The Motion Paradox

Motion quantification accuracy in dynamic CT of the wrist joint across multiple CT vendors: a phantom study

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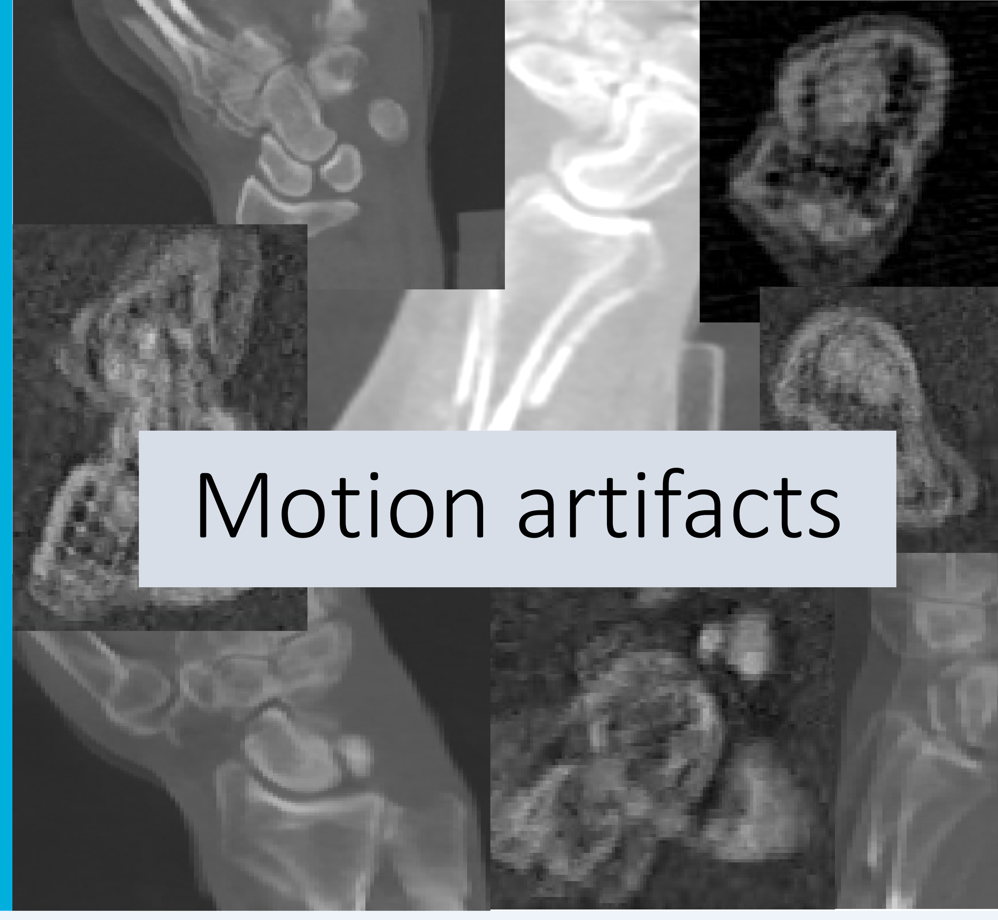
2026 JULY 19–22 VANCOUVER, BC
JOINT AAPM COMP MEETING



Introduction

- 4D CT provides non-invasive assessment of dynamic wrist kinematics for evaluating ligament instability.
- The motion required for 4D CT also introduces motion artifacts that may impair quantitative analysis, with severity dependent on scanner performance and acquisition and reconstruction protocols.
- Characterizing these errors defines measurement uncertainty, allowing true pathological motion to be distinguished from methodological error.

Objective

To evaluate the **motion quantification accuracy** across **acquisition and reconstruction protocols** of **different CT systems** in **4D CT images** of wrist bones.

Methods

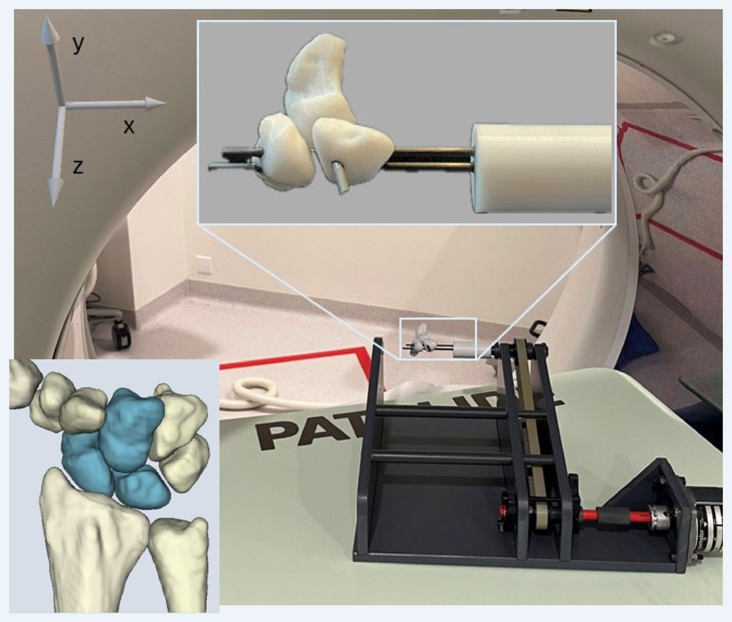


Figure 1. Phantom set-up, bones from left to right; the scaphoid, capitate, and lunate

TABLE 1. Acquisition protocol, showing the manufacturer, CT system, and phantom rotation speeds tested for each single- and dual-source acquisition protocol.

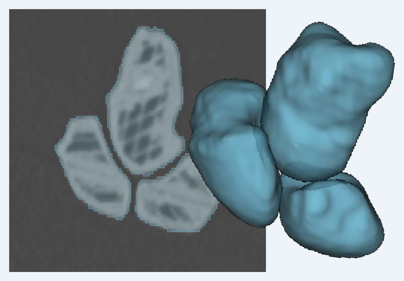
	Single source				Dual source
Acquisition protocols	WACT-P	WACT-V	WACT-R	SSCT	DSCT
Manufacturer	Canon	Canon	GE	Siemens	Siemens
CT system	Aquilion ONE PRISM	Aquilion ONE Vision	Revolution Apex	SOMATOM Force	SOMATOM Force
Phantom rotation speed (rps)	0.050, 0.075, 0.100, 0.125, 0.150, 0.200, 0.300				0.100, 0.200, 0.300, 0.400, 0.500, 0.600

For every acquisition protocol (Table 1) and phantom rotation speed

4D CT acquisition and reconstruction

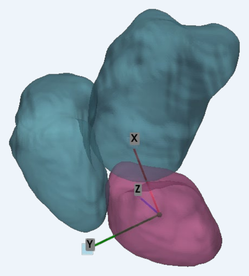
Static 3D CT scans and dynamic 4D CT scans were acquired, each with a 10-second acquisition time. All 4D datasets were reconstructed using both full and, when available, partial reconstructions.

Image analysis



Carpal bones were segmented from static scans and rigidly registered to each 4D CT frame.
Relative scaphoid and capitate motion versus the lunate (reference) was computed per frame as:
$TM_{relative} = TML^{-1} \cdot TM_{Bone}$

Calculate motion quantification error



Motion quantification error was quantified as the difference between static and dynamic frames:

$\Delta t_{total} = \sqrt{\Delta x^2+\Delta y^2+\Delta z^2}$
$\Delta \varphi_{total} = \sqrt{\Delta \varphi x^2+\Delta \varphi y^2+\Delta \varphi z^2}$

Calculate normalized parameter

Rotational motion was normalized across scanners using 360°·f·T, and compared using pooled linear regression.

f = phantom rotation speed (rot/s)
T = temporal resolution (s)

Results

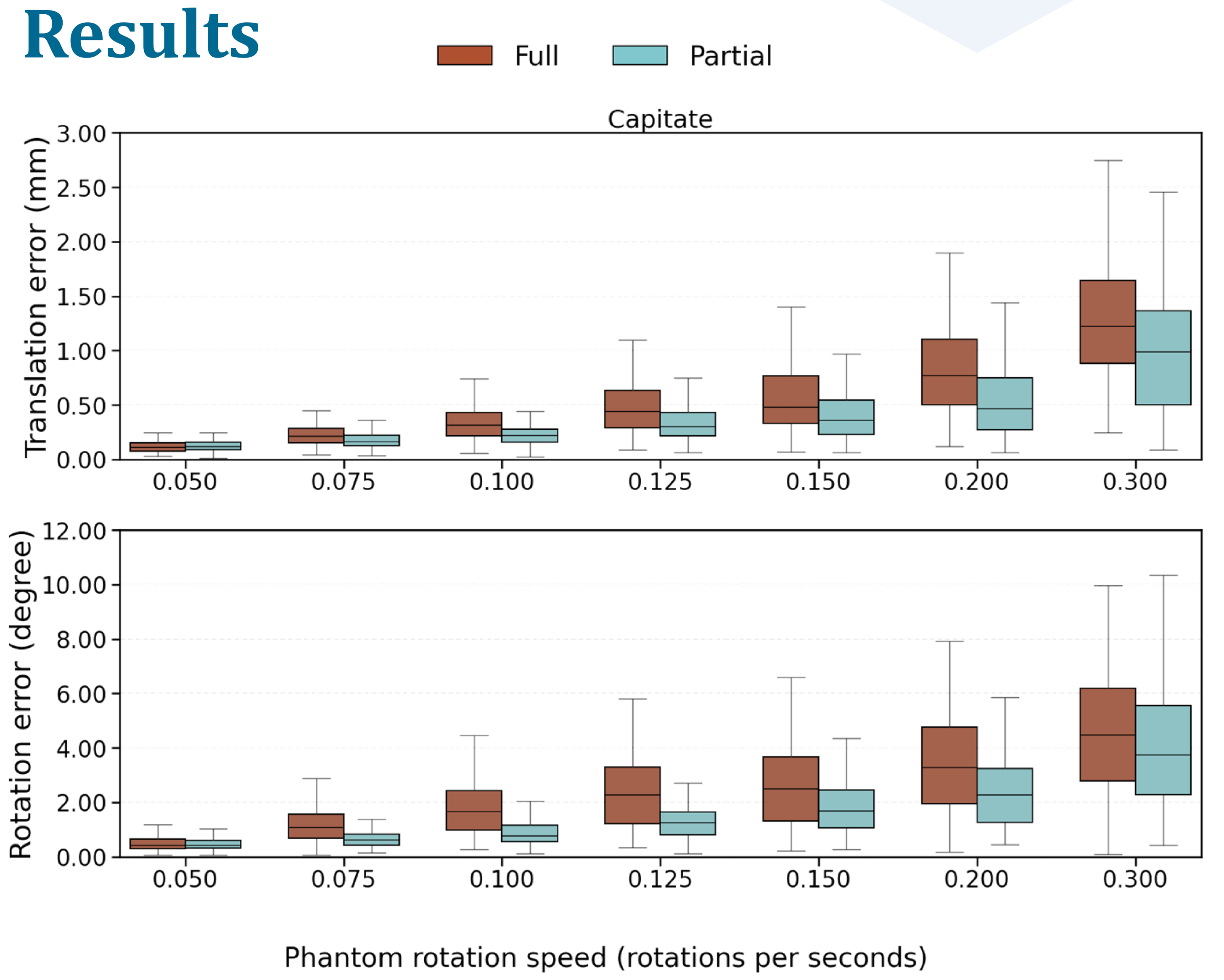


Figure 2. Average errors across single-source scanners. Partial reconstructions show lower translational and rotational errors than full reconstructions, across all rotation speeds.

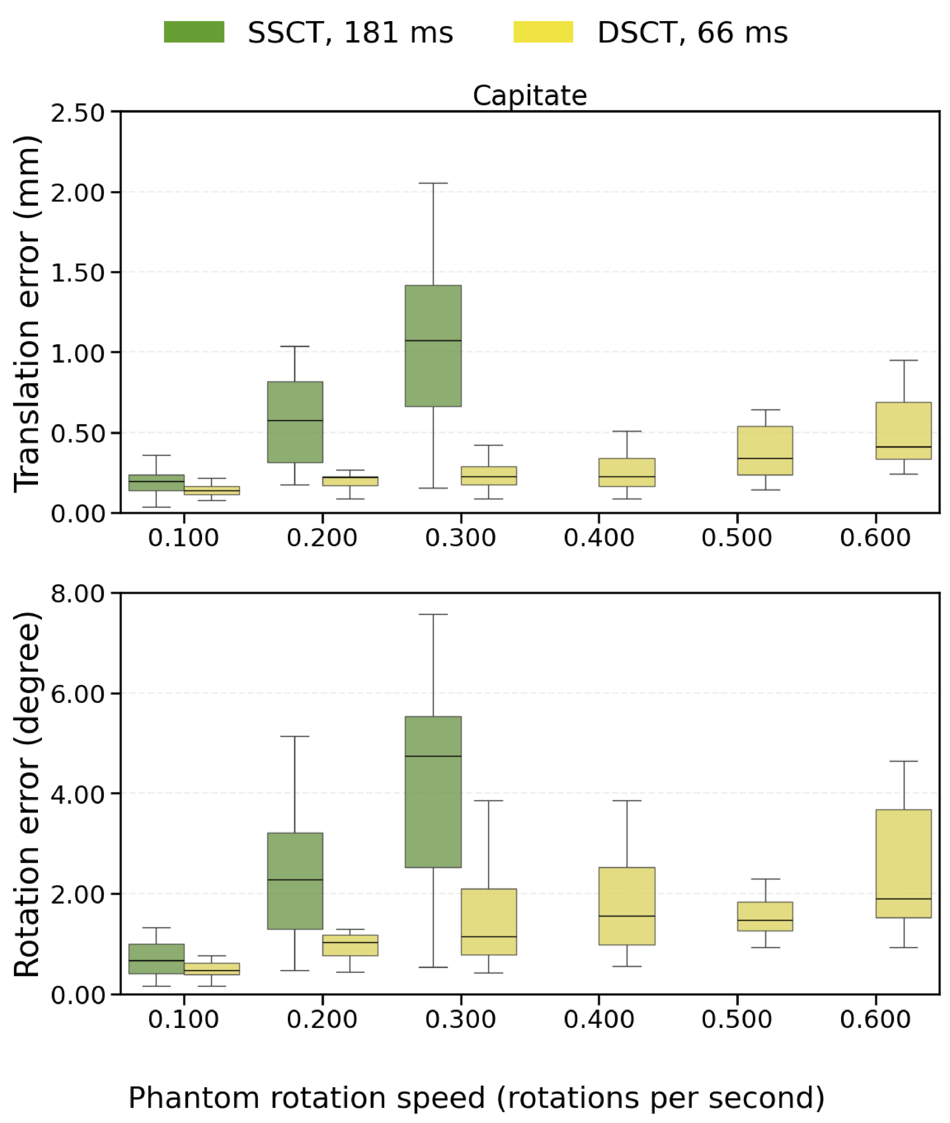


Figure 3. Dual-source (yellow) shows significantly lower errors than single-source partial reconstruction (green) for the Siemens scanner.

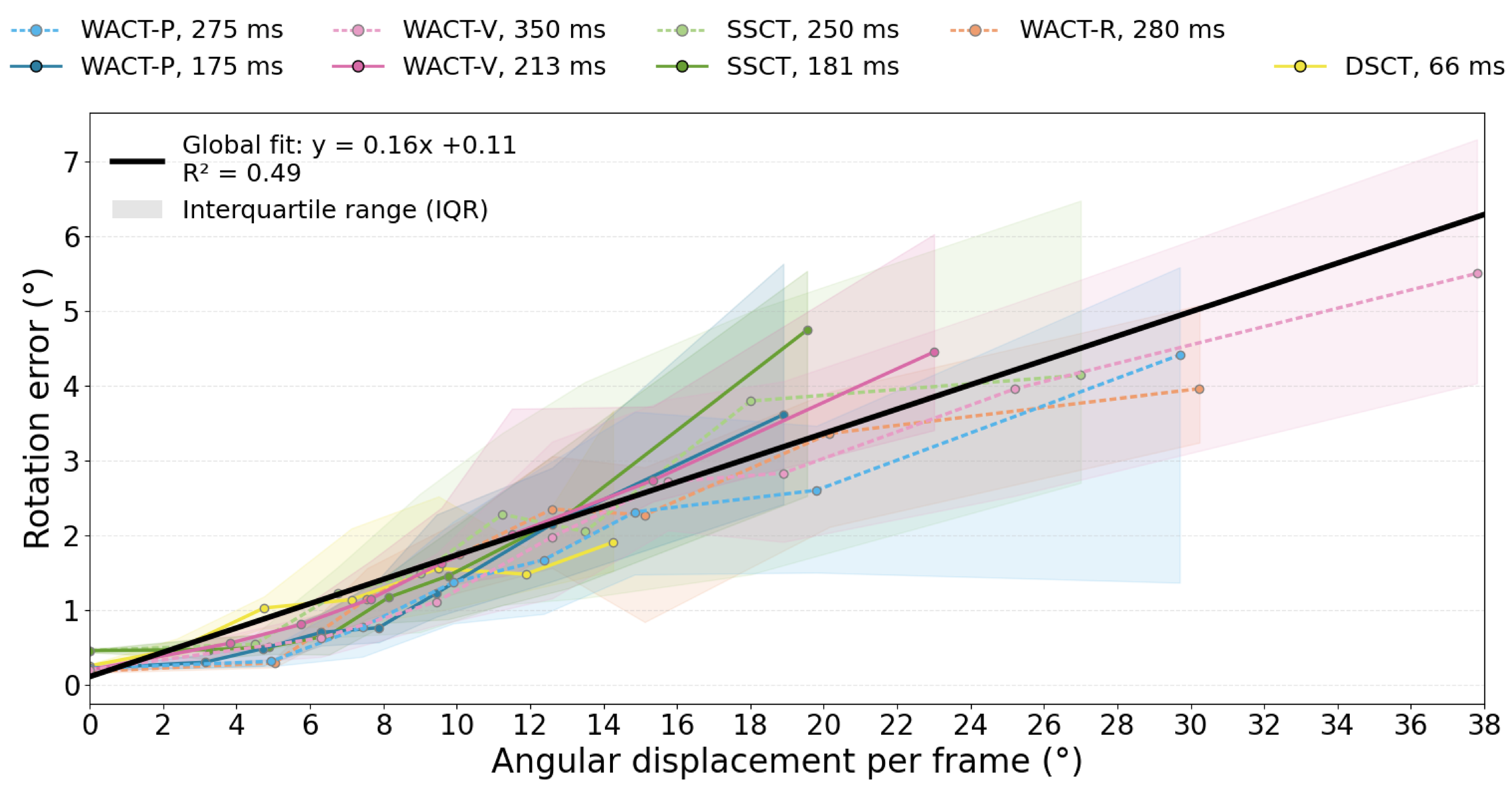


Figure 4. Rotation error shown as function of capitate angular displacement in degrees per reconstructed frame.

Conclusions

- Partial reconstructions consistently showed lower motion-quantification errors than full reconstructions, with dual-source CT achieving the lowest errors overall.
- Motion quantification errors are largely determined by phantom rotation speed and temporal resolution, as captured by the normalized parameter.
- By quantifying motion accuracy, these findings provide a first step toward addressing the motion paradox and distinguishing true kinematics from apparent displacement.

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