SCIENTIFIC ARTICLE

Carpal and Forearm Kinematics During a Simulated Hammering Task

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Purpose Hammering is a functional task in which the wrist generally follows a path of motion from a position of combined radial deviation and extension to combined ulnar deviation and flexion, colloquially referred to as a dart thrower's motion. The purpose of this study was to measure wrist and forearm motion and scaphoid and lunate kinematics during a simulated hammering task. We hypothesized that the wrist follows an oblique path from radial extension to ulnar flexion and that there would be minimal radiocarpal motion during the hammering task.

Methods Thirteen healthy volunteers consented to have their wrist and distal forearm imaged with computed tomography at 5 positions while performing a simulated hammering task. The kinematics of the carpus and distal radioulnar joint were calculated using established markerless bone registration methods. The path of wrist motion was described relative to the sagittal plane. Forearm rotation and radioscaphoid and radiolunate motion were computed as a function of wrist position.

Results All volunteers performed the simulated hammering task using a path of wrist motion from radial extension to ulnar flexion that was oriented an average of 41° ± 3° from the sagittal plane. These paths did not pass through the anatomic neutral wrist position; rather, they passed through a neutral hammering position, which was offset by 36° ± 8° in extension. Rotations of the scaphoid and lunate were not minimal but averaged 40% and 41%, respectively, of total wrist motion. The range of forearm pronation-supination during the task averaged 12° ± 8°.

Conclusions The simulated hammering task was performed using a wrist motion that followed a coupled path of motion, from extension and radial deviation to flexion and ulnar deviation. Scaphoid and lunate rotations were greatly reduced, but not minimized, compared with rotations during pure wrist flexion/extension. This is likely because an extended wrist position was maintained throughout the entire task studied. *(J Hand Surg 2010;35A:1097–1104. © 2010 Published by Elsevier Inc. on behalf of the American Society for Surgery of the Hand.)*

Key words Carpal, kinematics, hammering, scaphoid, lunate.

HAMMERING IS ACCOMPLISHED via tightly coordinated motion of the shoulder, elbow, forearm, and wrist.[1] The general sequence of events during the swing phase of hammering includes combined shoulder and elbow extension, followed by forearm supination and "snapping" of the cocked wrist[1] from radial extension to ulnar flexion to generate high driving forces.

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Although there have been several studies on the ergonomics of hammering,[1–3] the specific bony motions that occur at the wrist and forearm have not been characterized in detail. At this point, it is generally acknowledged that the hand moves along a path from radial extension (a wrist position of combined radial deviation and extension) to ulnar flexion (a wrist position of combined ulnar deviation and flexion),[1,4] commonly referred to as the dart thrower's motion (DTM).[1] It has also been reported that the wrist is held in a position of extension throughout the hammering motion[1,4] and that the forearm naturally pronates during the windup phase (as the wrist is moved into radial extension) and supinates during the swing phase (as the wrist is snapped into ulnar flexion).[5] However, the specific motions of the carpal bones during the hammering task have not been quantified.

The previous kinematic studies of hammering have measured joint motion using electromechanical devices affixed to the surface of the distal forearm and hand.[1,4] Although these studies have provided important insight into the gross motion of the forearm and hand during hammering, their use of surface-based measurement methods has precluded analysis of carpal bone kinematics due to the movement of the skin relative to the underlying bone. Moreover, previous hammering studies have focused on the relative motion of the hand, with little if any emphasis on forearm pronation-supination.

Despite the lack of kinematic data on the hammering task, the kinematics of the carpus have been evaluated for less demanding tasks that employ the DTM in both living subjects and *in vitro* cadaver experiments.[6–10] These studies have generally reported that radiocarpal motion is reduced during the DTM, compared with that seen with pure flexion and extension of the wrist. However, findings regarding the relative contribution of radiocarpal motion to overall wrist motion have varied. In particular, scaphoid rotation during the DTM has been reported to be as little as 26% and as much as 50% of overall wrist motion,[6–8,10] whereas the range of reported lunate rotations has varied from 22% to 40% of overall wrist motion.[6–8,10] Analyzing *in vivo* carpal kinematics using data from 28 normal volunteers and 504 wrist positions, Crisco et al.[9] predicted near-zero scaphoid and lunate rotations for DTM motion paths oriented at angles of 33° and 20° to the sagittal plane, respectively.

Data on the intricacies of wrist and forearm bone motion during hammering are critical to the understanding of work-related injury, and necessary for the rational design of ergonomic tools, rehabilitation protocols, and wrist implants. The purposes of this study, therefore, were to determine the overall path of wrist motion during hammering, as defined by the third metacarpal motion, and to determine the specific 3-dimensional motions of the radius, ulna, and carpal bones that occur during hammering. Given the existing data in the literature and the high-demand nature of the hammering task, we hypothesized that wrist motion would follow the path of the DTM, and that during hammering, motion of the proximal carpal row with respect to the distal radius would be minimal.

MATERIALS AND METHODS

Volunteer selection and computed tomography (CT) scanning

With institutional review board approval, we enrolled 13 healthy, right hand–dominant volunteers (6 men, 7 women; average age, 24.8 years [range, 21–31 years]) in the study after a board-certified hand surgeon performed a brief wrist exam (including plain films). A priori exclusion criteria included any history or findings of prior wrist disease or injury, or any soft tissue or metabolic disease that could affect carpal motion. All enrolled volunteers were neophyte hammerers; none had held a job or had had hobbies that required substantial amounts of hammering.

Computed tomography (CT) volume images were generated of each volunteer's dominant wrist as they gripped a wooden hammer handle and performed a simulated hammering task. During scanning, the volunteers were positioned prone on the CT table (chests supported with a pillow), with their dominant arm near full shoulder flexion (overhead elevation), parallel with the center axis of the gantry. A custom-designed jig was affixed to the scanner table to facilitate wrist positioning and minimize artifactual motion during scanning. The jig included a wrist support and pegs that served as stops for the hammer handle at 5 targeted positions along the hammering path: 40° extension (full windup), 20° extension, 0° ("hammering neutral," defined as the position in which the hammer handle was oriented vertically, perpendicular to the forearm), 20° flexion, and 40° flexion ("impact") (Fig. 1). The term "wrist motion" is used in this study to describe the motion of the wrist along this hammering path.

CT scanning was performed with a GE LightSpeed 16 scanner (General Electric, Milwaukee, WI) at tube settings of 80 kVp and 80 mA, slice thickness of 0.625 mm, and field of view that yielded an in-plane resolution of 0.5 × 0.5 mm. A sixth, higher-resolution scan (0.3 × 0.3 × 0.625 mm) was acquired with the hand flat on the CT table (wrist near neutral, forearm pronated) to provide an image dataset that was used to gen-