SCIENTIFIC ARTICLE

# Arthrokinematics of the Distal Radioulnar Joint Measured Using Intercartilage Distance in an *In Vitro* Model

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**Purpose** Current techniques used to measure joint contact rely on invasive procedures and are limited to statically loaded positions. We sought to examine native distal radioulnar joint (DRUJ) contact mechanics using nondestructive imaging methods during simulated active and passive forearm rotation.

**Methods** Testing was performed using 8 fresh-frozen cadaveric specimens that were surgically prepared by isolating muscles involved in forearm rotation. A wrist simulator allowed for the evaluation of differences between active and passive forearm rotation. Three-dimensional cartilage surface reconstructions were created using volumetric data acquired from computed tomography. Using optically tracked motion data, the relative position of the cartilage models was rendered and used to measure DRUJ cartilage contact mechanics. The effects of forearm movement method and rotation angle on centroid coordinate data and DRUJ contact area were examined.

**Results** The DRUJ contact area was maximal at 10° supination. There was more contact area in supination than pronation for both active and passive forearm rotation. The contact centroid moved volarly with supination, with magnitudes of $10.5 \pm 2.6$ mm volar for simulated active motion and $8.5 \pm 2.6$ mm volar for passive motion. Along the proximal−distal axis, the contact centroid moved $5.7 \pm 2.4$ mm proximal during simulated active motion. These findings were statistically significant. The contact centroid moved $0.2 \pm 3.1$ mm distal during passive motion (not significant).

**Conclusions** It is possible to examine cartilage contact mechanics of the DRUJ nondestructively while undergoing simulated, continuous active and passive forearm rotation. The contact centroid moved volarly and proximally with supination. There were higher contact area values in supination compared with pronation, with a peak value at 10° supination.

**Clinical relevance** This study documented normal DRUJ arthrokinematics using a nondestructive *in vitro* approach. It further reinforced the established biomechanical and clinical literature on contact patterns at the native DRUJ during forearm rotation. *(J Hand Surg Am. 2017;■(■):1.e1-e9.* *Copyright © 2017 by the American Society for Surgery of the Hand. All rights reserved.)*

**Key words** Arthrokinematics, contact, distal radioulnar joint, intercartilage distance, triangular fibrocartilage complex.

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Much of the current research examining contact mechanics of the distal radioulnar joint (DRUJ) focuses on the effect of joint malalignment.[1–3] Altered DRUJ contact mechanics are thought to cause degenerative changes and arthritis after injury.[4] Kinematic studies have determined that under normal conditions the radius both rotates and translates relative to the ulna.[5] In supination, the ulnar head sits volar and proximal within the sigmoid notch, and in pronation it is relatively dorsal and distal.[6,7] Less is known about native cartilage contact mechanics of the DRUJ.

Previous techniques used to measure joint contact mechanics relied on invasive procedures and were often limited to static positions. Common direct methods are joint casting,[8–10] pressure-sensitive film,[11,12] and Tekscan (Tekscan Inc, South Boston MA).[13–15] Tekscan is a piezo-resistive array pressure sensor that permits dynamic evaluation of contact area and pressure during joint motion. It has been used to investigate contact relationships in the DRUJ.[13–15] However, the utility of direct techniques is limited because they may change the normal articular mechanics by sectioning capsuloligamentous structures to access the joint's interior, and because of the inherent thickness of the material interposed.[9] Novel, indirect methods of assessing joint contact have also been developed. Indirect techniques are noninvasive and compare relative positions of computed tomography (CT) or magnetic resonance imaging–generated joint models using computational means and proximity mapping.[16–19] The interaction between model surfaces can be calculated and used to characterize joint contact.[20–25]

Intercartilage distance (ICD) is a validated *in vitro* technique for assessing joint contact area, which uses CT-based bone and cartilage models, fiducial-based registration, and optical tracking motion capture data.[26] It has not been previously used to examine DRUJ contact mechanics. The advantage of *in vitro* methodology is that the state of specimens can be modified and more experimental conditions can be evaluated to determine their effect precisely.[27]

The purpose of this study was to use ICD to examine native DRUJ contact mechanics during simulated active and passive forearm rotation. The study hypotheses were that: (1) the contact area and centroid location would change during forearm rotation; and (2) there would be a difference in contact patterns between simulated active and passive forearm rotation.

## MATERIALS AND METHODS

### Specimen preparation

A sample size of 8 cadaveric wrists was determined using currently available data on clinically significant changes in DRUJ contact.[1] We established that this sample size would provide a power of 80% to detect changes of 0.8 mm in centroid position and 20 $mm^2$ in contact area at the 0.05 confidence level. Testing was performed on 8 fresh-frozen cadaveric forearm specimens (mean age 60 years; range, 29–75 years; 6 men and 2 women) with no CT evidence of pathology. The distal tendons of extensor carpi radialis longus (ECRL), extensor carpi ulnaris (ECU), flexor carpi radialis (FCR), flexor carpi ulnaris (FCU), pronator teres, and biceps (BIC) were sutured using number 2 Ethibond (Ethibond Excel, Ethicon, Inc, Piscataway, NJ). The supinator (SUP) was modeled with a suture anchor in the radial tuberosity routed through a Delrin sleeve (DuPont, Dupont City, West Virginia), which traversed the supinator crest.

Sutures were passed through alignment guides that reproduced the physiologic line of action of each muscle (Fig. 1). The elbow was placed in 90° flexion and the ulna was transfixed to a static post using 2 2-mm partially threaded Steinmann pins. The sutures of ECRL, ECU, FCR, FCU, and SUP were routed through alignment pulleys and attached to individual pneumatic actuators (Airpot Corp, Norwalk, CT).

### Simulation of motion

We first tested passive motion by manually rotating the forearm through a full arc of motion from pronation to supination. Active supination was initiated by attaching BIC to the servo motor (SM2315D; Animatic, Santa Clara, CA) set to motion control. The BIC and SUP were loaded to overcome a 20-N counterforce from pronator teres and generate simulated active supination at a rate of 5 mm/s. The muscles were loaded using a ratio based on a previous investigation of forearm muscle electromyography and cross-sectional area.[28] Constant tone loads of 10 N were applied to the FCU, FCR, ECU, and ECRL to stabilize the wrist. Simultaneous pneumatic actuator loads were regulated by proportional pressure controllers (MAC Valves, Wixom, MI) under computer control using custom-programmed software (LabVIEW, National Instruments, TX).

### Motion tracking and kinematic data acquisition

The specimens were tested with the wrist and DRUJ intact, with no violation of the capsule or ligamentous stabilizers. Infrared marker triads (optical tracking