Regional Analysis: Automated Extraction of False Lumen Flow Dynamics in Aortic Dissection Using 4D Flow MRI

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Impact:

In aortic dissection, automated regional peak orthogonal flow mapping localizes false lumen exchange hotspots, complements diameter criteria, and reveals etiology-linked patterns. If validated longitudinally, POF could guide surveillance and enable MRI-based hemodynamic risk scores that integrate with clinical decision pathways.

Synopsis:

• **Motivation:** Risk stratification in dissection needs automated hemodynamic markers beyond simple anatomic markers (aortic diameter).

• **Goal(s):** Localize and quantify regional peak orthogonal flow hotspots; test associations with false lumen ejection fraction and outcomes; compare distributions by etiology.

• **Approach:** 4D Flow-MRI in 24 patients; TL/FL masks, centerlines, 1-mm planes; voxel-wise FL to TL projection; POF; regional 99.5th-percentile hotspots; use most active region for comparisons.

• **Results:** Hotspots localized; POF correlated with FLEF (p=0.033). De novo type B dominated the top values; repaired type A had the lowest. POF and diameters separated outcomes; the other 4D Flow metrics did not.

Abstract:

Introduction:

Aortic dissection is a life-threatening condition involving a tear in the wall of the aorta[1], resulting in 2 spaces where blood can flow: a true lumen (TL) and a false lumen (FL). Dissection patients are managed medically (blood pressure medication) or referred to surgery, but risk stratification still leans heavily on simple anatomic metrics (e.g., descending aortic diameter[2]), which poorly capture the complex, dynamic FL hemodynamics that drive pressurization, remodeling, and adverse events. 4D Flow MRI

allows in-vivo quantification of complex three-dimensional blood flow patterns, offering hemodynamic biomarkers such as wall shear stress and flow energetics that could enhance risk stratification in aortic dissection[3]. However, clinical adoption remains limited by labor-intensive post-processing and uncertainty regarding which flow metrics are most prognostically relevant. Prior work from our group introduced an automated 4D Flow pipeline that projects voxel-wise velocities along an FL to TL orthogonal direction to quantify “peak orthogonal flow” (POF) and showed a significant association between FL ejection fraction (FLEF) and POF[4]. Building on this and motivated by evidence that retrograde diastolic flow through the dominant entry tear (FLEF) reflects FL pressurization and predicts aortic growth rate in TBAD[5], we ask whether regionalizing orthogonal flow “hotspots” can better localize and quantify clinically relevant exchange between lumina.

Methods:

We analyzed 24 patients with type B thoracic aortic dissection (both repaired type A and de novo type B, with and without adverse outcomes: surgery or death, Table 1). We extended our orthogonal-flow pipeline to a regional analysis of the FL (Figure 1). Briefly, TL/FL masks were defined; the whole aorta (TL plus FL) was then partitioned into anatomically defined regions (arch, proximal descending, mid descending, and distal descending aorta) via standardized planes. Automated TL and FL centerlines and 1-mm–spaced cross-sectional planes were generated. At each plane, velocities were projected onto the in-plane unit vector pointing from FL to TL to form orthogonal flow-time curves per voxel (negative values represent from TL to FL). From each voxel’s curve, we computed POF, defined as the absolute value of the minimum of the orthogonal flow curve (to get the magnitude of flow in the TL to FL direction). The resulting 3D POF volumes were summarized with slice-wise maximum intensity projection (MIP) maps. For each region containing FL, we computed a regional hotspot metric as the 99.5th percentile of the POF MIP. For the primary analysis, each patient’s most active region (the region with the highest hotspot) was selected; additionally, we compared regional distributions of POF across the predefined segments to evaluate spatial variability in orthogonal flow along the dissected aorta. Between-group differences (adverse outcome vs no adverse outcome) were tested with Welch’s t-test, and associations between POF (most active region) and clinical/hemodynamic variables were evaluated with Spearman correlation. Besides POF and FLEF, we also looked at max aortic diameter, max FL diameter, aortic growth rate, entry tear size, tortuosity index (TI) of the FL, and bending length (BL) of the FL.

Results:

Regional POF hotspot maps localized high-magnitude orthogonal exchange to discrete FL segments (Fig. 2). We observed a regional distribution bias in arch involvement: FL was present in the arch in 10/12 repaired type A vs 6/12 de novo type B. The arch and proximal descending aorta tended to have high orthogonal flows, with the mid and distal descending aorta showing lower orthogonal flows. In the correlation analysis (Fig. 3, top row), the most active region's POF was significantly correlated with FLEF ($p=0.033$). Notably, the two largest scatterplot outliers were both de novo type B. The most active region's POF was not significantly correlated with clinical metrics (Fig. 3, bottom row) or tortuosity of the FL (TI or BL, not shown). When evaluating outcomes (Fig. 4, top row), the only 4D Flow-derived metric that showed a difference between groups with adverse and no adverse events was POF (of the most active region). As expected, the max diameter of the aorta and FL also showed a difference in outcomes (as that is what current guidelines for surgery are based on). In an ROC analysis of adverse vs. no adverse events (not shown), the only metrics with an AUC 95% CI excluding 0.5 were POF (AUC=0.746 [0.521-0.936]), max aorta diameter (AUC=0.832 [0.646-0.968]), and max FL diameter (AUC=0.814 [0.620-0.964]).

Discussion:

Regionalizing peak orthogonal flow (POF) in aortic dissection concentrates the hemodynamic exchange of blood flow between lumens to anatomically meaningful segments and reduces dilution from quiet FL stretches. This improves the physiologic interpretability over global summaries over the entire FL. The observed association between POF (in the most active region) and FLEF aligns with the mechanism that FL pressurization is driven by luminal exchange near tears/fenestrations. Cohort patterns further suggest etiology-specific distributions: very high POF values clustered in de novo type B, whereas repaired type A more often had FL extending into the arch, which should be accounted for in comparative analyses. Outcome comparisons indicate that the regional POF captured group differences where metrics derived from 4D Flow imaging did not, while anatomic diameters remained discriminative as expected, together supporting a complementary role for POF alongside established anatomic markers. Limitations include modest sample size, potential confounding by etiology (only 3/10 with adverse events were repaired type A). Prospective, longitudinal studies should test whether regional POF dynamics predict growth or post-TEVAR remodeling and whether combining POF with anatomy yields a practical 4D Flow MRI-based risk score for surveillance and treatment planning.

Conclusion:

Automated regional analysis of POF is feasible and isolates clinically meaningful TL to FL exchange “hotspots.” POF in the most active region correlates with FLEF and shows etiology-specific patterns (e.g., higher extremes in de novo type B and more frequent arch involvement in repaired type A), suggesting added mechanistic insight beyond global summaries. In this cohort, POF differentiated outcomes where other 4D Flow metrics did not, complementing anatomic diameters and supporting a role for combined hemodynamic–anatomic risk stratification.

Table 1. Cohort Demographics**.**

[To be added]

Figure 1. Methods pipeline.

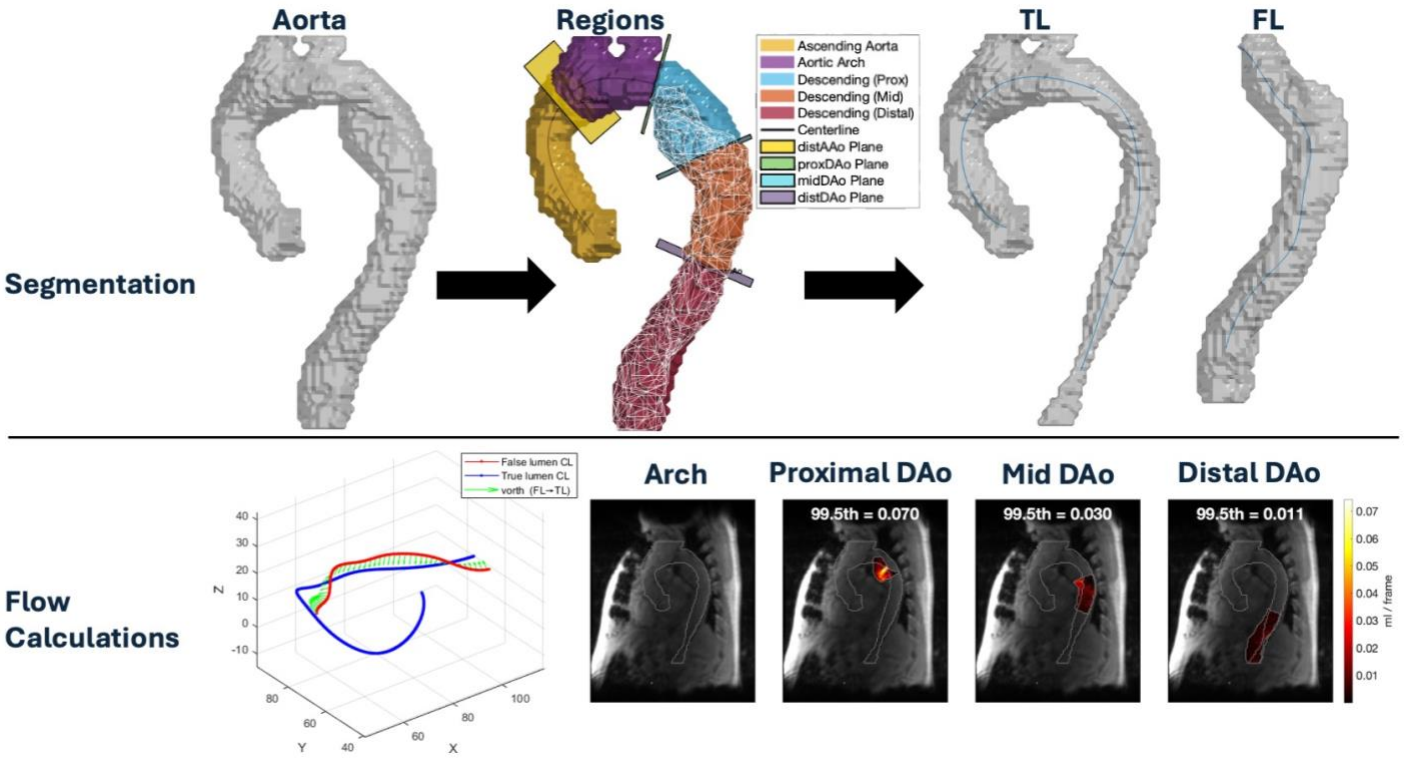


Figure 2. 99.5th percentile of Peak Orthogonal Flow of each regional MIP across the entire cohort.

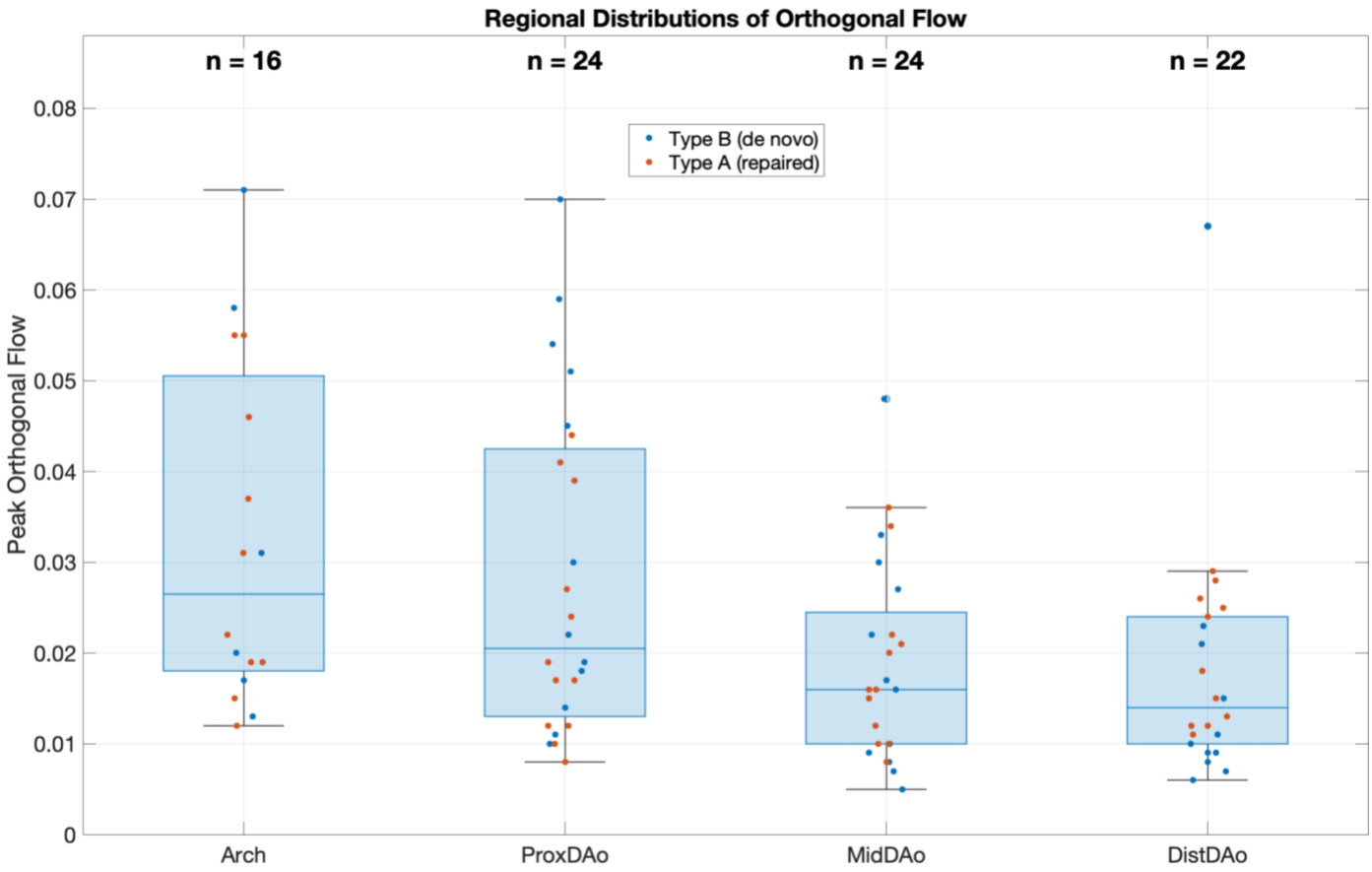
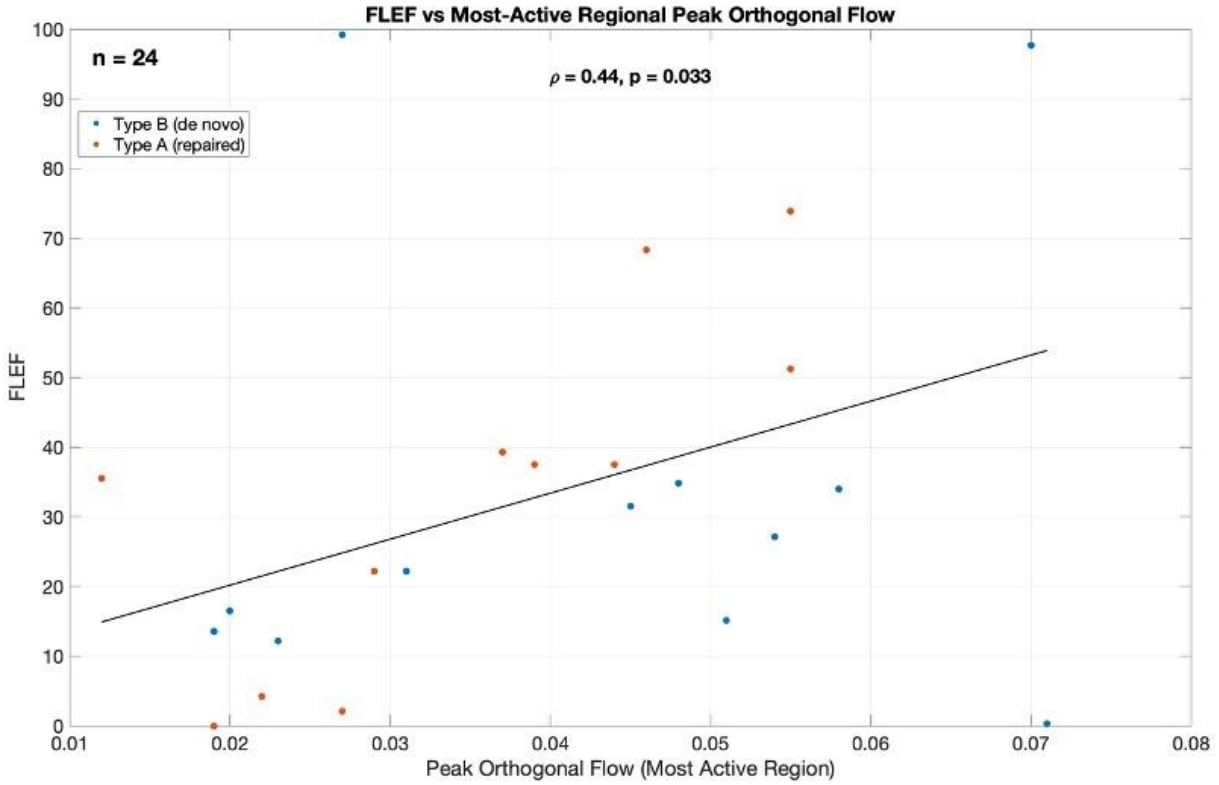


Figure 3. Correlations of Peak Orthogonal Flow with other metrics.



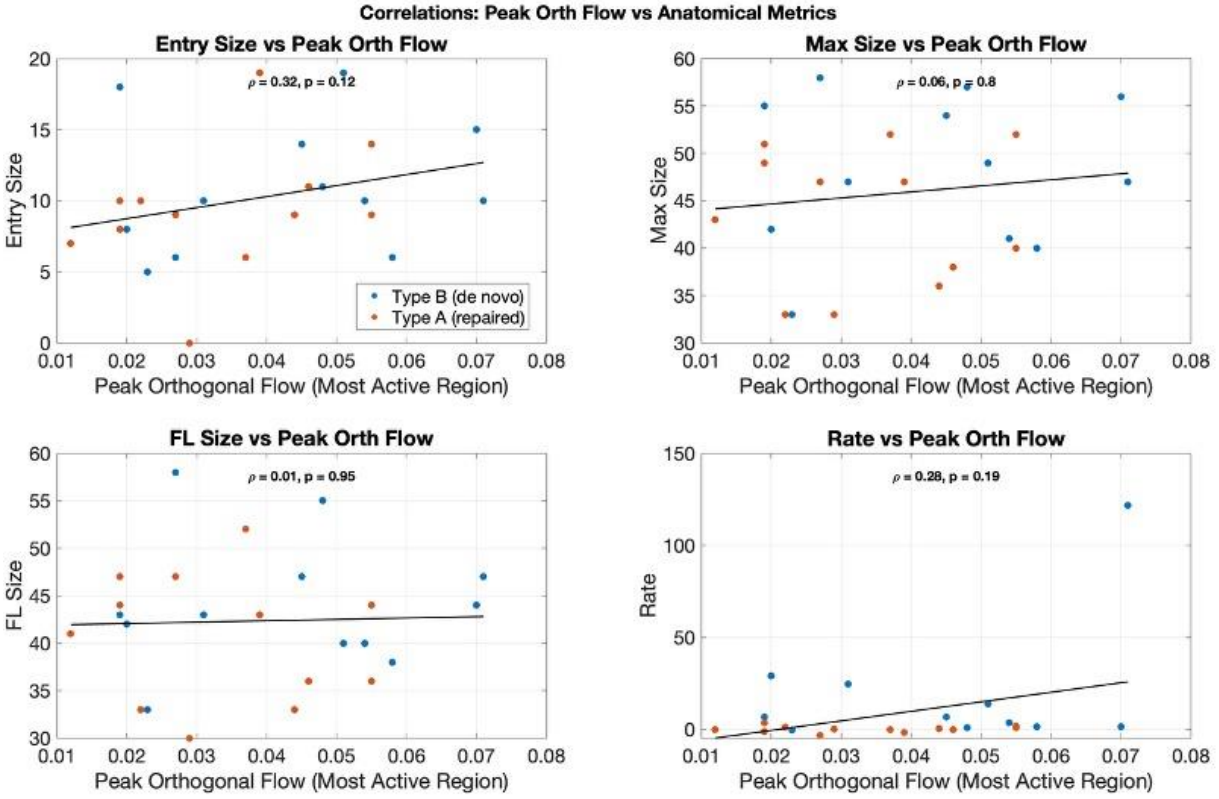
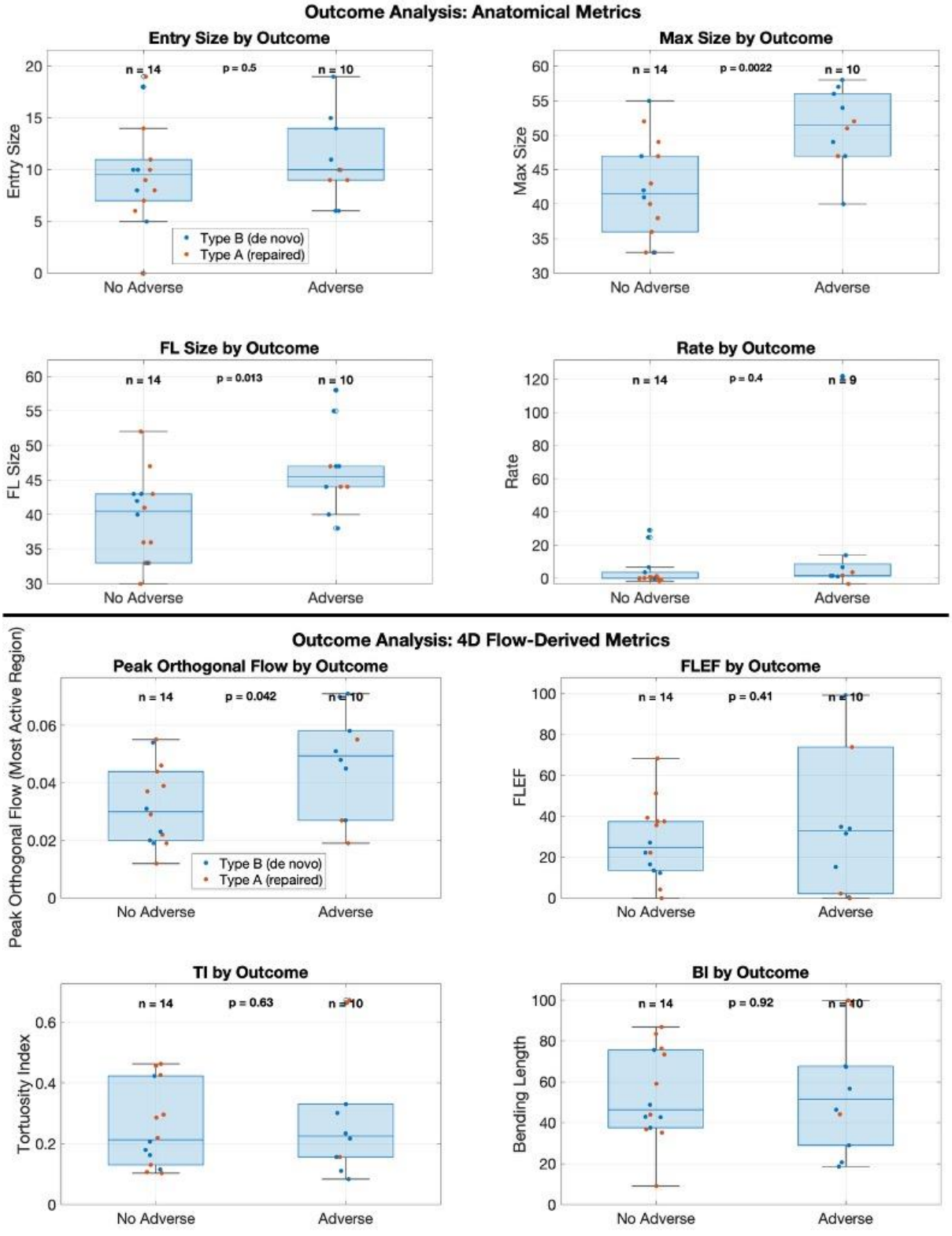


Figure 4. Comparing outcomes for anatomical and 4D Flow-derived metrics.



References:

[To be added]