Comparison of Computed Tomography Articular Surface Geometry of Male Versus Female Thumb Carpometacarpal Joints

HAND
2018, Vol. 13(1) 33–39
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DOI: 10.1177/1558944716688528
hand.sagepub.com

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Abstract

Background: Given the predilection of first carpometacarpal (CMC) joint osteoarthritis in women compared with men, we aim to determine the differences in first CMC joint surface geometry and congruence between young healthy males and females. **Methods:** Wrist computed tomographic scan data of 11 men and 11 women aged 20 to 35 years were imported into 3-dimensional software programs. The first metacarpal and the trapezium were aligned in a standardized position according to landmarks at key points on Gaussian and maximum curvature maps. Measurements of joint congruence and surface geometry were analyzed, including joint space volume, distance between the bones at the articular surface edges, area of the joint space, and radii of curvature in the radial-ulnar and volar-dorsal planes. **Results:** The mean thumb CMC articular space volume was $104.02 \pm 30.96 \text{ mm}^3$ for females and $138.63 \pm 50.36 \text{ mm}^3$ for males. The mean first metacarpal articular surface area was $144.9 \pm 10.9 \text{ mm}^2$ for females and $175.4 \pm 25.3 \text{ mm}^2$ for males. After normalizing for size, the mean thumb CMC articular space volume was $119.4 \pm 24.6 \text{ mm}^3$ for females and $117.86 \pm 28.5 \text{ mm}^3$ for males. There was also no significant difference for the articular space volume, articular surface distances, articular space, and mean radii of curvatures. **Conclusions:** This study found that there are sex differences in the first CMC joint articular volume without normalizing for size; however, there are no sex differences in first CMC joint articular volume, curvature characteristics, or joint congruence of young, healthy patients after normalizing for joint size.

Keywords: first carpometacarpal joint, trapeziometacarpal joint, osteoarthritis, surface geometry, CT scan, sex differences

Background and Purpose

Thumb carpometacarpal (CMC) joint osteoarthritis (OA) has a significant impact on functional tasks of daily living, disproportionately affecting women. Nearly 80% of diagnosed CMC joint arthritis occurs in women, with up to 3- to 4-fold increase in prevalence among women compared with men.²⁰ In studies with 3,000-11,000 patients, the prevalence of thumb CMC joint arthritis was found to be significantly greater in women versus men, ranging from 5% to 40% in women compared with 1.5% to 25% in men above the age of 65 years.^{8,16,17,20} There has been no correlation found between thumb CMC joint arthritis and type of occupation or physical activity,^{2,8,10} although a significant association between obesity and thumb CMC joint arthritis has been reported.^{8,16}

There are several hypotheses regarding increased prevalence of thumb CMC joint arthritis in women compared with men. It was traditionally thought that the laxity of the volar ligaments and shallowness of the saddle-shaped joint

contributed to the development of OA¹⁴; however, it has been established that dorsal rather than volar ligaments are the most important stabilizers of the CMC joint.¹³ Dorsal ligaments are taut during power pinch and grasp, with the metacarpal volar beak in close contact with the trapezium recess and up to 120 kg of compressive force during these motions.^{7,14} The volar areas of the CMC joint articular surface that undergo higher compressive forces lead to greater cartilage wear at the volar aspects, and less on the dorso-ulnar quadrant of the joint.^{7,11,15,22} Therefore, any sex differences in either ligament laxity or geometry of the joint can potentially promote greater cartilage wear and degeneration.

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Specific sex differences of the geometry of the CMC joint articular surfaces have been reported, with differences in shape of the metacarpal and trapezium articular surfaces, less joint congruence in females, smaller contact area in females, and different patterns of cartilage wear.^{1,12,22} Other hypotheses suggest that women have greater rates of thumb CMC joint arthritis due to increased generalized hypermobility, increased mobility at the CMC joint itself, and influence of hormones such as relaxin and estrogen.^{4,6,18,19,21} Given that the topography of the joint itself may play a large role in the development of thumb CMC OA, it is beneficial to have a greater understanding of anatomic factors that contribute to predisposition of OA in females.

There have been previous studies revealing sex differences in CMC joint geometry in arthritic joints, but there is a lack of studies to be found in young, nonarthritic populations. This study aims to (1) determine whether there are differences in thumb CMC joint anatomy between males and females and (2) quantify these differences through analysis of 3-dimensional reconstructions of computed tomographic (CT) scans in young, healthy patients. Our null hypothesis is that after adjusting for variability in size, there are no differences in the articular surface curvature and geometry of thumb CMC joints in young, healthy females compared with males.

Materials and Methods

All study procedures were approved by the appropriate Research Ethics Board. Using a radiology database, wrist CT scans of patients aged 20 to 35 years were identified excluding any CMC joint pathology including CMC joint arthritis, first metacarpal fractures, and trapezium fractures. A total of 11 male and 11 female left wrist CT scans were obtained for analysis. The CT images had a slice thickness of 0.625 mm and were imported into Mimics 16.0 (Materialise, Leuven, Belgium), and the first metacarpal and trapezium were segmented by thresholding, with areas of manual segmenting from adjacent bones. Analysis of the first metacarpal and trapezium was performed using the software programs Amira 5.3.3 (FEI, Hillsboro, Oregon), Geomagic Freeform (3D Systems, Inc, Rock Hill, South Carolina), Rhinoceros 5 (McNeel North America, Seattle, Washington), and VP-Sculpt 3.03 (Dr. David G. Alciatore, Fort Collins, Colorado).

Standardizing Joint Position

To standardize the position of the first metacarpal and trapezium relative to each other, a landmarking method was used to align the bones. Mathematical Gaussian and maximum curvature maps, which represent intrinsic measures of the extent of curvature at any given point, were mapped on the articular surfaces of both the first metacarpal and trapezium

in order to identify the peaks and edges of the articular surface, respectively. Five corresponding points on each surface were identified. First metacarpal landmarks included the volar peak, dorsal peak, midpoint between the volar and dorsal peak, and radial and ulnar edges of the articular surface perpendicular to the volar-dorsal ridge at the level of the midpoint. Similarly, identified trapezium landmarks included the ulnar and radial peaks along the radial-ulnar axis of the saddle, the midpoint between the ulnar and radial peaks, and the volar and dorsal edges of the articular surface perpendicular to the radial-ulnar axis at the level of the midpoint (Figure 1). These landmarks were used to mathematically align the bones in the configuration that had the least average distance between each corresponding landmark. Because this configuration allows the bones to overlap in space, the bones were then distracted from each other along the vertical axis of the metacarpal until it reached the single point at which the bones are just touching. This configuration represents the final standardized joint position used for measurements (Figure 2).

Joint Space Measurements

In the final standardized joint position, the edges of the articular surface were defined using mathematical maximum curvature maps. The joint space surrounded by both the metacarpal articular surface superiorly and the trapezium articular surface inferiorly was used to measure the volume between the 2 articular surfaces of the CMC joint. The measurement of joint space surface area from a bird's-eye view was used to normalize the specimens for size. The distance between the 2 articular surfaces was measured using guidance from the previously defined landmarks at the volar, dorsal, radial, and ulnar edges of the joint space volume (Figure 3). The area between the first metacarpal and trapezium articular surfaces in the radial-ulnar plane and the volar-dorsal plane was then measured using the edges of the joint volume as the defining borders (Figure 4).

Radius of Curvature Measurements

Curvature along the radial-ulnar and volar-dorsal planes of the articular surfaces was evaluated by measuring the radius of curvature along 3 points, which were standardized as the landmarks described previously (Figure 5).

Normalization for Size Difference

To normalize the measurements for size differences between specimens, the 2-dimensional surface of the thumb CMC joint space in the axial plane was used as the reference value. This bird's-eye view of the smallest enclosing surface in the axial plane allows for adjustment of size without the confounding variables of curvature of the joint,

Figure 1. Landmarking method based on mathematical curvature maps: Imported image of tomographic scan first metacarpal and trapezium (left) with volar (V), dorsal (D), radial (R), and ulnar (U) orientation shown, peaks represented on Gaussian curvature maps (middle), and remainder of landmarks represented on maximum curvature maps (right).

Figure 2. Standardized alignment based on landmarks: Original position of joint on tomographic scan (left), aligned first metacarpal and trapezium based on landmarks (middle), and final position with bones distracted until just touching at a single point (right).

length of bone, or whole bone volume interfering with relative size. The following formula was used to normalize for size: $\sqrt{SA_{avg}/SA_x}$, where SA = surface area of thumb CMC joint space, avg = average, and x = subject number.

Statistical Analysis

The mean and standard deviations for all measurements were calculated and reported. Hypothesis testing was done for all measurements using 2-tailed 2-sample t tests assuming equal variance. The null hypothesis was rejected and

determined to be statistically significant if the critical value, P , was less than .05. A power analysis performed based a pilot study of 7 with a desired power of 80%, all tests were 2-tailed with probability of a type I error set at .05. This revealed a target sample size of 22.

Results

A total of 22 left wrist CT scans of 11 females (mean age 28.0 ± 4.4 years) and 11 males (mean age 30.2 ± 4.2 years) were included. Indications for wrist CT were most often for wrist fractures, with the results ranging from normal to

Figure 3. Volume and articular surface distance measurements: a, Volume between first metacarpal and trapezium represented in grey. b, Volume with articular surfaces shown only. c, Representation of volar (V), dorsal (D), radial (R), and ulnar (U) distances between the articular surfaces.

Figure 4. Area between the first metacarpal and trapezium articular surface curves in the radial-ulnar and volar-dorsal planes: Area between trapezium and metacarpal (metacarpal shown in red) in radial-ulnar plane outlined in green (left), and volar-dorsal plane (right).

distal radial fracture, scaphoid fracture, fourth metacarpal fracture, and perilunate dislocation. No CT scans had any evidence of first CMC joint arthritis or fractures of the trapezium or first metacarpal.

Joint Space Measurements

The mean thumb CMC articular space volume was $104.02 \pm 30.96 \text{ mm}^3$ for females and $138.63 \pm 50.36 \text{ mm}^3$ for males ($P = .066$). The mean first metacarpal articular surface area was $144.9 \pm 10.9 \text{ mm}^2$ for females and $175.4 \pm 25.3 \text{ mm}^2$ for males ($P = .0015$), and the mean 2-dimensional joint space surface area was $102.8 \pm 10.9 \text{ mm}^2$ for females and $125.3 \pm 14.6 \text{ mm}^2$ for males ($P = .0006$). After normalizing for size, the mean thumb CMC articular space

volume was $119.4 \pm 24.6 \text{ mm}^3$ for females and $117.86 \pm 28.5 \text{ mm}^3$ for males ($P = .90$). Mean distances at the articular surface volar, dorsal, radial, and ulnar edges are shown in Table 1, with no significant sex differences both prior to and after normalizing for size. The mean area between the first metacarpal and trapezium articular space after normalizing for size was $10.06 \pm 2.56 \text{ mm}^2$ for females and $9.38 \pm 3.15 \text{ mm}^2$ for males in the radial-ulnar plane ($P = .6$), and $8.19 \pm 1.76 \text{ mm}^2$ for females and $7.21 \pm 2.38 \text{ mm}^2$ for males in the volar-dorsal plane ($P = .3$). Mean radii of curvature of the first metacarpal and trapezium along the volar-dorsal and radial-ulnar planes are shown in Table 2, with no significant sex differences after normalizing for size. When comparing the radius of curvature of the first metacarpal and trapezium of each specimen by measuring the

Figure 5. Radius of curvature measurements with volar (V), dorsal (D), radial (R), and ulnar (U) orientation shown: First metacarpal volar-dorsal (MC VD) and radial-ulnar (MC RU) radii of curvature represented in red; trapezium volar-dorsal (Trap VD) and radial-ulnar (Trap RU) radii of curvature represented in grey.

difference between the 2 values in the volar-dorsal and radial-ulnar planes, there was also no significant sex differences (Table 2).

Discussion

This study presents thumb CMC articular surface geometry and joint congruence using articular surface and joint space measurements in a standardized position. Alignment of the joint in a consistent manner through the use of landmarks allowed for analysis of joint congruence, which cannot otherwise be quantified with varying position of the joint on CT scan.

There were significant sex differences in joint volume, articular surface area, as well as 2-dimensional joint surface area, which does not include extent of curvature as a variable. Our study used 2-dimensional surface area to normalize for size, as it represents joint size without allowing other variables to confound the size such as curvature of the joint itself, bone length, or bone width. Therefore, this method accounts for size of the joint alone rather than using total bone volumes as the normalizing factor. After normalizing for size, there was no significant difference between male and female joint space or congruence. The significance for the distance at the volar articular surface edge being greater in female first CMC joints approaches *P* value of .12.

There have been varying reports on whether sex differences of first CMC surface geometry exist in the hopes of determining whether anatomical differences are a contributing factor to female predominance of first CMC joint arthritis. Ateshian et al¹ described sex differences in cadaveric

surface anatomy of arthritic first CMC joints, with female joints being less congruent than male joints, with less congruence in the dorsovolar plane than in the radioulnar plane. However, it is known that different patterns in cartilage wear exist between males and females in arthritic joints of the first CMC joint^{11,15} based on higher contact stresses in certain areas of the joint.²² Therefore, studies are now investigating whether there are differences in surface anatomy of nonarthritic joints and in younger populations where cartilage wear is less of a factor. Conconi et al⁵ found no sex difference in joint congruence when comparing nonarthritic first CMC joints with early arthritic Eaton stage I joints. Halilaj et al⁹ compared articular surface curvature of both nonarthritic versus arthritic joints, as well as young versus older healthy nonarthritic joints, and found no sex differences in curvature, but rather significantly higher concave curvature and lower convex curvature of the saddle-shaped surfaces in the older compared with younger nonarthritic joints. Our study indicates no sex differences in joint articular surface characteristics after normalizing for size, supporting these previous reports, as well as no sex differences in joint space and volume between the trapezium and first metacarpal.

Limitations of this study include small sample size, which could lead to falsely accepting the null hypothesis. The results of our study may be limited by being underpowered, where the sample size required to obtain significance given the predetermined error rates ($\alpha = 0.05$ and $\beta = 0.8$) ranges from 50 to over 200. Another limitation includes a lack of anatomically correct joint positioning or kinematic analysis. A benefit of a computer-generated standardized configuration of the joint by landmarks is that it represents a very consistent joint position between subjects. This allows for measurement of joint space volume and other measures of joint congruence, rather than comparing surface geometry of the 2 bones independent of each other. However, given that this position was computer generated, it may not reflect true neutral anatomic positioning of the joint and does not account for biomechanical movement of the joint.

It is also important to note that given the analysis of bones using CT scan data, subchondral surfaces were only able to be identified rather than cartilaginous articular surfaces. This may have some effect on surface geometry as cartilage thickness ranges from 0.6 to 1.1 mm due to differences in wear, which varies throughout the surface and by advancing stages of arthritis.^{3,11} However, it is difficult to determine whether young, nonarthritic patients also exhibit varying cartilage thickness across the joint articular surfaces.

In conclusion, this study found that curvature characteristics and joint congruence are not influential factors in determining the predilection of first CMC joint OA in women compared with men. Given that there is no evidence

Table 1. Mean Distance Measurements at Carpometacarpal Articular Surface Edges.

	Volar	Dorsal	Radial	Ulnar
Mean distance (mm):				
Not normalized for size				
Females	2.31 ± 0.67	1.91 ± 0.63	2.07 ± 0.56	2.20 ± 0.71
Males	2.05 ± 0.79	2.05 ± 0.48	2.18 ± 0.88	2.16 ± 0.77
P value	.41	.57	.71	.92
Mean distance (mm):				
Normalized for size				
Females	2.43 ± 0.68	2.00 ± 0.61	2.17 ± 0.54	2.29 ± 0.67
Males	1.95 ± 0.69	1.96 ± 0.48	2.07 ± 0.80	2.05 ± 0.67
P value	.12	.88	.73	.40

Note. Distance (mm) between the first metacarpal and trapezium at the volar, dorsal, radial, and ulnar edges of the articular space volume, both not normalized and normalized for size.

*Statistically significant, with $P < .05$.

Table 2. Mean Radii of Curvature Normalized for Size.

Mean radius (mm)	Volar-dorsal	Radial-ulnar
First metacarpal		
Females	17.36 ± 6.23	8.95 ± 0.54
Males	15.70 ± 5.71	8.72 ± 0.59
P value	.52	.36
Trapezium		
Females	5.76 ± 0.44	19.24 ± 5.49
Males	6.17 ± 0.91	17.93 ± 4.75
Difference between		
2 curves		
Females	11.60 ± 6.22	10.29 ± 5.48
Males	9.53 ± 5.98	9.21 ± 4.66
P value	.43	.62

Note. Mean radii of curvature (mm) of the first metacarpal, trapezium, and difference between the two along the volar-dorsal and radial-ulnar planes of the saddle-shaped articular surfaces.

of surface geometry differences between young, nonarthritic joints of males and females, yet there are differential wear patterns by sex in the arthritic joint, the questions remains whether size of the joint itself leading to differential loads applied could play an important role in these sex differences. Further dynamic studies on the role of size on changes in articular surface geometry during active joint loading on the first CMC joint would be beneficial for greater understanding of sex differences underlying first CMC joint pathology.

Acknowledgments

We would like to thank Glenn Edwards of Sunnybrook Health Sciences Centre for his help understanding and applying the different capabilities of computer software programs. We would also like to thank Catherine McMillan of Sunnybrook Health Sciences Centre for her assistance in reviewing the article.

Ethical Approval

This study was approved by our institutional review board.

Statement of Animal and Human Rights

All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2008 (5).

Statement of Informed Consent

Informed consent did not need to be obtained and this was approved by Research Ethics Board as there was no identifying information involved with data collection for the study.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

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