# Beyond Average Values: A Novel TESLA Framework for Localized Hemodynamic Rupture Risk Assessment of Intracranial Aneurysms

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## Abstract:

**Background:** Rupture risk stratification of intracranial aneurysms (IAs) using computational fluid dynamics (CFD) has traditionally relied on spatially-averaged parameters, potentially overlooking critical localized phenomena. We hypothesize that the co-localization of extreme hemodynamic conditions is a critical marker for rupture.

**Methods:** We developed the TESLA (Targeted Evaluation of Synergistic Links in Aneurysms) framework to characterize these synergistic interactions. Patient-specific CFD models of 18 IAs were created from MR angiography. TESLA was used to analyze the spatial confluence of wall shear stress (WSS), oscillatory shear index (OSI), relative residence time (RRT), and vorticity.

**Results:** Our analysis demonstrated that ruptured aneurysms are characterized by distinct *hemodynamic hotspots*. These regions exhibited simultaneous peaks in key parameters: elevated WSS (max: 54.0 Pa) indicative of focal stress, high OSI (max: 0.50) and RRT signifying flow instability and stagnation, and intense vorticity (max: 4,645 $s^{-1}$) reflecting complex, energetic flow structures. The TESLA framework effectively captured this multi-parameter extreme environment, which was consistently more severe in ruptured versus unruptured cases.

**Conclusion:** The novel TESLA framework shifts the paradigm from global averages to a localized assessment of synergistic hemodynamic extremes. By pinpointing these high-risk hotspots, TESLA offers a more precise and physiologically-grounded method for evaluating IA rupture risk, with significant potential to guide clinical decision-making.

**Keywords:** CFD, Hemodynamics, Intracranial Aneurysm, Rupture Risk, TESLA Framework.