Supplementary Material

This supplementary document provides additional technical details and supporting analyses for the AneuG-Flow dataset. We provide a statistical overview of the morphological variation present in our dataset, followed by a convergence analysis of our computational fluid dynamics (CFD) pipeline. We then investigate the relationship between key morphological markers and biomechanical markers such as the Oscillatory Shear Index (OSI) and Relative Residence Time (RRT). Our results indicate that traditional geometric metrics alone may not sufficiently capture hemodynamic complexity. Finally, we present a visual gallery of representative aneurysm geometries and their corresponding flow field results to highlight the diversity of flow behaviors observed across the dataset. We also provide a ZIP file with this document, which contains the source code for the machine learning baselines mentioned in the main manuscript, as well as the associated trained model checkpoint files.

1. GEOMETRY VARIATIONS

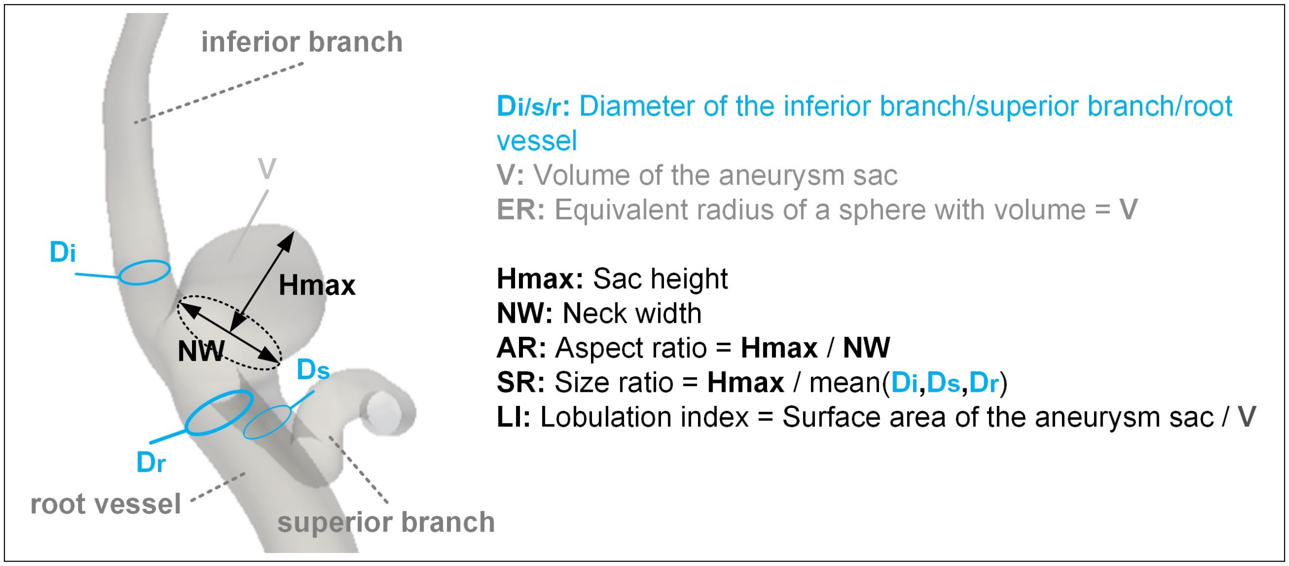

Fig. S1. Schematic of intracranial aneurysm morphological markers.

For intracranial aneurysms (IAs), physicians rely heavily on morphological markers for prediction and surgical decision [1, 2]. For example, NW and AR are known to play critical roles in aneurysm rupture risk and have been included by the unruptured intracranial aneurysm treatment score (UIATS) system [3]. To characterize the geometric statistics of IAs within our dataset, we quantify a set of six morphological markers: neck width (NW), sac height (Hmax), aspect ratio (AR), size ratio (SR), equivalent radius (ER), and lobulation index (LI). The definitions of each metric are illustrated in Fig. S1. Specifically, AR is defined as the ratio between Hmax and NW, reflecting aneurysm elongation; SR is the size of the aneurysm relative to the average of parent vessel diameters; LI quantifies the daughter-sac degree via the surface-to-volume ratio. ER denotes the radius of a hypothetical sphere with the same volume as the aneurysm sac which indicates the sac size. The statistical distributions of different markers are visualized in Fig. S2.

2. CONVERGENCE ANALYSIS

We performed convergence analyses to determine the volume mesh cell size and transient solver settings. We calculate Relative Percentage Error (RPE) of Wall Shear Stress (WSS) solutions at the aneurysm sac surface as the main evaluation metric. The RPE is computed as:

$$RPE = \frac{|\boldsymbol{\tau}_{w1} - \boldsymbol{\tau}_{w2}|}{\boldsymbol{\tau}_{w1}} \times 100\%$$

where $\boldsymbol{\tau}_{w1}$ and $\boldsymbol{\tau}_{w2}$ represent the wall shear stress values from different simulation configurations.

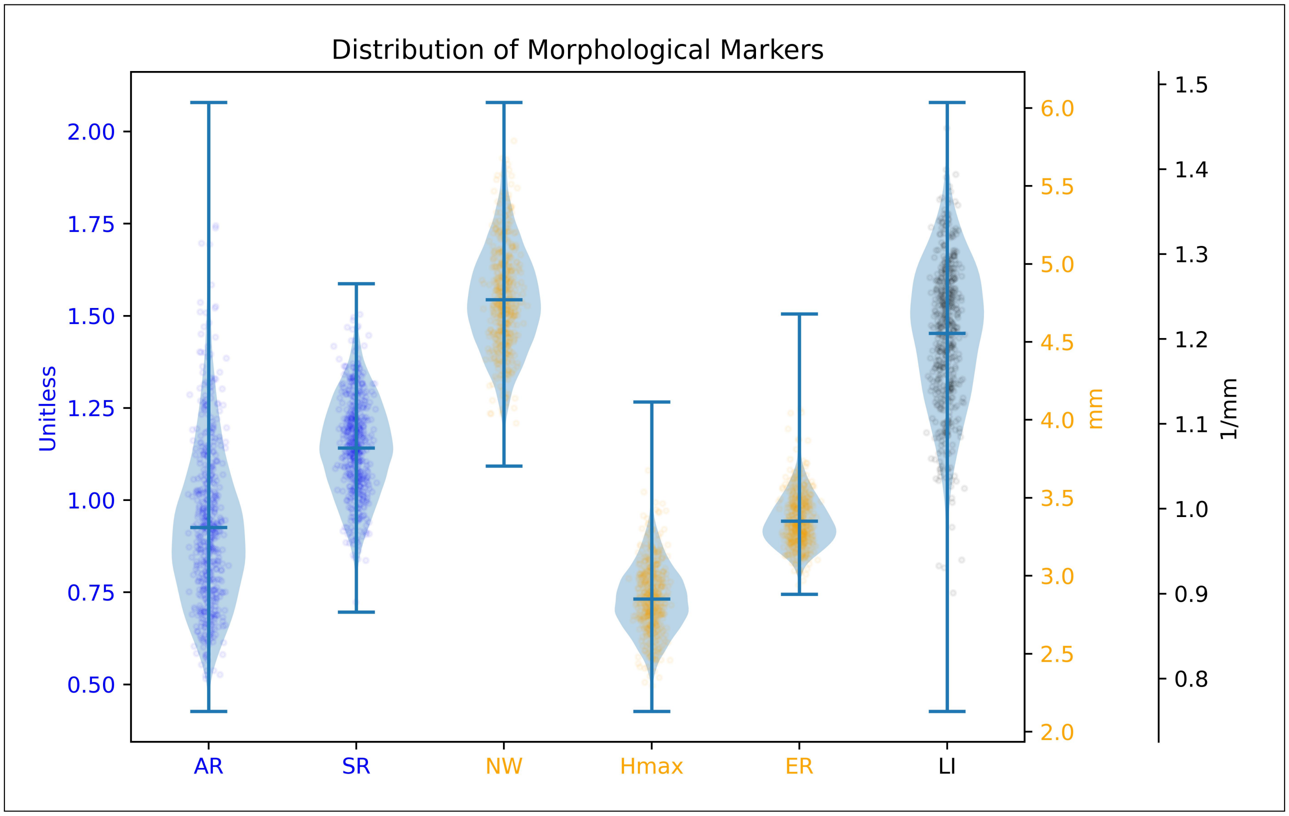

Fig. S2. Distribution of morphological markers. AR: aspect ratio, SR: size ratio, NW: neck width, Hmax: maximum sac height, ER: equivalent radius of sac, LI: lobulation index.

A. Mesh Convergence Analysis

Since the main contribution of our dataset is the geometric variations of aneurysm shapes, we perform mesh convergence for more than one shape (We randomly pick three shapes in the dataset). In addition to mean RPE (MRPE), we also follow [4] and compute relative difference (RD) for the averaged WSS value over the sac area:

$$\mathrm{RD} = \frac{|\bar{\tau}_{w1} - \bar{\tau}_{w2}|}{\bar{\tau}_{w1}} \times 100\%$$

The baseline meshes to compare with have the Vascular Modelling Toolkit (VMTK) edge factor set as 0.11 and contain an average of 5.09 million cells. The MRPE and RD of the three shapes are visualized in Fig. S3. Table S2 provides the average error metrics for different mesh configurations. We chose edge factor as 0.13 to generate volume meshes for our dataset. Such a configuration leads to an average of 3.15 million cells, which is already more than 0.72 million in [5], 1.3 million in [6], and 2 million in [7].

Table S1. WSS Error Analysis for Different Mesh Resolutions (Averaged over Three Shapes)

edge factor	0.24	0.22	0.20	0.19	0.18	0.17	0.16	0.15	0.14	0.13	0.12
cell count (million)	0.61	0.77	1.00	1.14	1.31	1.49	1.75	2.13	2.82	3.15	3.91
MRPE (%)	7.69	7.58	6.67	6.55	6.54	5.84	5.71	5.46	4.17	2.83	2.70
RD (%)	3.98	4.58	2.12	3.07	2.66	2.26	2.07	2.41	1.54	0.66	0.84

B. Transient Setup Convergence Analysis

We performed convergence tests on both the number of cardiac cycles and the temporal resolution using a representative intracranial aneurysm geometry. As summarized in Table S2, the average error in time-averaged wall

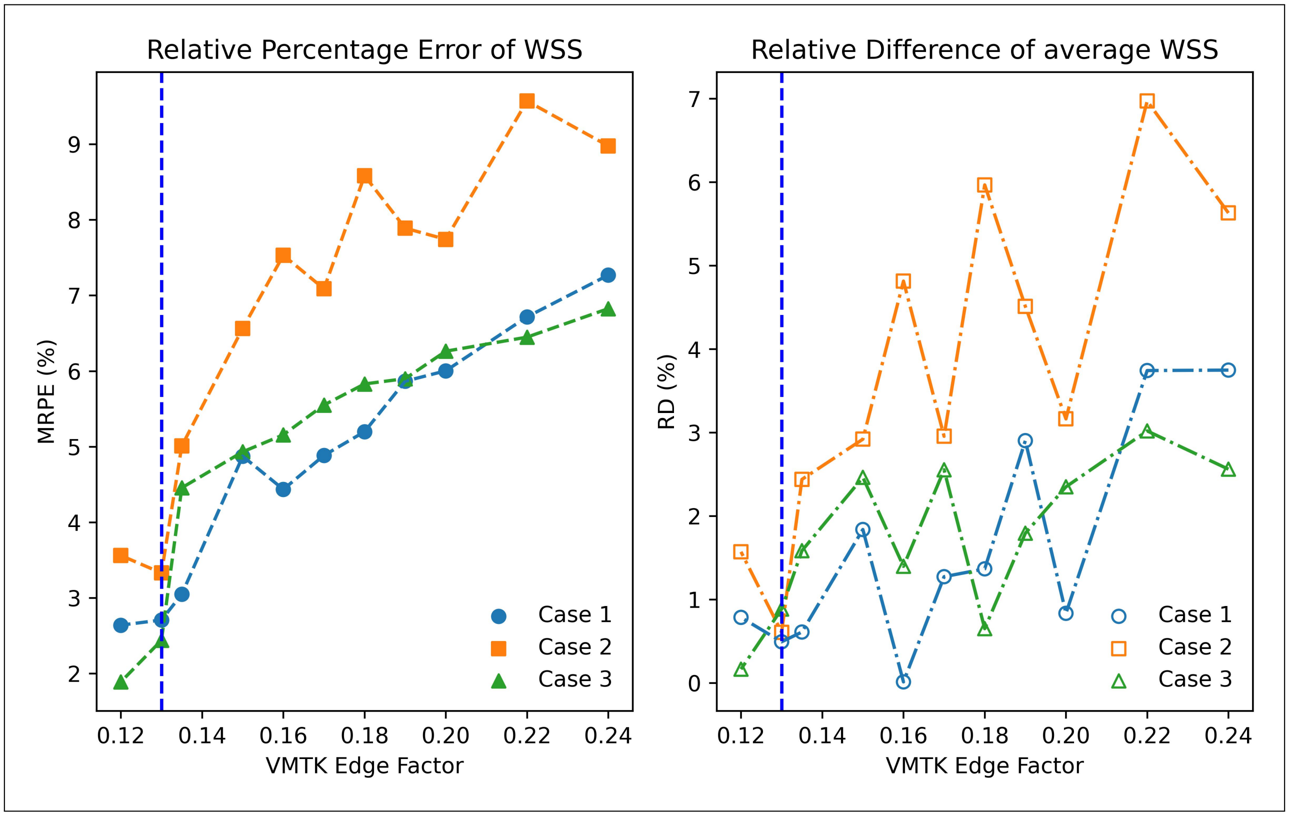

Fig. S3. MRPE and RD of cases solved with different element size ratio. Blue dash line indicates the VMTK edge factor used to generate the dataset.

shear stress (TAWSS) between simulations using two versus three cardiac cycles was only 0.011%, with a maximum local error of 0.240%. These results indicate that simulating two cardiac cycles is sufficient to achieve convergence in TAWSS.

For the time step sensitivity analysis, although the average TAWSS difference between simulations with time step equals to 0.001 s and 0.002 s was relatively small (0.052%) across the full domain, localized discrepancies were observed within the aneurysm sac, as illustrated in Fig. S4. To ensure adequate temporal resolution in regions with complex flow, we selected a time step of 0.001 s for all transient simulations.

Table S2. **TAWSS Difference Analysis for Convergence Test**

	Cardiac Cycle		Time Step (s)	
	2 vs. 3	3 vs. 4	0.001 vs. 0.002	0.002 vs. 0.004
Mean RPE (%)	0.011	0.013	0.052	0.218
Maximum RPE (%)	0.240	0.210	1.586	6.004

3. GALLERY OF FLOW RESULTS

We visualize a few biomechanical markers for transient cases in our dataset. Time-Averaged Wall Shear Stress (TAWSS) is the average magnitude of wall shear stress over a complete cardiac cycle, calculated as:

$$\text{TAWSS} = \frac{1}{T}\int_0^T |\boldsymbol{\tau}_w(t)|dt$$

where T represents the cardiac cycle period and $\boldsymbol{\tau}_w(t)$ is the wall shear stress vector. The Oscillatory Shear Index (OSI) measures the directional changes of wall shear stress throughout a cardiac cycle, defined as:

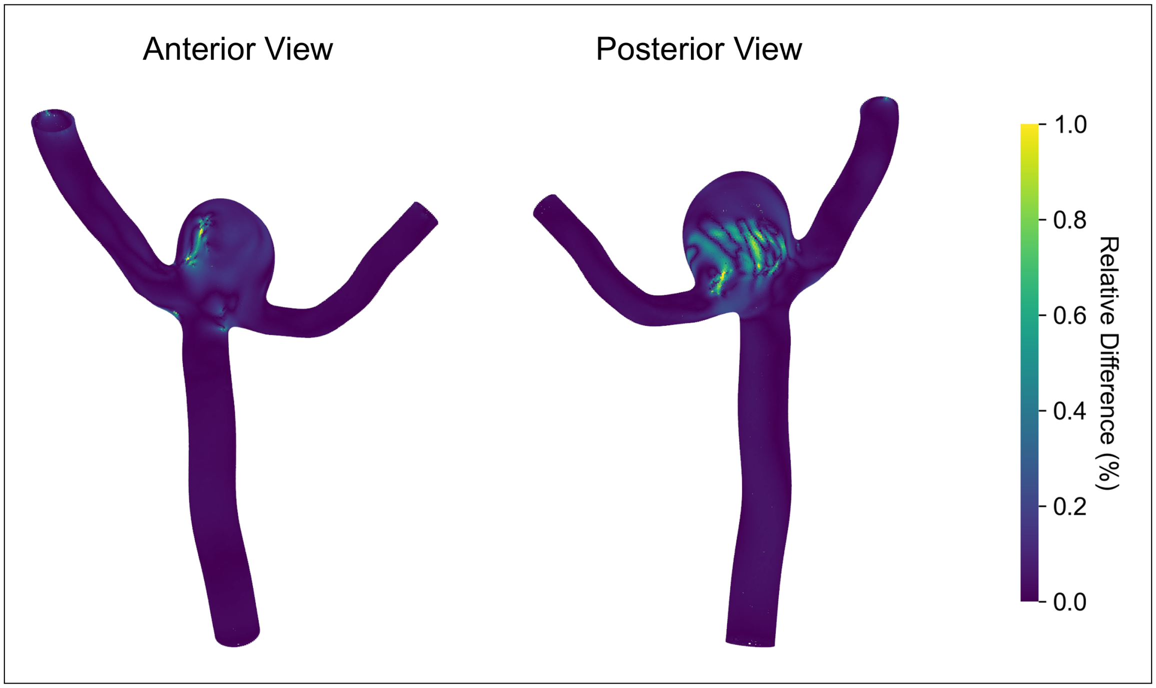

Fig. S4. Relative TAWSS Differences (%).

$$\text{OSI} = \frac{1}{2} \times \left(1 - \frac{|\int_0^T \boldsymbol{\tau}_w(t)dt|}{\int_0^T |\boldsymbol{\tau}_w(t)|dt}\right)$$

with values ranging from 0 (unidirectional flow) to 0.5 (oscillatory flow). Relative Residence Time (RRT) combines both parameters to evaluate flow stagnation.

$$\text{RRT} = \frac{1}{(1 - 2 \times \text{OSI}) \times \text{TAWSS}}$$

Figures S5–S7 show TAWSS, OSI, and RRT distributions across 30 example geometries.

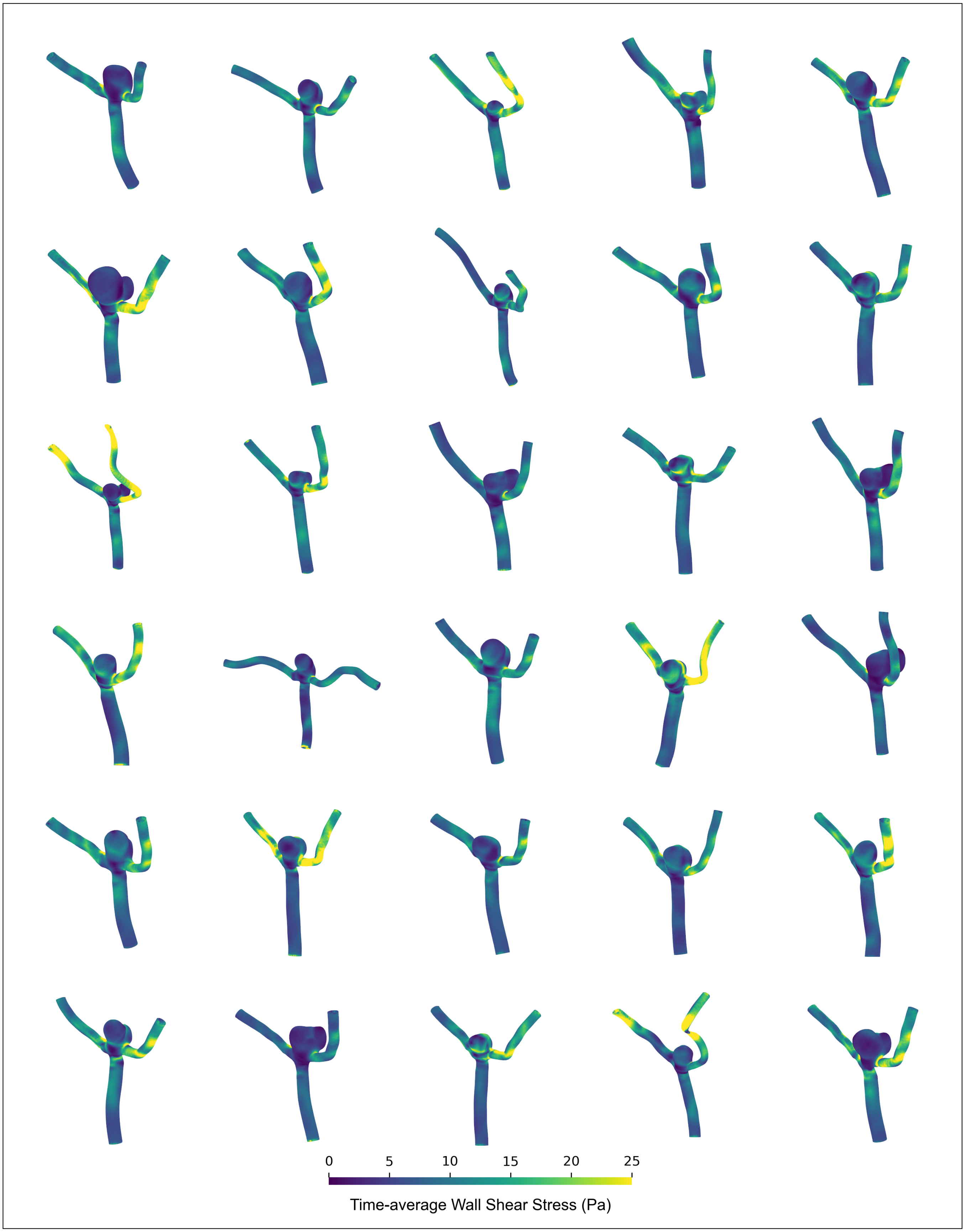

Fig. S5. Distributions of Time-averaged Wall Shear Stress (TAWSS).

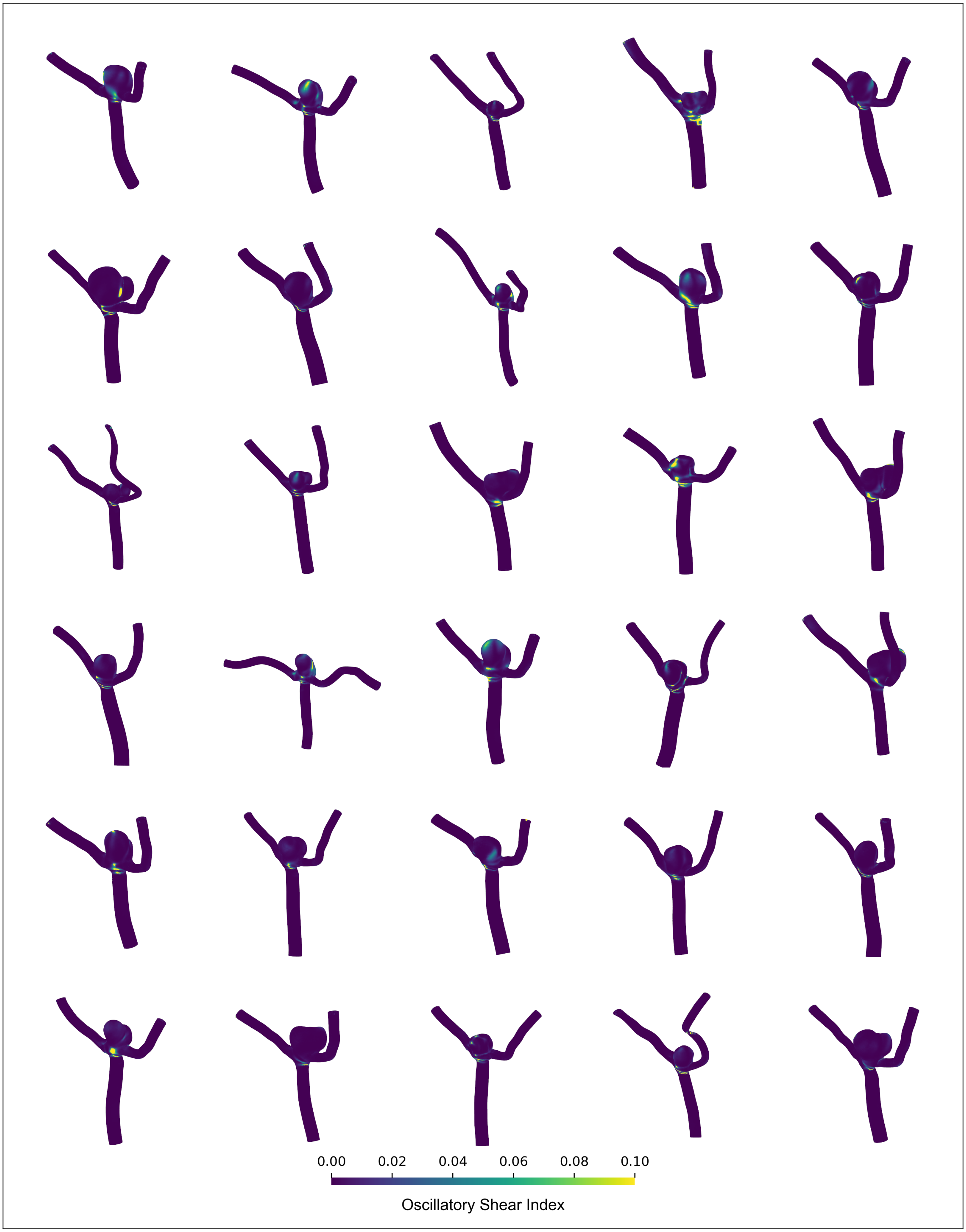

Fig. S6. Distributions of Oscillatory Shear Index (OSI).

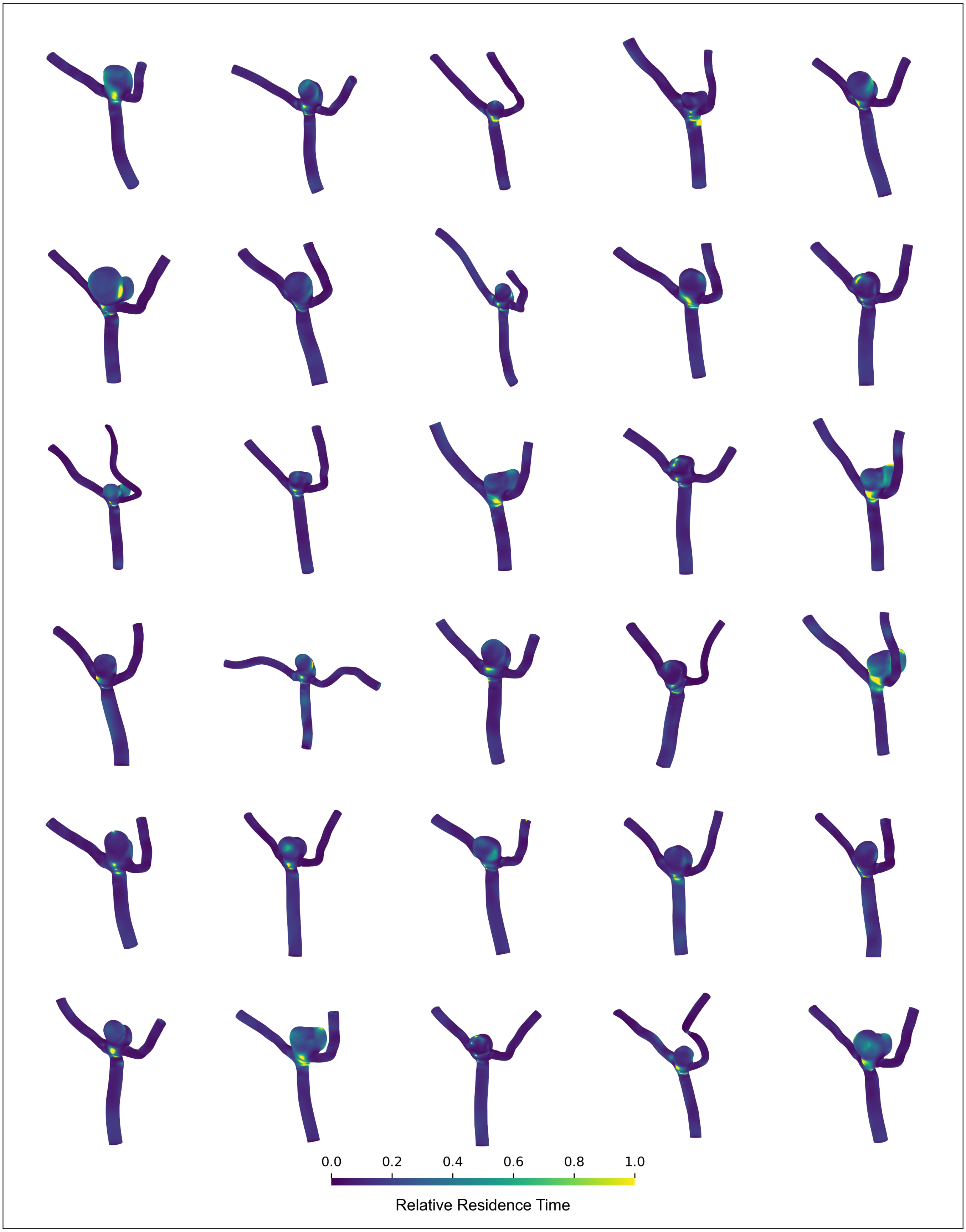

Fig. S7. Distributions of Relative Residence Time (RRT).

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