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

Taylor P. Trentadue[1,2], Andrew Thoreson[1], Cesar Lopez[1], Ryan E. Breighner[3], Shuai Leng[4], Sanjeev Kakar[5], Marco Rizzo[5], Kristin D. Zhao[1,6]
[1]Assistive and Restorative Technology Laboratory, Mayo Clinic, Rochester, MN, [2]Medical Scientist Training Program, Mayo Clinic, Rochester, MN, [3]Department of Radiology, Hospital for Special Surgery, New York, NY, [4]Department of Radiology, Mayo Clinic, Rochester, MN, [5]Department of Orthopedic Surgery, Mayo Clinic, Rochester, MN, [6]Department of Physical Medicine & Rehabilitation, Mayo Clinic, Rochester, MN
trentadue.taylor@mayo.edu

Disclosures: TPT (N/A), AT (N/A), CL (N/A), REB (Stryker Corporation), SL (N/A), SK (Arthrex, Sonex Health), MR (N/A), KDZ (N/A).

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 articular 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 (25^{th} – 75^{th} 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 anatomic 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 mm^3 versus 2572.9 mm^3, $p<0.001$), trapezium (median: 1667.4 mm^3 versus 2162.9 mm^3, $p<0.001$), and trapezoid (median: 1099.3 mm^3 versus 1251.7 mm^3, $p=0.008$) volumes were significantly smaller in females compared to males. Articular surface areas were significantly smaller in females than males at the scaphotrapezium (median: 25.8 mm^2 versus 33.3 mm^2, $p<0.001$) and trapeziotrapezoid (median: 36.1 mm^2 versus 51.8 mm^2, $p=0.002$) joints but not the scaphotrapezoid joint (median: 12.5 mm^2 versus 19.6 mm^2, $p=0.246$). 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 trapeziotrapezoid (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 scaphotrapezium and trapeziotrapezoid joints, and median interosseous proximities are smaller in females than males at each STT articulation (**Figure 2**). The similarities between mean and SSM CDFs by sex establish validity of the model. These findings largely support the hypotheses that articular surface areas and interosseous proximities differ by sex. The closer interosseous proximities, a proxy for reduced joint space, in females has been demonstrated in other joints. The findings should be interpreted in the context of study limitations. The study includes right-handed bones and does not consider bilateral asymmetry. During image acquisition, no specific posturing device was used for the participants' forearms. The study calculated interosseous proximities as a biomarker for articular joint space instead of using cartilage thickness, as the CT images used in this study were not optimized for cartilage visualization.

SIGNIFICANCE/CLINICAL RELEVANCE: This study quantifies morphological and articular variations at the STT joint, presenting a range of normative anatomy. The range 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.

ACKNOWLEDGEMENTS: This work was supported by the U.S. National Institutes of Health (NIAMS: F31 AR082227, R01 AR071338, T32 AR056950; NIGMS: T32 GM065841, T32 GM145408). References available upon request.

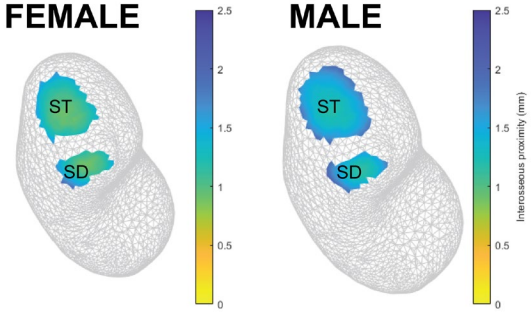
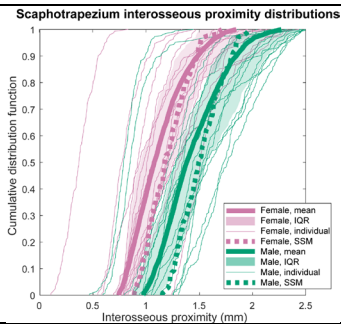


Figure 1. Interosseous proximity distributions of scaphotrapezium (ST) and scaphotrapezoid (SD) articulations, presented on the distal pole of the scaphoid, from multi-domain SSM-derived female and mean STT joints.



Comparison	KS2 statistic (p)
Female vs. male	0.435 (<0.001)
Female mean vs. SSM	0.243 (0.002)
Male mean vs. SSM	0.244 (0.001)

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