

Subchondral Bone Density Distribution and Age-Related Changes in Thumb Carpometacarpal Joint: A Comparative Analysis in Healthy Subjects

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INTRODUCTION:

The subchondral bone mineral density (BMD) distribution reflects the joint surface stress distribution¹. Understanding the normal BMD distribution of the thumb carpometacarpal (CM) joint is useful for predicting joint-loading patterns during functional activities. Furthermore, identifying age-related variations in otherwise normal joints is essential for understanding physiological adaptation and early degenerative processes. This study aimed to characterize the normal subchondral BMD distribution of the CM joint and to evaluate age-related changes.

METHODS:

This study was approved by the Institutional Review Board of The University of Osaka Hospital (Approval no. 14179-4), with informed consent waived due to its retrospective design. Among patients with upper limb disorders who underwent bilateral upper extremity CT scans including the thumb CM joints with a bone mineral calibration phantom, we selected 26 subjects (52 hands) without radiographic signs of thumb CM osteoarthritis. Patients were divided into a younger group (14 subjects, 28 hands; aged ≤ 49 years; 9 males and 5 females) and an older group (12 subjects, 24 hands; aged ≥ 50 years; 6 males and 6 females). In the subchondral regions of the first metacarpal and trapezium bones at the thumb CM joint, points of interest (POIs) were placed in an equally spaced grid²: 18 points on the metacarpal and 21 points on the trapezium (Figure 1). CT values within each POI were converted to volumetric BMD (mg/cm³) using the calibration phantom. For each subject, BMD values were standardized (z-scored) to minimize the influence of osteoporosis, and then averaged across subjects to identify the high-density regions (standardized values ≥ 0 ; $z \geq 0$). Within the high-density regions, we compared the mean standardized BMD between the younger and older groups using the Levene’s test for variance and the Mann–Whitney U test for mean values. A significance level of $p < 0.05$ was applied.

RESULTS SECTION:

The high-density regions were found on the radial and volar-ulnar aspects of the first metacarpal, and on the dorsal aspect of the trapezium (Figure 2). In the high-density regions, the older group showed significantly greater BMD variance in both bones (young vs. old; Metacarpal: 2.07 ± 1.91 vs. 1.47 ± 2.50 , $p = 0.046$; Trapezium: 0.29 ± 0.17 vs. 0.24 ± 0.24 , $p = 0.047$). In contrast, no significant differences were observed in the mean BMD values between the groups (Metacarpal: $p = 0.67$; Trapezium: $p = 0.36$).

DISCUSSION:

The high-density regions on the radial and volar-ulnar metacarpal correspond to the regions that contact the trapezium under peak grasp and pinch loading, likely reflecting physiological loading patterns³. The dorsal trapezium high-density regions correspond to the regions in sustained contact during the natural resting position, suggesting bone remodeling from chronic mechanical stress³. The increased variance in BMD observed in the older group reflects age-related changes in the stress acting on the thumb CM joint. This is one possible explanation for the pathogenesis of osteoarthritis.

SIGNIFICANCE/CLINICAL RELEVANCE:

This study characterized the normal subchondral BMD distribution of the thumb CM joint and demonstrated its age-related changes after eliminating the influence of osteoporosis. Understanding both aspects provides insight into the pathogenesis of osteoarthritis.

REFERENCES:

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- Miyamura S, et al. Sci Rep. 2024.
- Halilaj E, et al. J Biomech. 2015.

IMAGES AND TABLES:

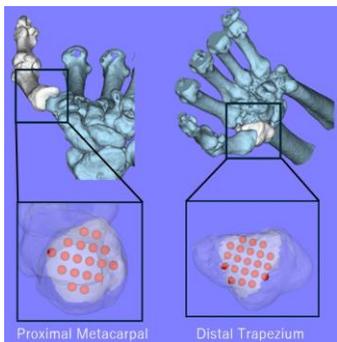


Figure.1 The subchondral points of interests. Equally spaced grids are applied to first metacarpal (18 points) and trapezium (21 points).

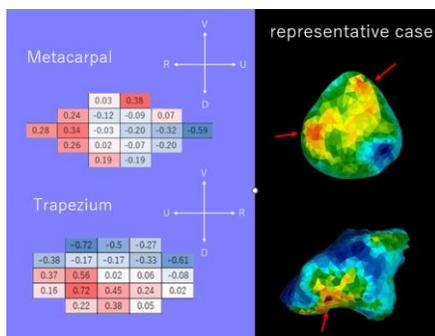


Figure.2 The heatmaps of the mean standardized (z-scored) subchondral bone mineral density across all subjects and a representative case (red arrows: high-density regions). The high-density regions are observed on the radial and volar-ulnar sides of the first metacarpal, and on the dorsal side of the trapezium. D dorsal direction, V volar direction, R radial direction, U ulnar direction

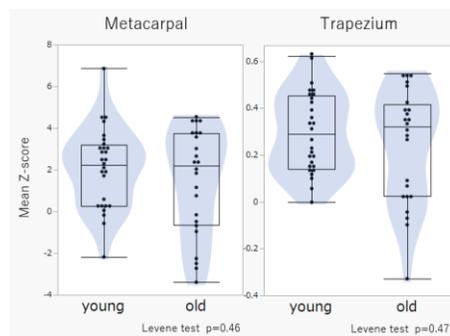


Figure.3 Violin plots with overlaid box plots and individual data points of standardized (z-scored) subchondral bone mineral density in the first metacarpal and trapezium. The older group shows significantly greater variance in both bones.