In Vivo Joint Contact Patterns within the Thumb Carpometacarpal Joint using Dynamic CT Imaging

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ABSTRACT INTRODUCTION:
The thumb carpometacarpal (CMC) joint arthritis is a debilitating disease affecting up to 30% of males and 40% of females[1]. Current treatment options are limited in terms of their longevity. To devise improved surgical techniques, a more detailed understanding of the dynamic function of the CMC joint is needed. The purpose of this project is to use dynamic 4 dimensional computer tomography (CT) imaging to delineate normal basilar thumb joint kinematics.

METHODS:

Image Acquisition
After IRB approval was obtained, a healthy subject was positioned prone within a CT scanner (Siemens Definition FLASH) with the forearm supported in a custom device and the thumb CMC joint centered in the field of view. The subject moved the left thumb in a circumduction motion. A non-gated perfusion-like CT scanning mode was used in which the x-ray is continuously on, without table translation. Two seconds of data were acquired. Images were reconstructed using the commercially implemented dual-source cardiac reconstruction algorithm with 75ms temporal resolution, resulting in 3D image volumes at 5% time increments throughout the motion cycle.

Image matching (voxel-based registration)
The trapezium and metacarpal were semi-automatically segmented from CT images using a 3D region growing method in the initial phase and then the segmented bones were superimposed on images of the same bones in each subsequent position (phase), using a voxel-based registration technique. 3D motion of individual bones and their relative motion was derived by computing the rigid transformation of each bone required to match the images.

Joint contact area
Joint proximity at the CMC joint was determined by segmenting the trapezium and metacarpal during all motion phases and calculating the linear distance between the two bone surfaces using Orthopedic Viewer software[2]. To extract both the areas of contact and the centroids of the contact areas with respect to each bone, a user-specified threshold distance (1.0 mm) was set. We evaluated the movements of the contact area and its centroid at each position, compared to the initial position. To provide a convenient database for the areas of contact, the joint was subdivided into nine anatomic regions, as shown in Figure 1. For each position, we calculated the percentage of the total contact area included within each of the nine regions.

RESULTS SECTION:
The initial position produced contact areas predominantly on the central region. In this position, the contact area was 69.1mm². During radio-dorsal flexion, the difference in the direction of the contact area movement was detected between the trapezium and the metacarpal bone. During this motion, the contact area of the metacarpal bone was located on the volar-ulnar regions (51.6 mm²). With the thumb flexed in an ulno-volar direction, the contact areas were observed on the radio-dorsal and the radio-volar regions. (Figure 2)

The distribution ratios of the contact areas on each bone are shown in Figure 3. The contact area of the trapezium tended to be located in the volar region and the ulno-volar regions. The distribution ratio of the contact area in each anatomic region at each joint position.

DISCUSSION:
The thumb CMC joint is a common site of osteoarthritis. The ulno-volar and dorso-radial regions of the trapezium were reported to be the most common sites of thin cartilage[3]. The results of this study indicate that the circumduction motion produced increased joint contact forces in these areas. In addition, a difference in the migration of the contact area was detected between the trapezium and the metacarpal bone during radio-dorsal flexion. The contact area of the trapezium was detected in the dorso-radial and dorso-central regions, and the contact area of the metacarpal was located in the volar-ulnar region, in which the articular cartilage is thin.

SIGNIFICANCE:
The precise determination of contact areas, as a function of joint position, is of primary importance in the understanding of joint biomechanics and the etiology of osteoarthritis. Our analysis approach provides a tool to assess the joint contact characteristics in vivo under true dynamic loading conditions. Further analysis using dynamic CT imaging can serve to further clarify basilar thumb joint kinematics and help us to devise improved anatomic surgical reconstructions.

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REFERENCES: