Midcarpal Joint Motion Dominates Carpal Motion During a Simulated Hammering Task

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INTRODUCTION:
Hampering is a forceful occupational task that is, accomplished via extension of the shoulder and elbow, and a “coupled” motion of flexion and ulnar deviation at the wrist [1]. This coupled motion of radial-extension to ulnar-flexion has been described as the Dart Thrower’s Motion (DTM). In vitro and in vivo wrist motion studies have demonstrated that scaphoid and lunate rotations are minimal during the DTM [2,3]. It has also been postulated that the ability to move the wrist in the DTM is a uniquely human motion that offered an evolutionary advantage for use of tools and weapons [4]. While carpal kinematics has been studied extensively with various wrist motion protocols, to date, carpal kinematics has not yet been studied during a functional task.

The purpose of this study was to examine the wrist motion selected during hammering and to determine the in vivo three-dimensional (3-D) carpal kinematics during this functional task. We hypothesized that wrist motion would follow the Dart Thrower’s path and that there would be no radiocarpal motion during this hammering task.

METHODS:
With IRB approval, 13 healthy, right hand dominant volunteers (6 male, 7 female; average age 24.8, range [21-31]) were recruited. All volunteers were right hand dominant at hammering and had no prior wrist injury or disease. Each volunteer performed a simulated hammering task using a custom-made jig that targeted 5 different positions along the hammering path: -40° (hammering extension), -20°, 0° (neutral, hammer handle orthogonal to forearm), 20°, and 40° (hammering flexion). An armrest was provided to minimize forearm movement, as were stops for the hammer handle at each position. At each hammering position, a single CT scan was acquired (80kVp and 80mA, 0.5mm x 0.5mm x 0.6mm).

The 3-D kinematics for each carpal bone were calculated using an established CT-based markerless bone registration methodology [5]. Briefly, each bone of interest was manually segmented in the neutral position using Mimics 9.11 (Materialize, Leuven, Belgium). Custom C++ and Matlab (The MathWorks, Natick, Massachusetts) code was used to track the position of each bone in the remaining scans and to calculate the carpal kinematics. Wrist position was defined by the orientation of the third metacarpal with respect to the radius. Kinematics of the scaphoid and lunate with respect to the radius (radioscaphoid and radiolunate motion) were described relative to the neutral position.

The coupling ratio, defined as the ratio of flexion/extension to radial/ulnar deviation during hammering, was computed from the linear regression of each subject’s path. We report the mean±SD of these slopes, as well as the R² values. P < 0.05 for the overall regression was established a priori as the threshold for determining a significant coupling ratio. Similar regression analyses were also used to calculate the percent of radio-scaphoid and radio-lunate rotation as a function of total wrist motion and their non-zero relationships.

RESULTS:
The wrist motion of the average hammering path had a non-zero (p<0.01) flexion/extension to radial/ulnar deviation coupling ratio of 1.2±0.5 (R² = 0.93±0.08). In other words, for every 10° of wrist ulnar deviation, there was approximately 12° of wrist flexion (Fig. 1).

Throughout the complete hammering path the total wrist rotation was 70±10°. The rotation of the scaphoid with respect to the radius was non-zero (p<0.01), rotating 37±10% (R² = 0.96±0.04) of the wrist motion. In other words, for every 10° of wrist rotation, the scaphoid rotated only 37±10%. Similarly, the lunate rotation was also non-zero (p<0.01), rotating 37±10% (R² = 0.94±0.14) of the overall wrist rotation. These percentages indicate that midcarpal rotation dominated the motion of the carpus during hammering and was approximately 63% of the total wrist motion (Fig. 2). Scaphoid and lunate translation was minimal (0.5±0.4mm and 0.6±0.5mm respectively throughout the entire task), indicating that the majority of radiocarpal motion was rotation.

DISCUSSION:
This study was performed to determine the path of wrist motion and radioscpahoid and radiolunate motion during hammering. We found that the hammering path was very close to the DTM reported in a recent cadaver study [3] as well as one subsequently reported from a comprehensive in vivo dataset [2]. Our use of static positions to model hammering is a potential limitation. However, we believe this effect is small, as we have previously shown that simulated hammering follows the same path as dynamic hammering [6].

The DTM used during hammering is purported to require minimal scaphoid and lunate rotation [2,4,5]. While radiocarpal motion was non-zero, we found a greater than 50% reduction in the rotation as compared to pure flexion/extension of the wrist [7]. These findings are also consistent with a previous cadaver study of dart-throwing motion [3]. Inter-subject variability in the hammering path did influence radiocarpal rotations; individuals with paths closer to the Dart Thrower’s path had less scaphoid and lunate rotation than those with more divergent paths. Some of this variability can likely be explained by the novice experience level of our volunteers. Despite the inter-subject variability, midcarpal rotation was still the dominant motion of the carpal joint in all subjects.

In vivo measurement of carpal motion during functional tasks is critical to our understanding of carpal function, and for the development of rehabilitation protocols customized to specific injuries, surgery and occupation.


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