Automated Extraction of False Lumen Flow Dynamics in Aortic Dissection Using 4D Flow MRI Correlates with False Lumen Ejection Fraction

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Background: Aortic dissection involves a tear in the aortic wall and is life-threatening [1]. Accurate risk stratification is critical, but currently relies on simple anatomical metrics (e.g., descending aortic diameter [2]), which fail to capture the complex pathophysiology. 4D Flow MRI enables in-vivo measurements of 3D blood flow dynamics and provides hemodynamic biomarkers, such as wall shear stress and flow energetics, that may improve risk stratification in aortic dissection [3]. However, adoption is hindered by manual analysis and uncertainty about relevant flow metrics. We present a method for the automated extraction of hemodynamic biomarkers in complex dissection anatomy.

Methods: We analyzed 12 patients with type B thoracic aortic dissection (with and without adverse outcomes: surgery or death, Table 1). We adapted the voxel-wise reverse-flow framework of Weiss et al. [4] to dissection. The aorta was segmented manually into false-lumen (FL) and true-lumen (TL) masks; Centerlines were automated for each. Along the FL centerline, cross-sectional planes were generated at 1-mm spacing. At each plane, a unit in-plane orthogonal direction that points from FL toward TL was used to project voxel-wise 4-D flow velocities onto this direction to obtain orthogonal flow over the cardiac cycle. For each FL voxel, we formed an orthogonal-flow time curve and derived peak positive flow (PPF, max over time), peak negative flow (PNF, min over time), and Peak Fraction = PNF/PPF. FL ejection fraction (FLEF) was obtained independently. PPF and PNF volumes were collapsed to 2-D maps (PPF: z-wise max intensity projection; PNF: z-wise min intensity projection). Per-patient "hotspot" metrics were defined as the 99.5^{th} percentile of each map. Group differences were assessed using two-sample t-tests; associations of our metrics with FLEF used Spearman correlation.

Results: In Figure 1A (high FLEF, adverse outcome), we see concentrated positive and negative orthogonal "hotspots" in the FL, whereas in Figure 1B (low FLEF, no adverse outcome), they were of lower magnitude. Across the cohort (Figure 2A), FLEF correlated with PNF (Spearman $\rho = -0.59$, $p = 0.045$), whereas correlations with PPF ($\rho = 0.37$, $p = 0.230$) and Peak Fraction ($\rho = 0.42$, $p = 0.177$) were not significant. Group comparisons (Figure 2B) showed no significant differences for PPF ($p = 0.343$), PNF ($p = 0.219$), or Peak Fraction ($p = 0.430$); FLEF was higher in the adverse group with a trend toward significance ($p = 0.059$).

Conclusion: An anatomically driven orthogonal FL to TL flow metric derived from 4D Flow MRI is feasible in aortic dissection and captures exchange between lumina. In this pilot cohort, FLEF correlated significantly with peak negative orthogonal flow. While other metrics were not significant, the method is automatable (aside from FL/TL segmentations) and merits validation in larger longitudinal studies.

Table 1: Cohort demographic summary statistics for patients included in this study, with cross-cohort t-test comparison (Fisher's exact test for sex and diagnosis) p-value shown for each parameter.

Subjects	Adverse Outcome (n=6)	No Adverse Outcome (n=6)	p-value
Age (mean ± SD, yrs.)	55.7 ± 4.6	58.8 ± 17.3	0.678
Height (mean ± SD, in.)	71.7 ± 5.4	66.5 ± 3.6	0.081
Weight (mean ± SD, lbs.)	201.8 ± 67.6	182.5 ± 44.1	0.570
BMI (mean ± SD, kg/m²)	27.0 ± 4.5	29.2 ± 7.8	0.572
Sex	4M/2F	2M/4F	0.567
Diagnosis	4 De Novo Type B, 2 Repaired Type A	1 De Novo Type B, 5 Repaired Type A	0.242

Figure 1: Example patients illustrating Peak Orthogonal Flow maps. A: Patient with high FLEF and an adverse outcome. Top: Peak positive orthogonal flow over a time-average magnitude background (middle slice); warmer colors indicate higher FL to TL flow. Middle: Peak negative orthogonal flow; darker colors indicate higher TL to FL flow. Colored area = FL; Solid gray outline = TL. The value at the top of each map reports the hotspot metric. Bottom: Bulk orthogonal flow-time curves across all FL voxels (mean, black; mean +/- SD, red/blue; 99.5^{th}/0.5^{th} percentile, green/magenta). Units: ml/frame; positive = FL to TL, negative = TL to FL. B: Patient with low FLEF and no adverse outcome.

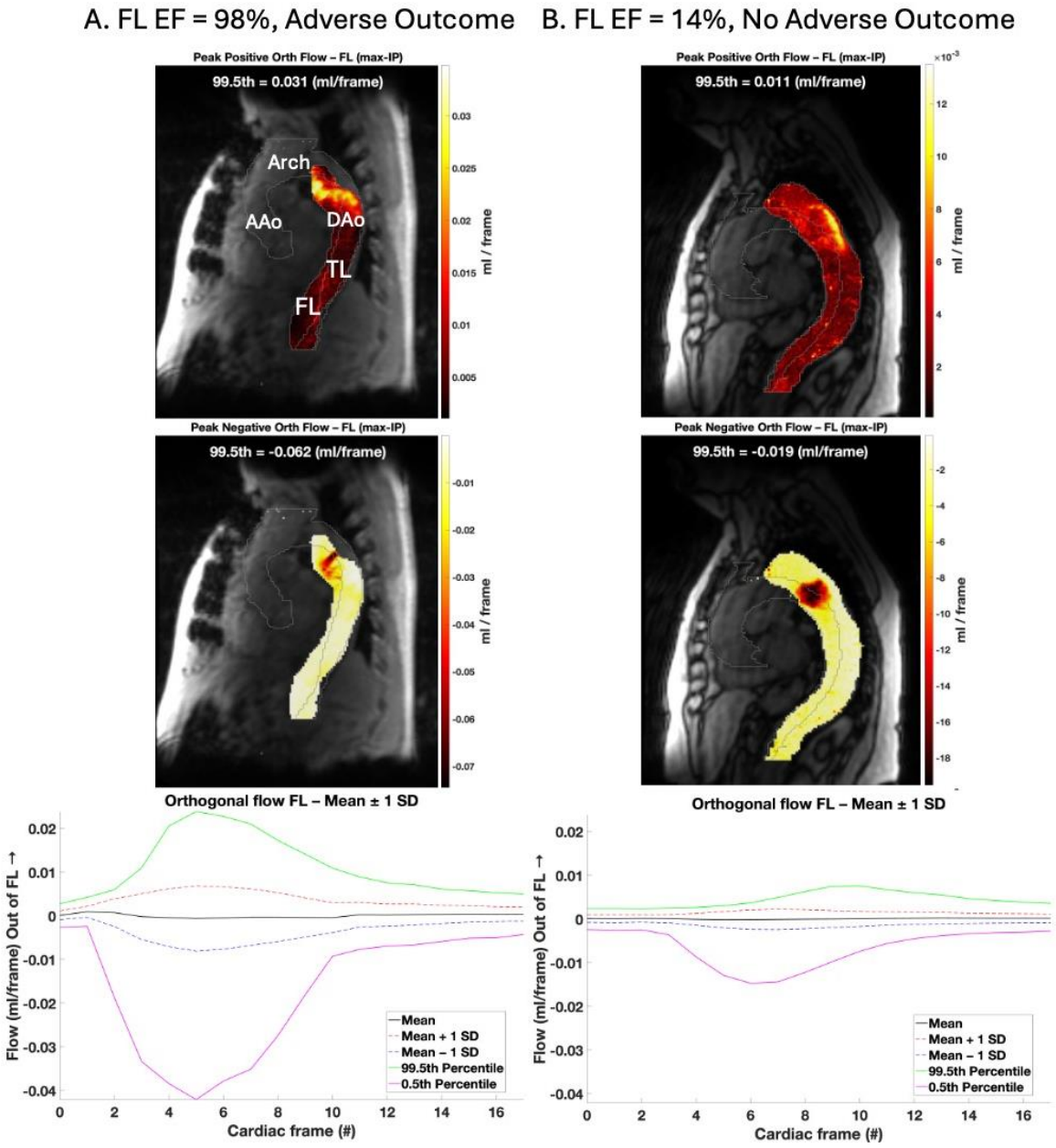
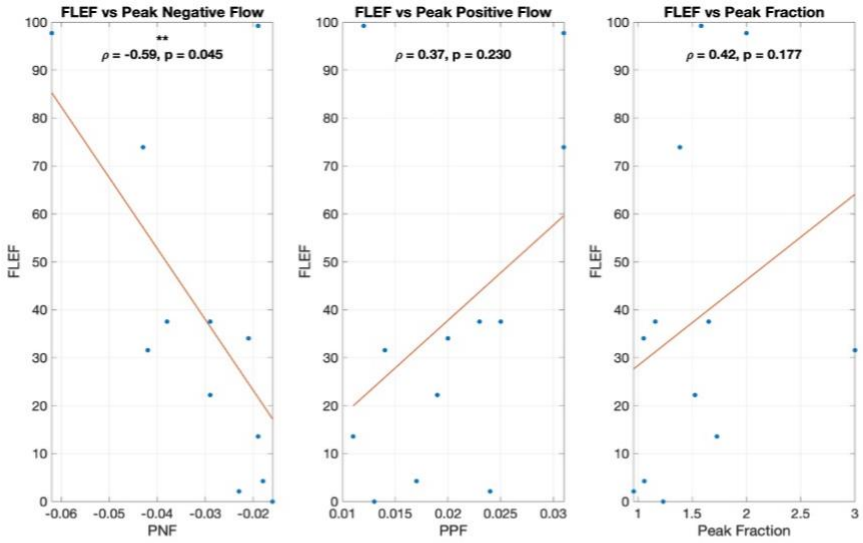
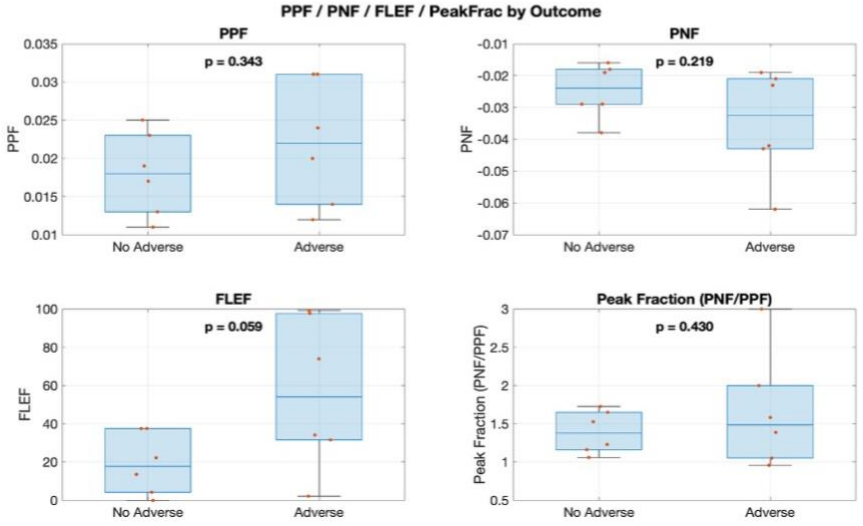


Figure 2: Relationships of orthogonal-flow metrics with FLEF and clinical outcome. Top (left–middle–right): patient-level scatter plots of FLEF vs PNF, FLEF vs PPF, and FLEF vs Peak Fraction (PNF/PPF). Solid line = least-squares fit; annotations report Spearman ρ and p. Bottom (four panels): group comparisons (adverse vs no adverse) for PPF, PNF, FLEF, and Peak Fraction using two-sample t-tests (p shown on each panel). Boxes show median and IQR; whiskers indicate range; points are individual patients. Units: PPF/PNF in ml/frame (positive = FL to TL, negative = TL to FL); FLEF = %.

A.


FLEF vs Peak Negative Flow
**
ρ = -0.59, p = 0.045
FLEF
PNF
FLEF vs Peak Positive Flow
ρ = 0.37, p = 0.230
FLEF
PPF
FLEF vs Peak Fraction
ρ = 0.42, p = 0.177
FLEF
Peak Fraction

B.


PPF / PNF / FLEF / PeakFrac by Outcome
PPF
p = 0.343
PPF
No Adverse
Adverse
PNF
p = 0.219
PNF
No Adverse
Adverse
FLEF
p = 0.059
FLEF
No Adverse
Adverse
Peak Fraction (PNF/PPF)
p = 0.430
Peak Fraction (PNF/PPF)
No Adverse
Adverse