Supplementary Material

Variable	Meaning	Measures
Hemodynamics		
Q	Mean aneurysm inflow rate (ml/s)	Strength of inflow jet
ICI	Inflow concentration index	Concentration of inflow jet
VE	Mean aneurysm velocity (cm/s)	Aneurysm flow speed
VD	Mean aneurysm viscous dissipation	Kinetic energy dissipation
corelen	Total vortex core-line length	Flow complexity
podent	Proper orthogonal decomposition entropy	Flow stability
WSSmax	Maximum wall shear stress	Strength of WSS
WSSmean	Time averaged mean wall shear stress	
MaxWSSnorm	Max normalized WSS (over vessel WSS)	Relative strength of WSS compared to parent vessel
WSSnorm	Mean normalized WSS	
LSA	Percent of aneurysm area under low WSS	Area exposed to low WSS
SCI	Shear concentration index	Concentration of WSS distribution
OSImax	Maximum oscillatory shear index	Oscillation of WSS
OSImean	Mean oscillatory shear index	
nCrPoints	Time-averaged number of critical points in WSS vector field	WSS field topology & complexity
Geometry		
Asize	Aneurysm maximum size	Aneurysm size
Nsize	Neck maximum size	Neck size
SR	Size ratio	Relative aneurysm to vessel size
GAA	Gaussian curvature	Mean radius of curvature
AR	Aspect ratio	Aneurysm depth elongation
VOR	Volume to ostium ratio	Aneurysm widening elongation
BF	Bottleneck factor	Relative aneurysm to neck width
NSI	Non-sphericity index	Departure from spherical shape
CR	Convexity ratio	Shape distortion
UI	Undulation index	Surface irregularity

Supplementary Table I. Hemodynamic and geometric variables. For detailed mathematical definitions of these variables and algorithms to compute them, see.[14,16]

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Characteristic	Variable	Aneurysms with deleted blebs	Aneurysms without blebs	p-value	Adjusted p-value
		Mean ± SD	Mean ± SD		
Hemodynamics					
Inflow jet	Q (ml/s)	0.57 ± 0.36	0.34 ± 0.34	<0.0001*	0.0002*
	ICI	0.60 ± 0.43	0.45 ± 0.58	0.0005*	0.0011*
Flow pattern	VE (cm/s)	11.4 ± 7.08	7.96 ± 6.36	0.0032*	0.0062*
	VD	1838 ± 2688	1224 ± 2202	0.0116*	0.0181*
	corelen (mm)	1.00 ± 0.62	0.49 ± 0.58	<0.0001*	<0.0001*
	podent	0.18 ± 0.15	0.16 ± 0.13	0.1689	0.2010
Wall shear stress pattern	WSSmax (dyn/cm^2)	447 ± 490	174 ± 138	<0.0001*	<0.0001*
	WSSmean (dyn/cm^2)	26.5 ± 19.5	18.9 ± 17.2	0.0110*	0.0181*
	MaxWSSnorm	8.49 ± 8.71	4.75 ± 2.26	0.0003*	0.0007*
	WSSnorm	0.53 ± 0.31	0.51 ± 0.38	0.4035	0.4386
	LSA (%)	46.4 ± 28.3	50.1 ± 35.6	0.4425	0.4610
	SCI	5.01 ± 4.70	3.14 ± 3.81	0.0068*	0.0121*
	OSImax	0.26 ± 0.11	0.22 ± 0.12	0.0736	0.0920
	OSImean	0.01 ± 0.01	0.01 ± 0.01	0.5921	0.5921
	nCrPoints	1.90 ± 0.95	1.23 ± 0.86	0.0002*	0.0007*
Geometry					
Size	Asize (mm)	5.5 ± 0.9	4.4 ± 1.5	0.0001*	0.0004*
	Nsize (mm)	4.0 ± 0.1	3.7 ± 0.1	0.1804	0.2050
	SR	1.96 ± 0.81	1.54 ± 0.80	0.0002*	0.0007*
	GAA (cm^{-1})	13.4 ± 4.9	25.3 ± 26.3	0.0148*	0.0217*
Elongation	AR	1.00 ± 0.54	0.73 ± 0.43	0.0006*	0.0013*
	VOR (mm)	0.49 ± 0.42	0.24 ± 0.28	<0.0001*	<0.0001*
	BF	1.26 ± 0.40	1.03 ± 0.25	<0.0001*	<0.0001*
Shape distortion	NSI	0.21 ± 0.05	0.18 ± 0.05	0.0001*	0.0005*
	CR	0.79 ± 0.14	0.75 ± 0.12	0.0542	0.0713
Irregularity	UI	0.21 ± 0.14	0.25 ± 0.12	0.0542	0.0713

Supplementary Table II. Hemodynamic and geometric characteristics of small aneurysms (<7mm) with blebs (after bleb removal, mimicking conditions before bleb formation) and aneurysms without blebs. When restricting the analysis to aneurysms smaller than 7mm, there were 36 aneurysms with blebs and 110 without blebs. Statistically significant differences are indicated with a "*". See Supplementary Table I for more details on the hemodynamic and geometric variables.

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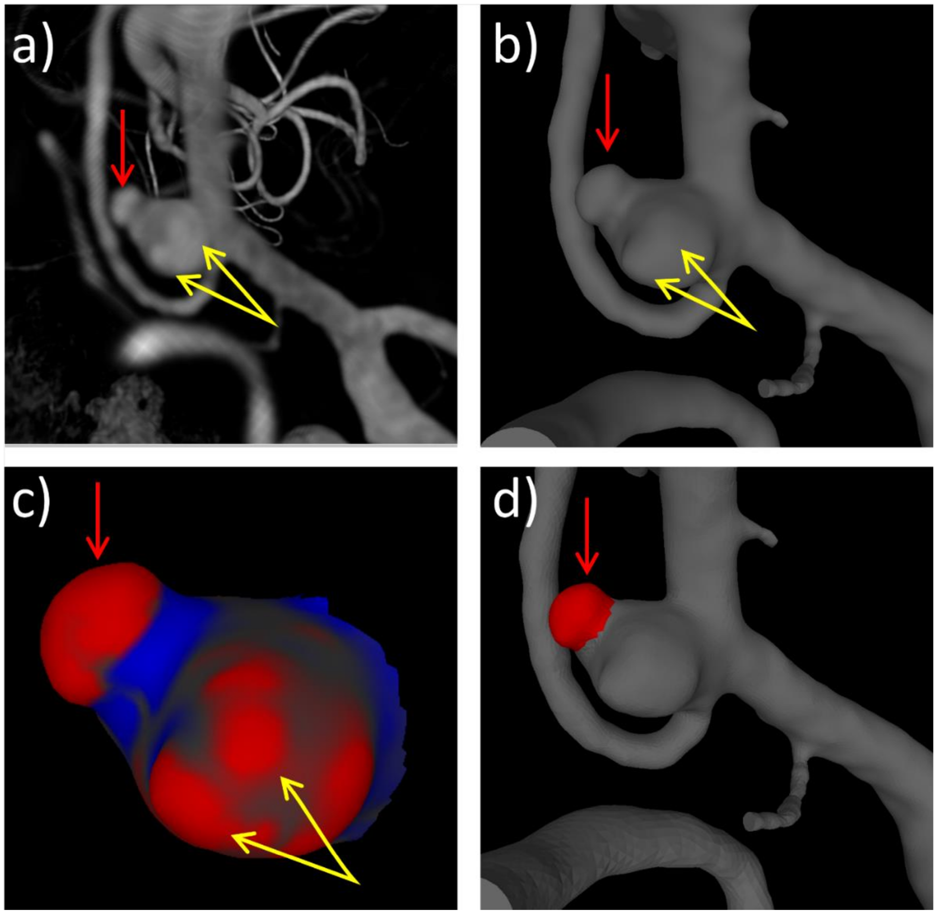

Supplementary Figure I. Example of bleb marking on vascular aneurysm model with the aid of curvature maps to decide if surface irregularities constitute blebs or not: a) volume rendering of 3D angiography image, where one bleb is clearly seen (red arrow) and two smaller suspicious "bumps" are also seen (yellow arrows), b) 3D patient-specific vascular model reconstructed from 3D angiography image, where the bleb (read arrow) and the bumps (yellow arrows) are also seen, c) aneurysm sac colored with local surface Gaussian curvature (red= positive curvature, blue= negative curvature, gray= no curvature) where the "true" bleb (red arrow) is seen as a region of positive Gaussian curvature surrounded by a band of negative Gaussian curvature, while the "bumps" (yellow arrows) are seen as regions of positive Gaussian curvature but are not surrounded by bands of negative Gaussian curvature, and d) marking of the "true" bleb (red arrow) using the ChePen3D tool and the curvature map for guidance. Note that curvature maps are used to aid the interactive identification and marking of blebs which should appear as well-defined distinct and separate sub-structures on the aneurysm sac.

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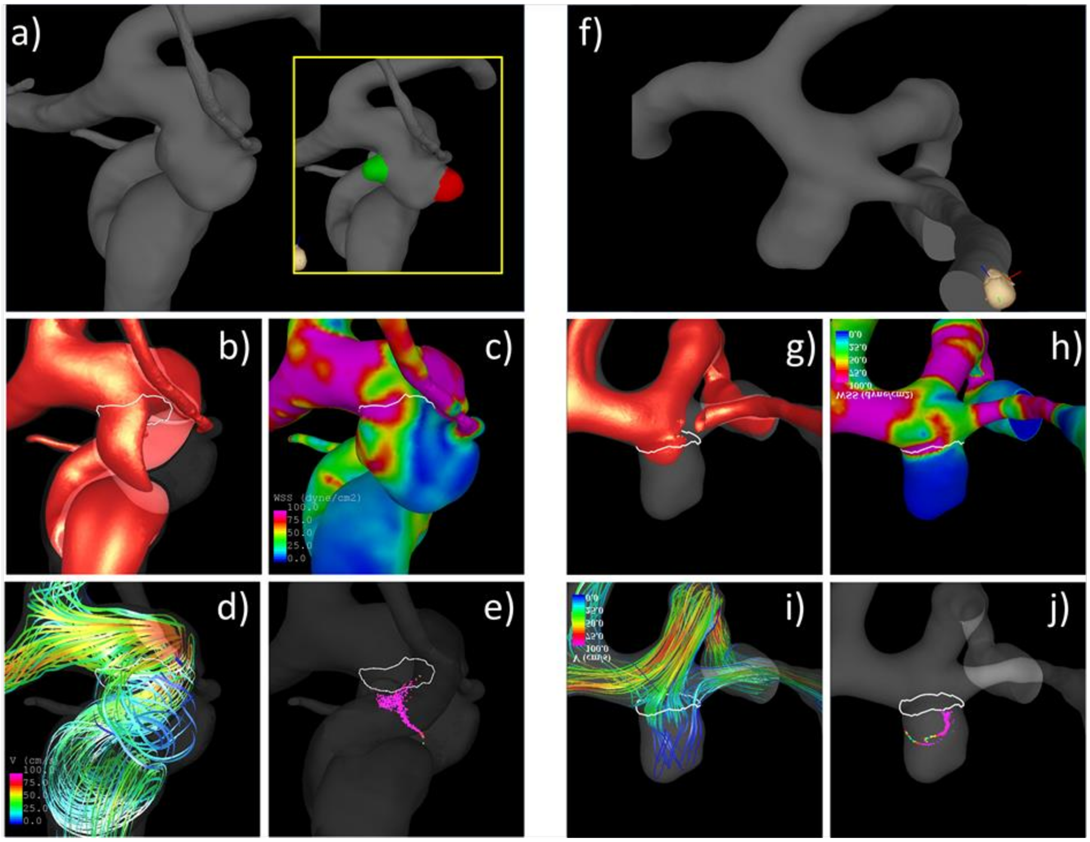
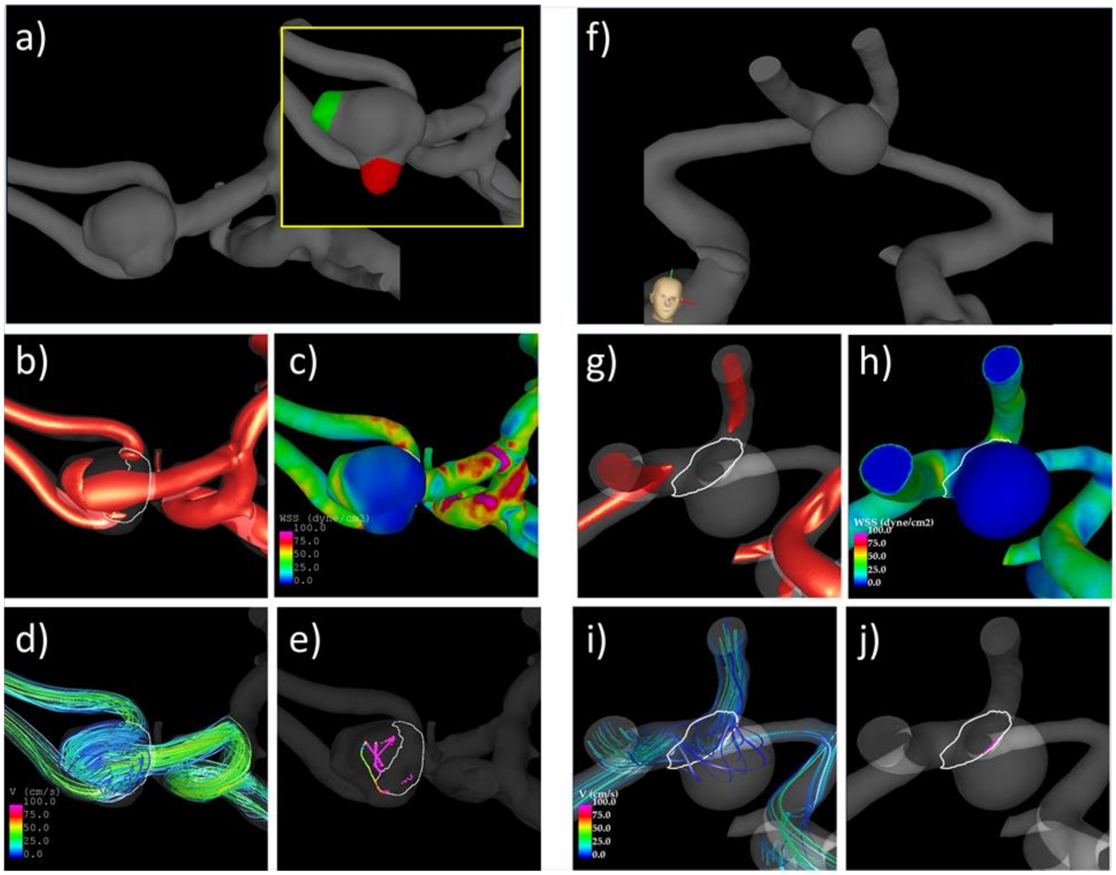
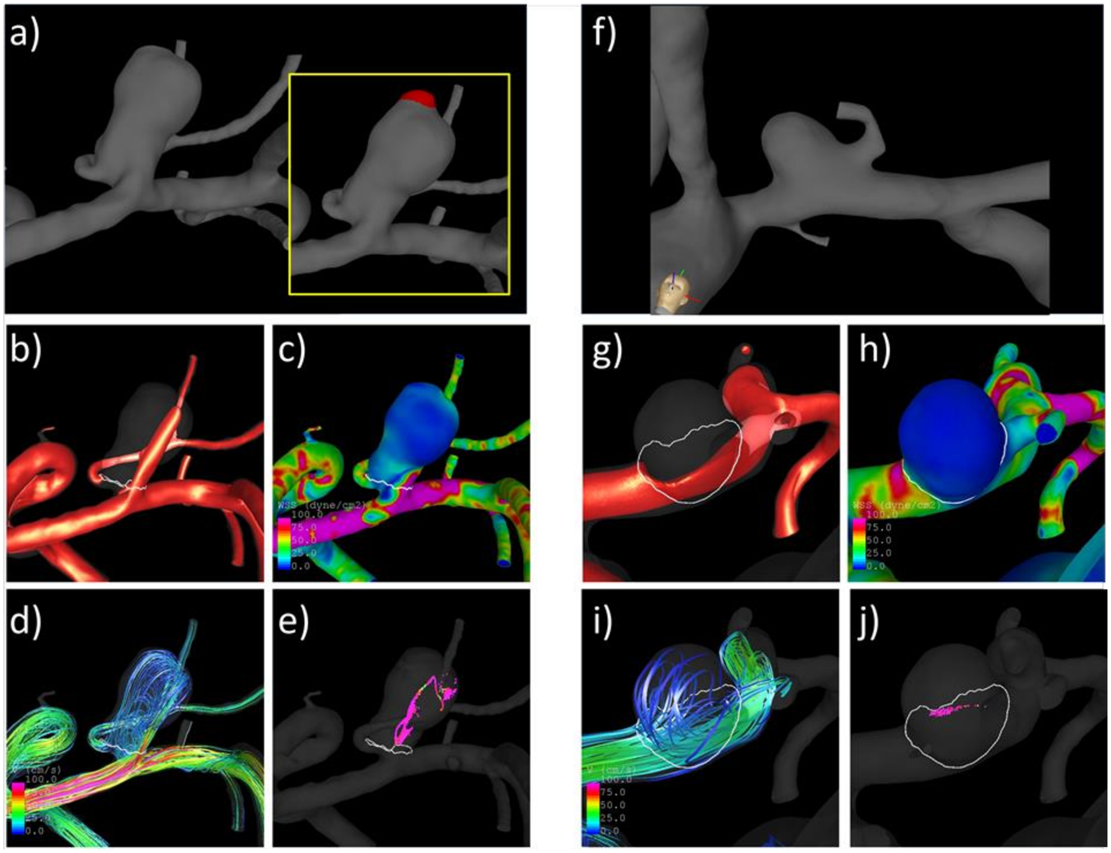


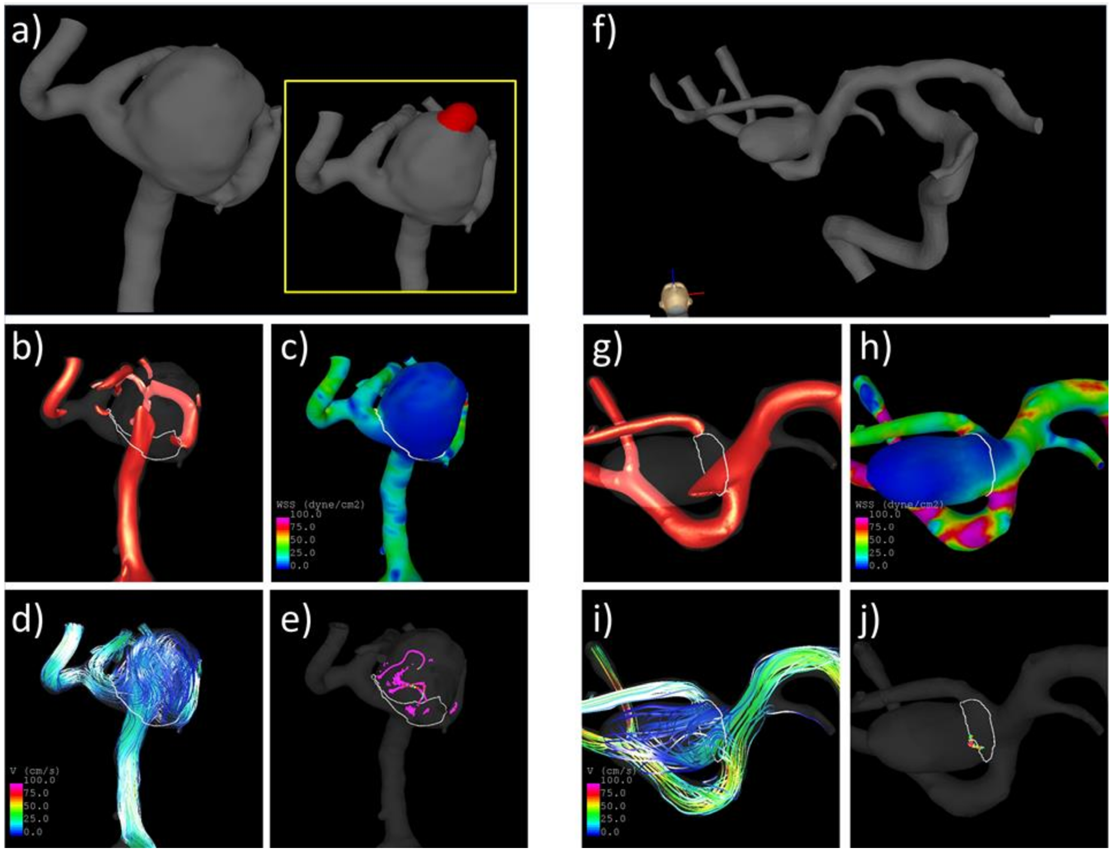
Supplementary Figure II. Examples of hemodynamics (at peak systole) for PCOM aneurysms with and without blebs. Left panel – aneurysm with blebs removed (surrogate for IA prior to bleb formation): a) geometry of PCOM aneurysm after removal of two blebs (insert shows marked blebs in red and green), b) inflow jet (iso-velocity surface), c) WSS magnitude, d) flow pattern (streamlines), e) vortex corelines. Right panel – aneurysm without bleb: f) geometry of PCOM aneurysm without bleb, g) inflow jet, h) WSS magnitude, i) flow pattern, and j) vortex corelines.



Supplementary Figure III. Examples of hemodynamics (at peak systole) for ACOM aneurysms with and without blebs. Left panel – aneurysm with blebs removed (surrogate for IA prior to bleb formation): a) geometry of ACOM aneurysm after removal of two blebs (insert shows marked blebs in red and green), b) inflow jet (iso-velocity surface), c) WSS magnitude, d) flow pattern (streamlines), e) vortex corelines. Right panel – aneurysm without bleb: f) geometry of ACOM aneurysm without bleb, g) inflow jet, h) WSS magnitude, i) flow pattern, and j) vortex corelines.



Supplementary Figure IV. Examples of hemodynamics (at peak systole) for MCA-M1 aneurysms with and without blebs. Left panel – aneurysm with bleb removed (surrogate for IA prior to bleb formation): a) geometry of MCA-M1 aneurysm after removal of one bleb (insert shows marked bleb in red), b) inflow jet (iso-velocity surface), c) WSS magnitude, d) flow pattern (streamlines), e) vortex corelines. Right panel – aneurysm without bleb: f) geometry of MCA-M1 aneurysm without bleb, g) inflow jet, h) WSS magnitude, i) flow pattern, and j) vortex corelines.



Supplementary Figure V. Examples of hemodynamics (at peak systole) for MCA-bifurcation aneurysms with and without blebs. Left panel – aneurysm with bleb removed (surrogate for bleb prior to bleb formation): a) geometry of MCA-bifurcation aneurysm after removal of one bleb (insert shows marked bleb in red), b) inflow jet (iso-velocity surface), c) WSS magnitude, d) flow pattern (streamlines), e) vortex corelines. Right panel – aneurysm without bleb: f) geometry of MCA-bifurcation aneurysm without bleb, g) inflow jet, h) mean WSS magnitude, i) flow pattern, and j) vortex corelines.

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