Torsional Heart Motion in Cone-beam Computed Tomography Reconstruction

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Introduction

Helical orientation of left ventricular (LV) myocardial fibers

- During systole: Not only radial contraction but also **twist** [1]

LV twist invisible in X-ray imaging, but

- Coronary arteries are attached to the myocardium and therefore follow LV rotation

Phase-resolved coronary artery reconstruction

- Interventional acquisitions: low temporal resolution
- Rotational motion may introduce **limited angle problems**

Materials and Methods

Extend XCAT heart [2] with rotation around LV long axis (Fig. 1):

- Twist angle $\Phi_i$of XCAT control point $\mathbf{c}^{(i)}$ at phase h_r

$$\Phi_i(h_r) = \frac{\mathbf{b}_z - \mathbf{c}_z^{(i)}}{\mathbf{b}_z - \mathbf{a}_z}\Phi_\mathbf{b}(h_r) - \frac{\mathbf{c}_z^{(i)} - \mathbf{a}_z}{\mathbf{b}_z - \mathbf{a}_z}\Phi_\mathbf{a}(h_r)$$

- $\Phi_\mathbf{a} = -2 \cdot \Phi_\mathbf{b}$: different sign and magnitude at apex and base
- $\Phi_\mathbf{b}(h_r) = \Phi_\mathbf{b}^{\max} \cdot (|2h_r - 1| - 1)$, and $\Phi^{\text{tot}} = \Phi_\mathbf{b}^{\max} - \Phi_\mathbf{a}^{\max}$ [3]

ECG-gated interventional FDK-type reconstruction at h_r [4]

- Streak reduction: omit the smallest and largest contributions
- Distance weights $\omega_i(\mathbf{x})$, gating function $\lambda_i(h_r)$ [4]

$$f_{h_r}(\mathbf{x}) = \sum_{i=1}^{N-2N_{\text{ign}}} \lambda_i(h_r) \cdot \omega_i(\mathbf{x}) \cdot p_i\left(A_i(\mathbf{x})\right)$$

Dense motion field compensated reconstruction

- Parzen-window interpolation on dense grids of sparse ground-truth displacement vector fields yields $T_{i,h_r}^{(3D)}(\mathbf{x})$ [5]

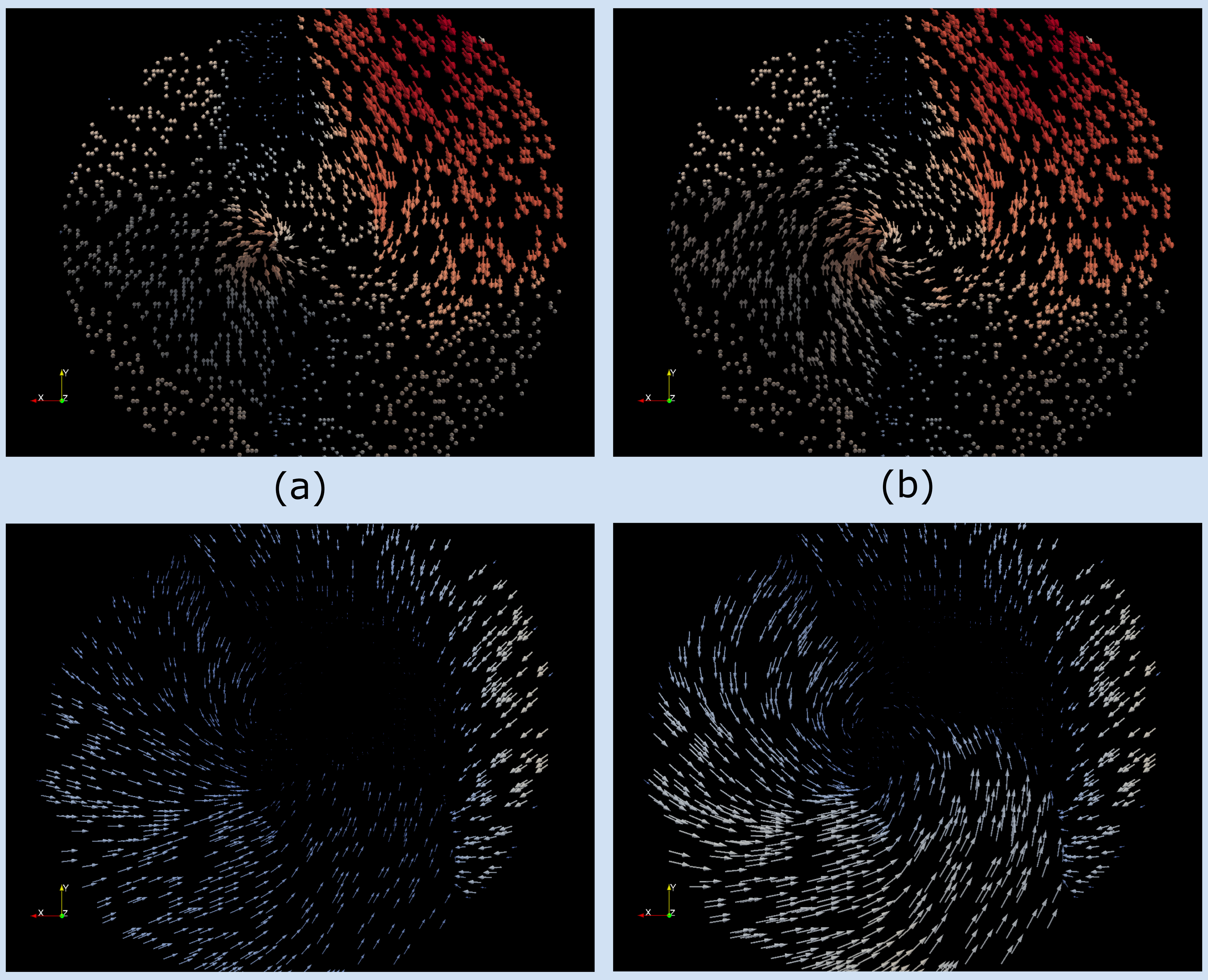
$$f_{h_r}(\mathbf{x}) = \sum_{i=1}^{N} \omega_i(\mathbf{x}') \cdot p_i\left(A_i(\mathbf{x}')\right), \qquad \mathbf{x}' = T_{i,h_r}^{(3D)}(\mathbf{x})$$

Experimental Setup (in CONRAD [6])

- 133 projections over 200° at 80kV (noise free)
- Detector: 620*480 pixels with 0.616mm isotropic spacing
- Reconstruction: 256³ voxels with 1mm isotropic spacing
- Five twist angles: $\Phi^{\text{tot}} \in \{0°, 9°, 15°, 21°, 30°\}$

Evaluation at systole and diastole

- Vasulature: Area under Precision-Recall-Curves (AUPRC) [7]
- Overall: Cross-correlation (r) with ground-truth in ROI



(a) (b) (c) (d)

Figure 1: Basal **(a,b)** and apical **(c,d)** short-axis cross sections of the heart motion field with 0° and 30° twist angle on the left and right hand side, respectively. The strong motion in the upper right corner of the apical slices originates from right ventricular dynamics.

ECG-gated:	Φ^{tot} in °	0	9	15	21	30
AUPRC	$h_r = 0.5$	0.201	0.201	0.203	0.190	0.195
	$h_r = 0.8$	0.296	0.317	0.314	0.310	0.309
Pearson r	$h_r = 0.5$	0.639	0.631	0.631	0.631	0.631
	$h_r = 0.8$	0.525	0.518	0.520	0.520	0.523

Table 1: AUPRC and Pearson correlation coefficient for the ECG-gated reconstruction method at systole (*h_r=0.5*) and diastole (*h_r=0.8*) for twist angles from 0° to 30°.

Motion field:	Φ^{tot} in °	0	9	15	21	30
AUPRC	$h_r = 0.5$	0.189	0.202	0.194	0.190	0.176
	$h_r = 0.8$	0.185	0.204	0.199	0.196	0.194
Pearson r	$h_r = 0.5$	0.922	0.920	0.920	0.921	0.921
	$h_r = 0.8$	0.950	0.951	0.952	0.952	0.952

Table 2: AUPRC and Pearson correlation coefficient obtained with the dense motion field compensated reconstruction at a fast and quiet heart phase (*h_r=0.5 and 0.8*) at five twist angles.

Results and Discussion

AUPRC largely constant at all twist angles (cf. Tab. 1 and 2)

- Slight deteriorations at $\Phi^{\text{tot}}(h_r = 0.5) > 21°$
- Structures with $\Phi^{\text{tot}} = 24.98°$: stationary during contraction
- But: Deteriorations also at $\Phi^{\text{tot}}(h_r = 0.8) = 0$
- Effects other than cardiac twist?
- Streak reduction: Higher AUPRC for ECG-gated reconstruction

Correlation: substantially higher for motion field compensation

- ECG-gated reconstruction only used subset (56 and 57 of 133 projections at systole and diastole, respectively)
- Myocardium and cardiac chambers dominate the image, but are only marginally affected by cardiac twist

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Conclusions

- Vasculature reconstruction: Slight quality decrease at larger twist angles as per-projection twist motion approaches average angular increment.
- Overall reconstruction quality (Pearson r) remained mostly constant.
- Twist angles of $21.1° \pm 15.2°$ were observed in pathologic cases [7]
- Limited angle problems may occur, but should not drastically affect the acquisition.

References

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