

Characterizing Accuracy in 4DCT Deformable Registration Using the POPI Model

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Purpose

Deformable image registration can aid in fully utilizing 4DCT data without significantly increasing workload. In this study, we characterize the accuracy of a commercially available free-form intensity-based DIR algorithm¹ on 4DCT using both successive registration through intermediate phases (SERIAL) and direct registration between the phases of interest (DIRECT).

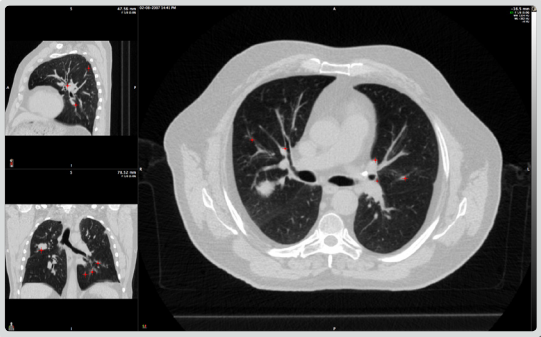
Materials/Methods

Two real-patient 4DCT phantom datasets from the POPI model(2,3) were used to test the SERIAL and DIRECT registration methods (Figure 1). One POPI model (patient1) displayed typical respiratory motion, 6.3mm +/- 3.0mm while the other (patient2) displayed significant respiratory motion, 14.0mm +/- 7.2mm, between end-expiration and end-inspiration (Figure 2). The phantoms were also used to study the relationship between initial rigid registration error and residual registration error after deformation. Distances were measured between corresponding points in the 0% and 50% phase images after rigid and deformable registration. The residual registration error was measured as the distance between corresponding points after deformation.

Results

For patient1, the residual errors after DIRECT and SERIAL deformation were 0.8mm +/- 0.4mm and 1.8mm +/- 1.4mm, respectively. For patient2, the errors after DIRECT and SERIAL were 5.1mm +/- 7.5mm and 1.6mm +/- 1.6mm, respectively. The correlation between initial and residual error was significant for both DIRECT ($r = 0.72$: linear, $r = 0.80$: second order polynomial) and SERIAL ($r = 0.32$: linear) (Figure 3). The mean residual errors for points of interest with <5mm, 5-10mm, 10-15mm, 15-20mm, 20-25mm, and 25+mm initial error (Table 1) were 0.9mm, 0.9mm, 1.4mm, 4.7mm, 9.7mm, and 20.2mm after DIRECT and 1.3mm, 1.4mm, 2.1mm, 2.3mm, 1.9mm, and 3.1mm after SERIAL, respectively.

Figure 1
POPI with Landmark Points



POPI Model with manually identified points of interest on the 0% phase image. Corresponding points were also manually identified on the 50% image.

Table 1

Average residual error measured after DIRECT and SERIAL deformation. Initial displacement is the distance measured from corresponding points after rigid registration.

Displacement*	DIRECT Residual Error*	SERIAL Residual Error*
<5	0.9	1.3
5-10	0.9	1.4
10-15	1.4	2.1
15-20	4.7	2.3
20-25	9.7	1.9
25+	20.2	3.1

*All values in mm

Figure 2a

Patient 1 displaying typical respiratory motion between 0% and 50% phase

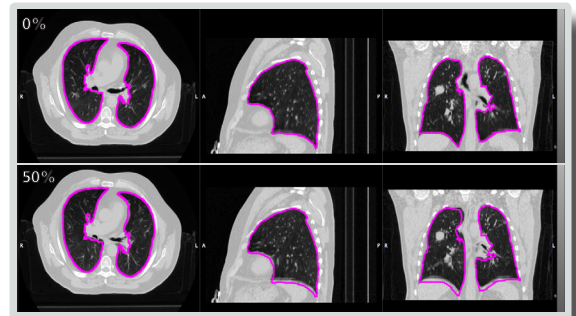


Figure 2b

Patient 2 displaying significant respiratory motion between 0% and 50% phase

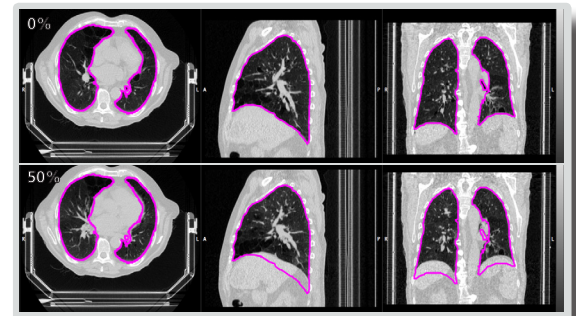
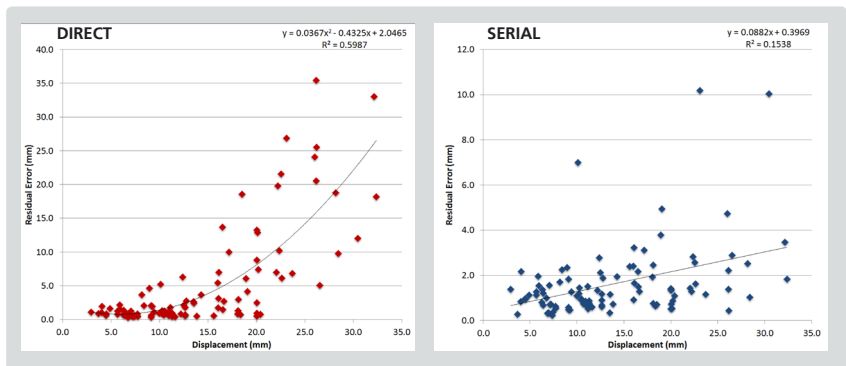


Figure 3

Correlation Between Initial Displacement and Residual Error for Both DIRECT and SERIAL Methods



Conclusions

DIRECT was more accurate for typical respiratory motion while SERIAL was more accurate when significant respiratory motion was present. There was flat correlation between residual and initial error for SERIAL as compared to a very steep correlation for DIRECT. Results show that the DIRECT approach delivers excellent results when the movement is limited to 15mm but when the movement increases, the SERIAL approach is favorable.

References

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- <http://www.creatis.insa-lyon.fr/rio/popi-model/>
- Vandemeulebroucke J, Rit S, Kybic J, et al. Spatiotemporal Motion Estimation for Respiratory-correlated Imaging of the Lungs. Med Phys 2011; 38(1):166-178.