Automatic analysis of the scapholunate distance using dynamic CT imaging; normal values in the moving wrist

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INTRODUCTION: The scapholunate interosseous ligament (SLIL) is an important stabilizer in the wrist that is commonly injured. A consequential alteration in wrist kinematics caused by such injuries is an increased scapholunate distance (SLD). Four-Dimensional Computed Tomography (4DCT) holds promise as a dynamic imaging modality for the assessment of these injuries. Current methods often measure the SLD in a 2D plane, thereby not fully capitalizing on the available 3D data. Furthermore, current methods to assess the SLD in 4DCT are either manual or semi-automated, resulting in a time-intensive procedure given that each 4DCT dataset encompasses a range of 100 to 200 CT scans of the moving wrist. As the high number of frames per second can provide valuable information on wrist kinematics, we propose an automated approach for the continuous measurement of the SLD in 4DCT datasets. Considering the absence of established normal values of the SLD from 4DCT measurements, we implemented our methodology on a dataset of healthy wrists.

METHODS: This study was approved by an Ethics Committee. 4DCT scans of healthy wrists from adult subjects (> 18 years old) obtained from both healthy volunteers (unilaterally scanned) and the contralateral, healthy wrist of patients who received a 4DCT scan were included. The imaging protocol included a static CT scan of the forearm and wrist followed by three dynamic imaging sequences involving wrist radial to ulnar deviation (RUD), wrist flexion to extension (FE) and a clenched fist (CF) movement. CT scans were reconstructed at a 10 Hz sampling rate, yielding a total of 140 to 190 dynamic CT scans per wrist. Post-processing included carpal bone segmentation through a previously-developed artificial intelligence algorithm and registration of static bone meshes onto corresponding dynamic positions. Automatic calculation of the SLD was performed using these registered scaphoid and lunate meshes in all dynamic positions. First, the articulating surface of the lunate was automatically determined in a neutral wrist position. Subsequently, the center point of this surface was identified and the SLD was computed as the shortest Euclidean distance from this point to the surface of the scaphoid in each dynamic wrist position. Wrist position was defined as the radiocapitate angle in the sagittal plane (during FE) and coronal plane (during RUD) and SLD data were linearly interpolated based on this angle. Median, maximum and range (maximum-minimum) values of the SLD were calculated per wrist movement (RUD, FE and CF).

RESULTS: Unilateral 4DCT scans of 41 healthy subjects (18 females) aged between 18 to 55 years old were included in this study. Static CT scans revealed no abnormalities. Due to incorrect wrist movements and technical errors, some data were excluded, resulting in a final dataset of 40 wrists for RUD and FE analysis, and 37 wrists for CF analysis. Segmentation, registration, and automatic SLD measurements were performed successfully in the whole dataset. Median SLD measurements during RUD, FE and CF were 0.87 mm [0.66 mm – 1.06 mm], 0.91 mm [0.70 mm – 1.15 mm] and 0.84 mm [0.61 mm – 1.06 mm], respectively (Table 1). As shown in Figure 1, the SLD measurements remained continuously below 2 mm, indicating that healthy wrists exhibit minimal changes in the SLD during wrist movement, as can also be seen by the small range values in Table 1.

DISCUSSION: In this study we have successfully developed a method to compute the SLD automatically from 4DCT datasets. 41 healthy wrists were analyzed, forming a unique database of normal SLD values. Within this cohort, all wrists exhibited an SLD below 2 mm, which is consistent with previous literature indicating that an SLD larger than 3 mm correlates with SLIL injury. In this study, we uncovered novel insights into carpal kinematics, revealing minimal variation in SLD during normal wrist motion, with ranges between 0.2 mm and 0.6 mm for the three wrist movements (Table 1). The proposed automatic method not only provides measurements at similar, and thus comparable, locations between subjects, it also eliminates operator-dependent discrepancies and mitigates the variability between SLD measurement methods. In future studies, it is suggested that the proposed method be applied to wrists with suspected SLIL injury, thereby facilitating an evaluation of its sensitivity and specificity in a clinical context.

SIGNIFICANCE/CLINICAL RELEVANCE: This study is the first to present a fully automated method to analyze 4DCT scans and compute the SLD continuously during wrist motion. Implementation of this method in clinical practice can improve the user-friendliness and interpretation of 4DCT scans and thereby enhance the value of 4DCT for early diagnosis of SLIL injuries in a non-invasive manner.

Table 1. Median, maximum and range values of the scapholunate distance (mm) for all three wrist movements.
Results are presented as median and interquartile range.

SLD metric \ Wrist motion	RUD	FE	CF
Median	0.87 [0.66 – 1.06]	0.91 [0.70 – 1.15]	0.84 [0.61 – 1.06]
Maximum	1.05 [0.90 – 1.23]	1.32 [1.01 – 1.49]	0.96 [0.69 – 1.16]
Range	0.39 [0.28 – 0.52]	0.62 [0.37 – 0.74]	0.23 [0.15 – 0.38]

Figure 1. A) Frontal view of scaphoid (orange) and lunate (yellow) bone meshes showing the articulating surface of the lunate (grey points) and the corresponding automatic SLD measurement (black line). B) Scapholunate distance measurements (mm) during wrist ulnar to radial deviation and C) during wrist extension to flexion.