Motions of the Carpal-Thumb Kinematic Chain Are Complex and Differ from Both Thumb and Wrist Motion

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INTRODUCTION: Thumb carpometacarpal (CMC) osteoarthritis is highly prevalent with aging, especially in women. To assess disease progression, and the efficacy of treatments and therapies, thumb range of motion (ROM) is an important metric. However, thumb motion - herein equivalent to measuring motion of the first metacarpal (MC1) with respect to the radius (Rad-MC1) - is complex because it reflects the summed motion at three carpal joints: the radius-scaphoid joint (Rad-Sca), the scaphoid-trapezium joint (Sca-Tpm) and the trapezium-MC1 joint (Tpm-MC1), also referred to as the first CMC joint (**Fig. 1**). The relative contributions of these three carpal joints to thumb motion have not been previously investigated. The aim of this study was to examine carpal bone motions in the thumb-carpal kinematic chain and to determine if these contributions vary with the thumb and wrist tasks performed.

METHODS: Computed Tomography (CT) volumes from 46 healthy subjects (24F, 22M, 39.2 ± 14.2 yrs.) were analyzed using advanced 3D image-based markerless tracking algorithms to compute Rad-MC1 (thumb), Rad-Sca, Sca-Tpm, Tpm-MC1, Rad-MC3 (wrist) motion from a neutral thumb position to 10 discrete thumb poses: four with the thumb at maximum active ROM positions (extension, flexion, abduction, and adduction), and six while performing unloaded and loaded functional tasks: jar lid twisting ("jar"), lateral key pinch ("key"), and grasping ("grasp"). The CT scans were acquired as part of a longitudinal study of CMC biomechanical changes in early osteoarthritis. Each bone was segmented in the neutral position, then registered to its location in each subsequent ROM position or task using established image-based tracking algorithms. The motions were described using the rotation angle computed from helical axis of motion (HAM) parameters. Motion at each joint as a function of task was assessed with a two-way repeated-measures ANOVA and Tukey's multiple comparisons test and linear regression with wrist motion.

RESULTS: The contributions (mean and 95% CI) of the three carpal-thumb joints (radius-scaphoid (Rad-Sca), scaphoid-trapezium (Sca-Tpm), and trapezium-first metacarpal (Tpm-MC1)) as a percentage of overall thumb motion (radius-first metacarpal (Rad-MC1)) varied for each thumb position (Abd – abduction, Add – adduction, Ext – extension, Fle – flexion) and task (Grasp and Grasp-Loaded, Jar and Jar-Loaded, and Pinch and Pinch-Loaded) (**Fig. 2**). Data across all tasks illustrates that thumb motion cannot predict CMC (Tpm-MC1) motion. Sca-Tpm joint motion was notably less than at other the other joints and was also not correlated with thumb rotation (**Fig. 3A**). Data across all tasks for Rad-Sca motion was highly correlated with wrist rotation and slightly less than a 1:1 ratio (**Fig. 3B**). Sca-Tpm joint motion was notably less than at the other joints and was not correlated with wrist rotation (**Fig. 3**).

DISCUSSION: Joint rotations of the thumb-carpal kinematic chain summed to more than Rad-MC1 (thumb) rotation itself across all tasks by at least 50%, and in some poses by approximately 100%. The contributions of each of the three joints in the thumb-carpal kinematic chain (Rad-Sca, Sca-Tpm, Tpm-MC1) varied by task. Rigorous terminology when describing CMC joint motion is strongly encouraged. It is incorrect to measure thumb motion and call it CMC motion. Rotation at the Rad-Sca joint was highly correlated with wrist motion. Only the magnitude of the total rotations was analyzed, referred to as motion herein. Therefore, the values presented here are likely to include complex coupled motion whose magnitude likely varies with task.

SIGNIFICANCE: Direct, rigorous measurements of thumb-carpal kinematic chain joints, with accurate terminology, are essential for assessing disease progression, treatment and therapies at specific joints.

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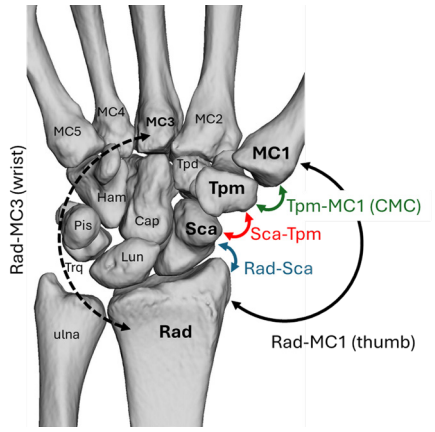

Figure 1. Relative joint rotations of the carpal thumb pilar joints.

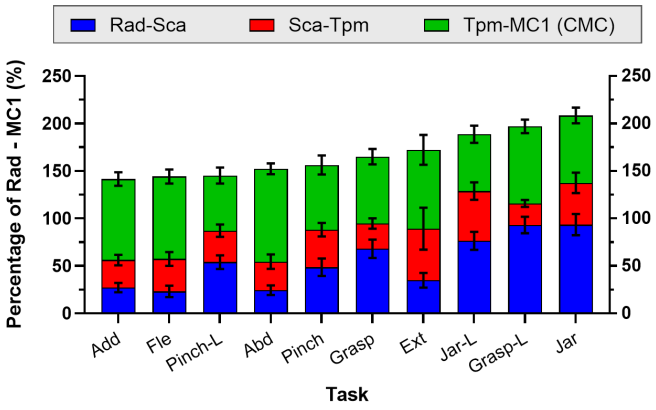

Figure 2. The contributions (mean and 95% CI) of the three carpal-thumb joints as a percentage of overall thumb motion (radius-first metacarpal (Rad-MC1)).

Figure 3A (*left*)**.** Data across all tasks illustrates that thumb motion cannot be used to predict CMC (Tpm-MC1) motion. Sca-Tpm joint motion was notably less than at other the other joints and was not correlated with thumb rotation.

Figure 3B (*right*). Data across all tasks for Rad-Sca motion was highly correlated with wrist rotation and slightly less than a 1:1 ratio. Sca-Tpm joint motion was notably less than at the other joints and was also not correlated with wrist rotation.