**In Vivo Triquetrum-Hamate Kinematics During a Hammering Motion**

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**INTRODUCTION:**

The triquetrum-hamate (TqH) joint has classically been described as a saddle joint with the hamate (HAM) having a helicoidal or screw shape into which the triquetrum (TRQ) rotates. The kinematics of the TqH joint lacks consensus, however, as some believe the TRQ follows a path on an oval surface. A complete understanding of the normal kinematics of the TqH joint is needed for the development of treatment of pathologic midcarpal motion. Previous kinematic analysis of the TqH joint has been based on measurements taken from two-dimensional radiographs. Three-dimensional (3-D) models generated from CT or MRI have recently been used to describe the TqH joint in flexion/extension (FE) or ulnar/radial (UR) deviation. TqH motion along the dart thrower’s path (DTM), wrist motion from radial extension to ulnar flexion and suggested by some as the most important functional motion of the wrist, remains to be studied. The purpose of this study was to determine the in vivo kinematics of the TRQ with respect to the HAM during a DTM.

**METHODS:**

Following IRB approval and informed consent, 6 male and 6 female, right-handed volunteers, average age 24.8 ± 3.8 yrs were screened for any injury or diseases that would affect carpal motion by a board certified orthopedic hand surgeon (EA). The right wrist of each subject was CT scanned using a custom designed jig in the neutral wrist position and 5 positions along a simulated hammering path. Positions along the path included -40º (windup), -20º, 0º (hammer handle perpendicular to forearm), 20º, and 40º (impact). Separate tessellated 3-D bone surface models representing the outer cortical shell of the third metacarpal, radius, ulna, and all eight carpal bones were generated through segmentation of the neutral CT scan in Mimics 9.11 (Materialize, Leuven, Belgium).

Six-degree-of-freedom global transforms describing the motion of each bone from the neutral wrist position to each hammering position were calculated using a previously established markerless bone registration technique. Motion of the TRQ with respect to the HAM was calculated by mathematically fixing the HAM. Wrist FE and UR were calculated using the projection of the long axis of the 3rd metacarpal onto a radius-based coordinate system.

Wrist range of motion in FE and UR was calculated for each subject. Since the hammering pathway follows a DTM that combines FE with UR, wrist motion was described as the total arc of motion from the 0º hammering position. The average wrist range of motion throughout the hammering pathway in UR was 40.3 ± 4º, and in FE was 49.6 ± 13º. The average coupling ratio of FE to UR was linear (P < 0.01) with an average ratio of 1.14 ± 0.43.

Distances fields, the distances between the bone surfaces, of the TRQ and HAM were calculated according to previous methods. A contour line on the HAM surface that enclosed the area where the TRQ was within 1.8 mm of the HAM was then calculated. The 1.8 mm contour line was selected because articular cartilage has been shown to have a thickness ranging from 0.5 mm to 1 mm. The centroid (CC) of the 1.8 mm contour line was tracked as the TRQ moved with respect to the HAM through each of the five hammering positions, and described in the inertial-based coordinate system of the capitate. The capitate coordinate system was extended to the HAM because the HAM is tightly bound to the capitate throughout the full range of wrist motion and corresponds well to HAM anatomy. CC location in both the dorsal-volar and proximal-distal directions was plotted as a function of DTM. When TRQ CC translation was expressed in the proximal/distal plane, and in the dorsal/volar plane, there was a statistically significant linear relationship with the hammering motion. Motion in the volar plane appeared to follow a quadratic function. This indicates that initially as the TRQ translates distally on the HAM, there is minimal motion in the volar direction. However, at a certain point in its motion, the TRQ shifts volarly as it continues to travel towards the hook. While recent literature has suggested that the TqH joint follows a rotational motion about an oval, we propose that the shift in translation of the TRQ towards the volar direction may occur when it approaches the prominent ridge at the distal end of the HAM articulating surface.


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**RESULTS:**

In wrist radial extension, at the windup position, we consistently found that the TRQ was located on the proximal and dorsal aspect of the ulnar side of the HAM. As the wrist moved into ulnar flexion, the TRQ translated along the HAM distally and volarly in a path oblique to the sagittal plane along the ulnar surface of the HAM (Fig 1a). As the TRQ approached the distal aspect of the ulnar surface (at a prominent ridge), it shifted from an oblique course to a volar course towards the convex surface of the base of the hook. The path of the CC mirrored TRQ motion confirming our visual findings (Fig 1b). There was a positive linear (R² 0.93 ± 0.06) relationship (P < 0.05) between the proximal/distal movement of the CC and DTM. The total excursion of the CC along the proximal-distal path was 3.7±1.7mm (Fig 1c).

As the TRQ moved distally it simultaneously moved in a volar direction towards the base of the hook of the HAM. In this plane, the TRQ translated 2.6±1.1mm, and had a positive linear relationship with DTM in 8 out of 12 subjects (P < 0.05). Interestingly, dorsal-volar movement of CC location along the DTM was better modeled by a quadratic function, with R² values increasing from 0.74 ± 0.22 in a linear model to 0.96 ± 0.03 in a quadratic model (Fig 1d).

**DISCUSSION:**

We measured the in vivo kinematics of the TRQ in reference to the HAM through a DTM during a simulated hammering task. Our visual understanding of the TRQ translating along an oblique path over the HAM from proximal and dorsal to distal and volar as the wrist moved along the DTM was confirmed by the changes in articular contact surface areas and their centroids. When TRQ CC translation was expressed in the proximal/distal plane, and in the dorsal/volar plane, there was a statistically significant linear relationship with the hammering motion. Motion in the volar plane appeared to follow a quadratic function. This indicates that initially as the TRQ translates distally on the HAM, there is minimal motion in the volar direction. However, at a certain point in its motion, the TRQ shifts volarly as it continues to travel towards the hook. While recent literature has suggested that the TqH joint follows a rotational motion about an oval, we propose that the shift in translation of the TRQ towards the volar direction may occur when it approaches the prominent ridge at the distal end of the HAM articulating surface.


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