INTRODUCTION

The wrist is one of the most intricate articulations of the musculoskeletal system, in which the delicate balance is maintained by a complex set of intrinsic and extrinsic ligamentous connections between seven carpal bones. Injuries to the bones and ligaments in the wrist may potentially irreversibly disrupt this balance and initiate progressive degenerative disease and osteoarthritis (OA). Muscle forces across the hand and wrist, as well as the numerous and complex articulations, pose significant challenges for diagnosis and treatment.

Researchers and clinicians are fortunate to utilize biplanar fluoroscopy methods to accurately determine the arthrokinematics of articulations in real time for joints such as the hip, shoulder, and knee, where limited superposition of bone geometry occurs within the 2D fluoro images. Our 4D CT method will complement biplanar fluoroscopy because, as a tomographic imaging modality, its strength lies in imaging joints with complicated, multi-articulated structures (such as the wrist) that are problematic for the biplanar approach. 4D CT provides a widely available, high spatial and temporal resolution, geometrically precise method to dynamically image the complicated multi-articulated joints of the wrist. This technique was demonstrated in a cadaveric forearm/hand specimen.

METHODS

A custom motion simulator was fabricated to simulate radial-ulnar deviation at the wrist joint. We exposed the proximal ends of the radius and ulna bones in the cadaveric forearm, and firmly mounted them to the device (Fig. 1). The hand was attached to an acrylic paddle via a single plastic screw through the second intermetacarpal space, just proximal to the deep intermetacarpal ligament. Two linear slides under the paddle provided composite motions in the x and z-axes. A programmable stepper motor (connected to a laptop) produced belt-driven motion of the paddle in the x-axis, with free motion of the paddle in the z-axis, allowing the hand to perform periodic radioulnar motion through a maximum arc of 30° (10° of radial deviation and 20° of ulnar deviation). The wrist was programmed to move at 30 cpm, representing a typical wrist motion speed.

![Figure 1: Cadaveric wrist in custom simulator.](image-url)
were generated using volume rendering techniques (VRT) on the scanner’s image processing workstation. Dose values were assessed for the 4D scanning technique by scanning the cadaveric wrist at different dose levels. Image quality was evaluated at each dose level to determine the minimal dose at which the scans still had sufficient diagnostic image quality.

RESULTS AND DISCUSSION

The carpal bones, distal radius, ulna, and joint spaces were clearly delineated in the rendered images (Fig. 2), without motion blurring or banding artifacts, in all motion phases. 4D image sequences were generated from the 3D images to visualize the motion of each carpal bone and the change in joint spaces throughout the motion cycle. The estimated skin dose in this preliminary study, with scanning parameters of 140 kVp, 200 mAs per rotation, and a 2 second scan time, was about 55 mGy, which is a factor of 40 lower than the minimum threshold for skin effects (2 Gy) [1]. Thus, no deterministic skin injury is possible. Potential cancer risk is similarly negligible because of the small exposure volume and insensitivity of the exposed tissues to radiation.

The 4D CT technique provides dynamic, high spatial and temporal resolution, and geometrically precise dynamic images of the complex wrist joint. Future work aimed at assessing the arthrokinematics and joint contact characteristics during dynamic wrist joint movements in vivo will provide valuable clinical information for assessing dynamic joint instabilities before they progress to static deformities and OA.

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REFERENCES


Figure 2: Three volumes from the dynamic 4D CT imaging sequence, volume rendered (top row, dorsal view) and virtual radiography images (bottom row) in radial deviation (A, D), neutral (B, E), and ulnar deviation positions (C, F).