Sex differences in scaphotrapeziozapeoid joint morphology: A multi-domain statistical shape modelling approach

Taylor P. Trentadue1,2, Andrew Thoreson1, Cesar Lopez1, Ryan E. Breighner3, Shuai Leng4, Sanjeev Kakar5, Marco Rizzo5, Kristin D. Zhao1,6
1Assistive and Restorative Technology Laboratory, Mayo Clinic, Rochester, MN, 2Medical Scientist Training Program, Mayo Clinic, Rochester, MN, 3Department of Radiology, Hospital for Special Surgery, New York, NY, 4Department of Radiology, Mayo Clinic, Rochester, MN, 5Department of Orthopedic Surgery, Mayo Clinic, Rochester, MN, 6Department of Physical Medicine & Rehabilitation, Mayo Clinic, Rochester, MN

trentadue.taylor@mayo.edu

INTRODUCTION: The scaphotrapeziotrapezoid (STT) joint is involved in load transmission between the wrist and thumb. Despite its functional and clinical importance, with osteoarthritis prevalence associated with advancing age and female sex, the STT joint has received limited diagnostic attention. Photon-counting detector computed tomography (PCD-CT) offers high spatial resolution musculoskeletal imaging, and three-dimensional renderings offer the ability to improve measurement of articual space. Statistical shape modelling (SSM) techniques capture three-dimensional shape variations and differences between groups. The objectives of this study are to characterize sex differences in STT joint morphology using PCD-CT data and multi-domain SSM. We hypothesize that bone and joint articulation sizes are smaller in females than males and that SSM-derived joints capture average morphometrics.

METHODS: Data were collected from the right hands of 30 participants without pathology, trauma, or surgery to the wrists recruited to an IRB-approved study of healthy wrist biomechanics (50% female, 96.7% right hand dominant). The median (25th – 75th percentile) age at the time of imaging was 27.0 (23.0 – 33.0) years. Participants gave written informed consent prior to participation. Static CT data were acquired using a dual-source PCD-CT scanner (NAEOTOM Alpha, Siemens). Data were acquired using 120 kVp, 120 effective mAs, 0.5 second rotation time, and 0.6 helical pitch. Images were reconstructed using a sharp bone kernel (Br72), 120 mm × 120 mm field-of-view in-plane, 512 × 512 matrix, and slice thickness/increment of 0.4/0.2 mm. Data were resampled to isometric voxels with standard dimensions of 0.20 mm using standard trilinear interpolation. Segmentation maps of the carpus were converted to three-dimensional triangular surface meshes in a radius-based anatomical coordinate system. Rigid body parameters of individual bones were calculated. A multi-domain, particle-based entropy SSM was used to capture sex differences in articulation morphology and compare sex-stratified mean data to a morphological average (ShapeWorks Studio v6.3.2, University of Utah). Articular surface areas and interosseous proximity distributions were calculated between mesh vertex pairs on adjacent bones within distance (2.5 mm) and surface-normal angular (30°) thresholds using custom software (MATLAB, MathWorks). Cumulative distribution functions (CDFs) of participant interosseous proximity distributions were interpolated and averaged to quantify mean interosseous proximity distributions by sex. Morphometrics were compared between males and females using Wilcoxon rank-sum tests. Mean CDFs were compared between males and females as well as sex-stratified mean and SSM CDFs with two-sample Kolmogorov-Smirnov tests.

RESULTS: Scaphoid (median: 1857.6 mm3 versus 2572.9 mm3, p<0.001), trapezium (median: 1667.4 mm3 versus 2162.9 mm3, p<0.001), and trapezoid (median: 1304.5 mm3 versus 1637.7 mm3, p=0.002) joints but not the scaphotrapezoid joint (median: 12.5 mm2 versus 19.6 mm2, p=0.246). Scaphotrapezium (median: 1.15 mm versus 1.40 mm, p=0.003), scaphotrapezoid (median: 1.08 mm versus 1.40 mm, p=0.023), and trapezotrapezoid (median: 0.43 mm versus 0.63 mm, p=0.002) joint median interosseous proximity distributions were significantly closer in females than males (Figure 1). Interosseous proximity cumulative distribution functions were shifted towards closer proximities in females relative to males (Figure 2). SSM-predicted mean female and SSM-predicted mean male STT joints estimated the true mean female and mean male metrics well, with errors being within the spatial resolution of the CT scanner (Figure 2). Maximum differences between mean and SSM-derived CDFs were less than 0.20 mm at any percentage threshold along the CDF, which is less than the spatial resolution of the CT scanner (in-plane resolution: 0.20 mm; slice thickness: 0.40 mm).

DISCUSSION: The current study provides insights into the articular morphometrics of the STT joint. The current study found that carpal bones—measured by both surface area and volume—are smaller in females than males (Figure 1). This supports the hypothesis that bone sizes differ by sex. These results align with previous studies reporting carpal bones are smaller in females than males. Articular surface areas are smaller in females than males at the scaphotrapeziotrapezoid joint (median: 25.8 mm2 versus 33.3 mm2, p<0.001) and trapeziozapeoid joint (median: 56.1 mm2 versus 51.8 mm2, p<0.002) but not the scaphotrapezoid joint (median: 12.5 mm2 versus 19.6 mm2, p=0.246). Scaphotrapezium (median: 1.15 mm versus 1.40 mm, p=0.003), scaphotrapezoid (median: 1.08 mm versus 1.40 mm, p=0.023), and trapezotrapezoid (median: 0.43 mm versus 0.63 mm, p=0.002) joint median interosseous proximity distributions were significantly closer in females than males (Figure 1). Interosseous proximity cumulative distribution functions were shifted towards closer proximities in females relative to males (Figure 2). SSM-predicted mean female and SSM-predicted mean male STT joints estimated the true mean female and mean male metrics well, with errors being within the spatial resolution of the CT scanner (Figure 2). Maximum differences between mean and SSM-derived CDFs were less than 0.20 mm at any percentage threshold along the CDF, which is less than the spatial resolution of the CT scanner (in-plane resolution: 0.20 mm; slice thickness: 0.40 mm).

SIGNIFICANCE/CLINICAL RELEVANCE: This study quantifies morphological and articular variations at the STT joint, presenting a range of normative anatomy. The results of estimated interosseous proximities may guide interpretation of imaging-derived STT joint space, and the performance of the SSM demonstrates its utility in capturing the range of normal anatomical variation in the wrist.

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Figure 1. Interosseous proximity distributions of scaphotrapezium (ST) and scaphotrapezoid (SD) articulations, presented on the distal pole of the scaphoid, from multi-domain SSM-derived female and mean STT joints.

Figure 2. Interosseous proximity distribution cumulative distribution functions at the scaphotrapezium (ST) joint for all participants, averaged (25th – 75th percentile) by sex, and from the multi-domain SSM.

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