onto a custom fixation device, the forearm secured with restraints, the four fingers secured around a cylinder and the thumb left in a neutral orientation or placed in 45 degrees of extension. A CT scan was taken for each specimen and a simulated radiographic image was generated from the CT data. 3D models of the first metacarpal and trapezium were extracted. The articular surfaces of both bones were manually identified, a fifth order polynomial was fit to each, and the saddle point of the first metacarpal was approximated [4]. A sphere of radius 2 mm was defined centered at the saddle point. The intersection of the sphere with the articular surface defined a boundary, within which the minimum distance to the trapezium articular surface was calculated as the CT-based joint space (Figure 1). The surface of the first metacarpal was projected in 2D (Figure 2a) onto a series of planes and the projection resembling the simulated radiographic projection (Figure 2b) was selected for analysis. The location of the joint space analysis region was standardized based on the arc length of the projected articular surface of the first metacarpal and the radiograph-based joint space was calculated within this standardized region (Figure 2c). A correction factor was defined as the ratio of the CT-based joint space and the radiograph-based joint space for each specimen. Leave-one-out validation was used to correct the radiograph-based joint space of each specimen using the average correction factor and standardized analysis locations for the remaining specimens. A two-tailed t-test was used to compare the differences between the CT-based and corrected radiograph-based joint space ($\alpha = 0.05$).

RESULTS: The radiograph-based TMC joint space was less than the CT-based joint space for all specimens, the female specimens and the male specimens (Figure 3). The radiograph-based method underestimated the joint space by 1.4 mm [95% CI: 0.987-1.858 mm; $p < 0.001$] in comparison to that based on CT from all specimens. The radiograph-based joint space needed to be scaled 1.7 ± 0.4 times for all specimens. The leave-one-out validation procedure increased the magnitude of the radiograph-based joint space. The difference between the CT-based joint space and the corrected radiograph-based joint space for all specimens was -0.1 mm [95% CI: -0.635 – 0.414 mm; $p = 0.669$].

DISCUSSION: The leave-one-out validation procedure performed well. There were no significant differences between the CT-based joint space and the corrected radiograph-based joint space measurements for all specimens, the female specimens or the male specimens. The difference between CT-based and radiograph-based measurements represents the systematic error. After correction, the magnitude of the error was reduced to 0.1 mm. The definition of joint space was uniquely defined in this study and allowed for the identification of a localized region of analysis that could be correspondingly identified between the respective three-dimensional and radiographic visualizations of the TMC joint. Future work will seek to increase the accuracy and utility of the radiographic measurement method through expanded in-vivo measurement and subsequent development for arthritic joint space measurement.

SIGNIFICANCE/CLINICAL RELEVANCE: This study provides a novel methodology for measuring the radiographic joint space of the healthy TMC joint and, with continued development, has potential for application in the advancement of quantitative radiographic study of the TMC joint.

REFERENCES: [1] Zarb et al., Hand Clin, 38, 2022. [2] Wilder et al., Osteoarthritis Cartilage, 14, 2006. [3] Halilaj et al., J Biomech, 47, 2014. [4] Halilaj et al., J Biomech, 46, 2013.

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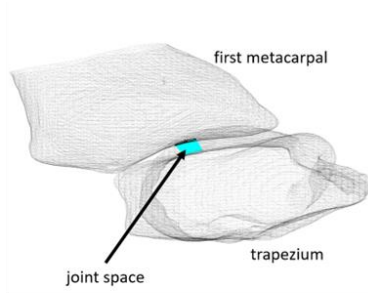


Figure 1: Representative example of CT-based joint space calculation for the TMC joint using the 3D models of the first-metacarpal and trapezium.

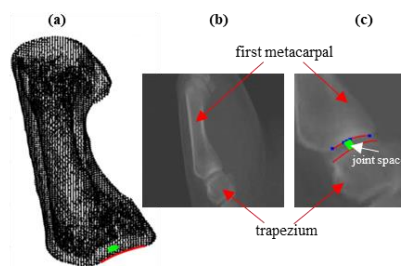


Figure 2: Standardization of joint space analysis region in 2D. (a) Selected projection of first metacarpal for analysis with projected joint space analysis region (green) and articular surface function (red). (b) Enhanced radiographic TMC joint visualization. (c) Radiographic TMC joint space calculation.

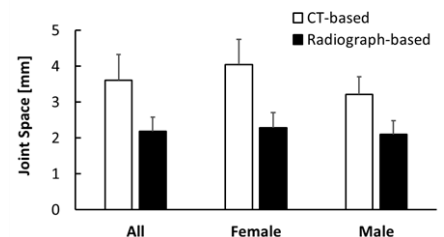


Figure 3: CT-based and radiograph-based TMC joint space results for all specimens, female specimens and male specimens.