On-line Table 1: Patient and aneurysm characteristics

Patients				Aneurysms (n = 65)						
Sex	No.	Age	Years	Variable	Mean	SD	Min	Max	Location	No.
									MCA	41
Female	36	Mean	54.6	Max size	8.56	3.56	2.19	20.4	ICA	10
Male	14	SD	10.2	Neck size	5.80	2.48	1.28	14.2	AcomA	8
Unknown	7	Min	30	Aspect ratio	1.11	0.59	0.16	3.73	PcomA	4
Total	57	Max	77	Size ratio	1.56	0.55	0.96	3.94	PICA	2

Note:—AcomA indicates anterior communicating artery; PcomA, posterior communicating artery.

On-line Table 2: Hemodynamic variables studied on each aneurysm wall region

Variable	Definition	Measure
PRE	$\bar{p} = \frac{1}{T}\int_0^T p\, dt$	Provides an indication of flow impingement where the pressure is higher
WSS	$\bar{\tau} = \frac{1}{T}\int_0^T \lvert\tau\rvert\, dt$	Measures the average magnitude of the viscous forces of the blood flow on the vascular wall
OSI	$OSI = \frac{1}{2}\left(1 - \left\lvert \int_0^T \tau\, dt \right\rvert / \int_0^T \lvert\tau\rvert\, dt\right)$	Measures the degree of directional oscillation of the WSS vector during the cardiac cycle
RRT	$RRT = \frac{1}{(1 - 2 \times OSI) \times \bar{\tau}}$	Measures, on average, how slow the flow is near the vascular wall
WSSGRD	$\boldsymbol{G} = \nabla\lvert\tau\rvert$ $G = \lvert\boldsymbol{G}\rvert$	Measures the average magnitude of the wall shear stress gradient (variations of wall shear stress magnitude)
WSSDIV	$D = \nabla \times \boldsymbol{G}$	Measures the average degree of convergence/divergence of WSS vectors
GON	$GON = \frac{1}{2}\left(1 - \left\lvert \int_0^T \boldsymbol{G}\, dt \right\rvert / \int_0^T \lvert\boldsymbol{G}\rvert\, dt\right)$	Measures the degree of directional oscillation of the wall shear stress gradient vector during the cardiac cycle

Note:—GON indicates gradient oscillatory number; p, the instantaneous pressure; τ, the instantaneous wall shear stress vector; T, the period of the cardiac cycle.

On-line Table 3: Summary of hemodynamic variables over the 5 aneurysm wall regions and the entire aneurysm sac[a]

Variable	A (*n* = 32)	H (*n* = 61)	T (*n* = 78)	R (*n* = 13)	N (*n* = 61)	*P*	Whole Sac (*n* = 61)
OSImax	0.087 (0.026–0.253)	0.086 (0.021–0.275)	0.031 (0.006–0.099)	0.117 (0.037–0.223)	0.27 (0.187–0.363)	<.001[b]	0.33 (0.237–0.405)
OSIavg	0.012 (0.005–0.032)	0.011 (0.004–0.022)	0.006 (0.002–0.012)	0.012 (0.008–0.019)	0.013 (0.006–0.02)	<.001[b]	0.013 (0.009–0.021)
OSImin	0.001 (0–0.003)	0.00 (0–0.001)	0.00 (0–0.001)	0.001 (0–0.001)	0.00 (0–0)	<.001[b]	0.00 (0–0)
WSSmax	20.247 (6.204–50.168)	36.673 (19.121–51.04)	28.067 (10.037–52)	20.219 (4.51–33.722)	76.33 (34.469–107.27)	<.001[b]	84.071 (48.316–137.99)
WSSavg	6.472 (2.419–20.753)	9.7 (5.299–22.681)	13.813 (4.431–27.974)	3.502 (2.533–13.449)	12.182 (5.774–20.872)	.09	11.978 (5.401–21.031)
WSSmin	0.823 (0.483–3.53)	1.479 (0.599–5.57)	3.4 (1.182–9.626)	1.665 (0.471–1.795)	0.571 (0.203–1.402)	<.001[b]	0.314 (0.12–0.795)
PREmax	1998.33 (1575.22–4350.99)	2154.95 (1395.49–4450.29)	1949.34 (951.176–4277.51)	1467.8 (1104.85–5276.45)	2157.87 (1161.31–6060.67)	.86	2157.87 (1246.98–6060.67)
PREavg	1908.01 (1563.66–4254.1)	2077.32 (1343.62–4357.96)	1874.47 (938.024–4205.03)	1371.74 (1048.57–4640.82)	1936.72 (1049.65–4378.17)	.88	1929.39 (1046.39–4405.53)
PREmin	1854.5 (1555.44–4046.99)	1906.65 (1264.43–4130.58)	1737.71 (908.966–4126.97)	1315.31 (1017.11–4379.42)	1698.72 (846.361–3705.44)	.71	1467.21 (825.304–3550.19)
RRTmax	1.643 (0.726–5.102)	0.835 (0.186–4.187)	0.329 (0.117–1.136)	1.182 (0.626–2.494)	3.833 (0.91–19.093)	<.001[b]	8.381 (2.497–25.156)
RRTavg	0.395 (0.093–0.652)	0.204 (0.064–0.402)	0.109 (0.045–0.253)	0.386 (0.13–0.977)	0.211 (0.095–0.542)	.003[b]	0.231 (0.107–0.812)
RRTmin	0.051 (0.02–0.169)	0.028 (0.02–0.053)	0.036 (0.02–0.1)	0.05 (0.03–0.226)	0.013 (0.009–0.03)	<.001[b]	0.012 (0.007–0.021)
GONmax	0.562 (0.379–0.709)	0.601 (0.425–0.758)	0.41 (0.263–0.579)	0.588 (0.525–0.666)	0.793 (0.677–0.871)	<.001[b]	0.84 (0.723–0.892)
GONavg	0.05 (0.025–0.101)	0.06 (0.038–0.091)	0.041 (0.019–0.065)	0.06 (0.035–0.088)	0.062 (0.047–0.083)	<.001[b]	0.06 (0.053–0.089)
GONmin	0.00 (0–0.001)	0.00 (0–0.001)	0.00 (0–0.001)	0.00 (0–0.001)	0.00 (0–0)	<.001[b]	0.00 (0–0)
WSSDIVmax	797.149 (117.648–2347.34)	972.411 (366.794–1873.63)	796.119 (141.758–1793.64)	173.792 (159.715–936.614)	3389.54 (1577.48–8564.27)	<.001[b]	6298.13 (3389.54–11916)
WSSDIVavg	9.405 (−41.012–83.128)	3.361 (−80.042–56.757)	8.961 (−67.936–184.01)	−3.287 (−53.965–82.407)	6.216 (−36.183–49.359)	.75	25.498 (6.323–45.645)
WSSDIVmin	−673.202 (−1465.48 to −83.799)	−873.752 (−1433.32 to −355.594)	−629.641 (−1474.23 to −242.559)	−364.995 (−609.969 to −156.414)	−2164.16 (−4212.58 to −748.606)	<.001[b]	−2942.55 (−5636.66 to −1204.95)
WSSGRDmax	1016.65 (166.46–1940.3)	1385.98 (596.903–2165.81)	953.849 (366.306–2139.57)	525.83 (177.07–1095.26)	3442.6 (1414.75–6410.17)	<.001[b]	5215.49 (2566.13–8098.6)
WSSGRDavg	273.177 (59.423–538.36)	268.379 (127.283–455.09)	359.303 (136.56–646.408)	116.625 (64.414–290.717)	313.57 (148.346–537.11)	.23	295.205 (144.333–545.926)
WSSGRDmin	15.023 (4.158–41.35)	23.1 (4.791–52.966)	45.416 (15.871–87.563)	10.857 (4.065–38.541)	7.213 (2.612–19.299)	<.001[b]	4.666 (1.501–14.244)
WSSnorm	0.242 (0.079–0.641)	0.271 (0.15–0.549)	0.428 (0.203–0.785)	0.141 (0.06–0.393)	0.322 (0.2–0.616)	.04[b]	0.308 (0.186–0.585)

Note:—K-W indicates Kruskal-Wallis; norm, normal; A, atherosclerotic; H, hyperplastic; T, thin; R, ruptured; N, normal-appearing; WSSDIV, WSS divergence; WSSGRD, WSS stress gradient.

[a] Values of median and lower and upper quartiles are given. The number of regions of each type in the headers is indicated in parentheses. *P* values correspond to the K-W test.

[b] Significant.

On-line Table 4: Multivariate model of atherosclerotic and hyperplastic versus normal regions[a]

Variable	Coefficient	Frequency	Std Coeff	OR (95% CI)
GONmin	88.80773	1	2.52083	3.7043e + 38 (14.66–2.47669e + 56)
RRTavg	2.01944	1	1.88564	7.53 (1.47–8.46)
WSSGRDmax	−0.05881	1	−1.72039	0.94 (0.92–0.99)
OSImax	−0.12794	1	−1.54099	0.88 (0.87–0.95)
OSImin	−7.29386	0.542	−1.20267	0 (0–1)
OSIavg	0.76674	1	0.88435	2.15 (1.03–3.05)
WSSGRDmin	3.98366	1	0.77905	53.71 (3.19–85.41)
WSSmax	0.04052	0.186	0.64801	1.04 (1–1.13)
PREavg	−18.8527	1	−0.57273	0 (0–0.01)
WSSmin	1.69471	1	0.43032	5.45 (1.6–12.13)
RRTmax	−0.00509	0.971	−0.404	0.99 (0.99–1)
GONavg	−0.46981	0.36	−0.24288	0.63 (0.41–1)
RRTmin	0.5952	0.558	0.21015	1.81 (1–3.21)
WSSGRDavg	−0.15048	0.186	−0.18058	0.86 (0.68–1)
PREmin	1.51198	1	0.1632	4.54 (1.75–4.94)
WSSDIVmax	0.00035	0.712	0.14986	1 (1–1)
WSSavg	0.13314	0.542	0.12466	1.14 (1–1.18)
GONmax	−0.01021	0.915	−0.04779	0.99 (0.97–1)
WSSDIVmin	0.00014	0.186	0.03344	1 (1–1)
PREmax	−0.05266	0.523	−0.0109	0.95 (0.69–1)
WSSDIVavg	0	0.091	0	1 (1–1)
Intercept	17.14893	–	–	–
Regularization			0.002	
AUC			0.9214	

Note:—AUC indicates area under the receiver operating characteristic curve; Std Coeff, standardized coefficients; OR, odds ratio, CI, confidence intervals; WSSDIV, WSS divergence; WSSGRD, WSS stress gradient.

[a] The model variables are ordered by their influence on the outcome—that is, by the magnitude of the standardized coefficients. "Frequency" indicates the percentage of times the variable was retained in the cross-validation step.

On-line Table 5: Multivariate model of thin-versus-normal regions[a]

Variable	Coefficient	Frequency	Std Coeff	OR (95% CI)
WSSGRDmin	10.60181	1	2.222	40207.4 (18.96–46534.3)
WSSGRDmax	−0.06647	0.999	−2.03258	0.94 (0.88–0.99)
GONavg	−1.87558	0.981	−1.15092	0.15 (0.09–0.93)
RRTmin	4.35777	1	1.08302	78.08 (21.97–111.22)
RRTmax	−0.01476	1	−0.89416	0.99 (0.98–0.99)
PREmax	−4.29996	1	−0.81946	0.01 (0–0.38)
GONmax	−0.16194	1	−0.74147	0.85 (0.83–0.85)
OSIavg	0.68091	0.981	0.51464	1.98 (1.02–2.07)
PREmin	2.92509	0.997	0.37532	18.64 (1.24–19.3)
WSSDIVavg	0.02076	0.931	0.373	1.02 (1–1.04)
OSImin	1.71287	0.86	0.31894	5.54 (0.58–13.47)
WSSGRDavg	0.12232	0.61	0.2182	1.13 (1–5.1)
GONmin	1.17317	0.677	0.2113	3.23 (1–1.66303e +31)
OSImax	−0.01405	0.995	−0.17754	0.99 (0.98–1)
WSSDIVmin	0.00028	0.64	0.0671	1 (1–1)
WSSmax	−0.00168	0.507	−0.02824	1 (0.83–1)
PREavg	0	0.425	0	1 (1–1.32078e +07)
WSSavg	0	0.021	0	1 (1–1)
WSSmin	0	0.062	0	1 (1–1.54)
RRTavg	0	0.224	0	1 (1–1.34)
WSSDIVmax	0	0.317	0	1 (1–1)
Intercept	3.83878	–	–	–
Regularization			0.004	
AUC			0.9666	

Note:—AUC indicates area under the receiver operating characteristic curve; Std Coeff, standardized coefficients; WSSDIV, WSS divergence; WSSGRD, WSS stress gradient.

[a] The model variables are ordered by their influence on the outcome—that is, by the magnitude of the standardized coefficients. "Frequency" indicates the percentage of times the variable was retained in the cross-validation step.

On-line Table 6: Multivariate model of atherosclerotic and hyperplastic versus thin regions[a]

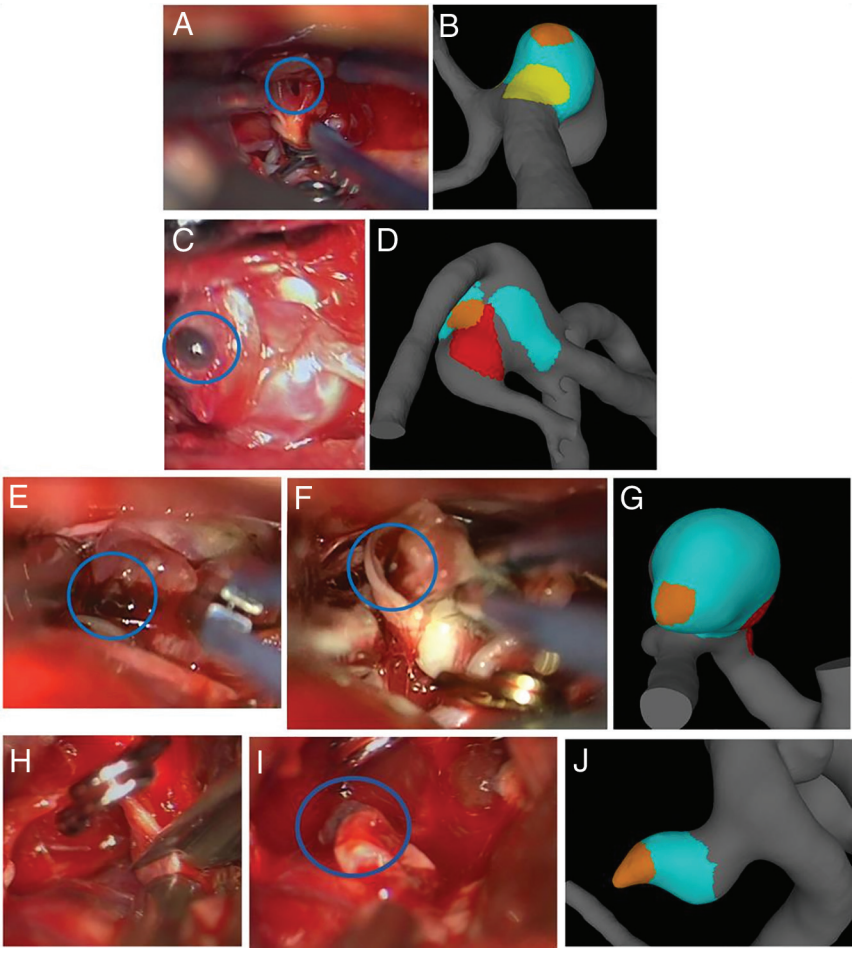
Variable	Coefficient	Frequency	Std Coeff	OR (95% CI)
RRTavg	0.25935	1	0.25919	1.3 (1.42–1.87)
GONmax	0.05254	1	0.22511	1.05 (1.06–1.13)
WSSmin	−0.02742	0.996	−0.02742	0.98 (0.17–0.9)
RRTmax	0.00366	0.992	0.00366	1 (1–1.03)
GONavg	0	0.961	0	1 (1–2.33)
GONmin	0	0.984	0	1 (0.01–0.7)
PREavg	0	0.631	0	1 (0.05–1)
PREmax	0	0.942	0	1 (1–13.62)
PREmin	0	0.845	0	1 (0.53–1)
WSSavg	0	0.25	0	1 (0.71–1)
WSSmax	0	0.979	0	1 (1.02–1.58)
OSIavg	0	0.002	0	1 (1–1)
OSImax	0	0.951	0	1 (0.92–1)
OSImin	0	0.977	0	1 (0.48–0.94)
RRTmin	0	0.149	0	1 (1–1.24)
WSSDIVavg	0	0.953	0	1 (0.97–1)
WSSDIVmax	0	0.984	0	1 (1–1.01)
WSSDIVmin	0	0.953	0	1 (1–1.01)
WSSGRDavg	0	0.156	0	1 (0.99–1)
WSSGRDmax	0	0.946	0	1 (0.8–1)
WSSGRDmin	0	0.946	0	1 (1–16.84)
Intercept	−0.02742	–	–	–
Regularization		0.00366		
AUC		0.6953		

Note:—AUC indicates area under the receiver operating characteristic curve; Std Coeff, standardized coefficients; WSSDIV, WSS divergence; WSSGRD, WSS stress gradient.
[a] The model variables are ordered by their influence on the outcome—that is, by the magnitude of the standardized coefficients. "Frequency" indicates the percentage of times the variable was retained in the cross-validation step.

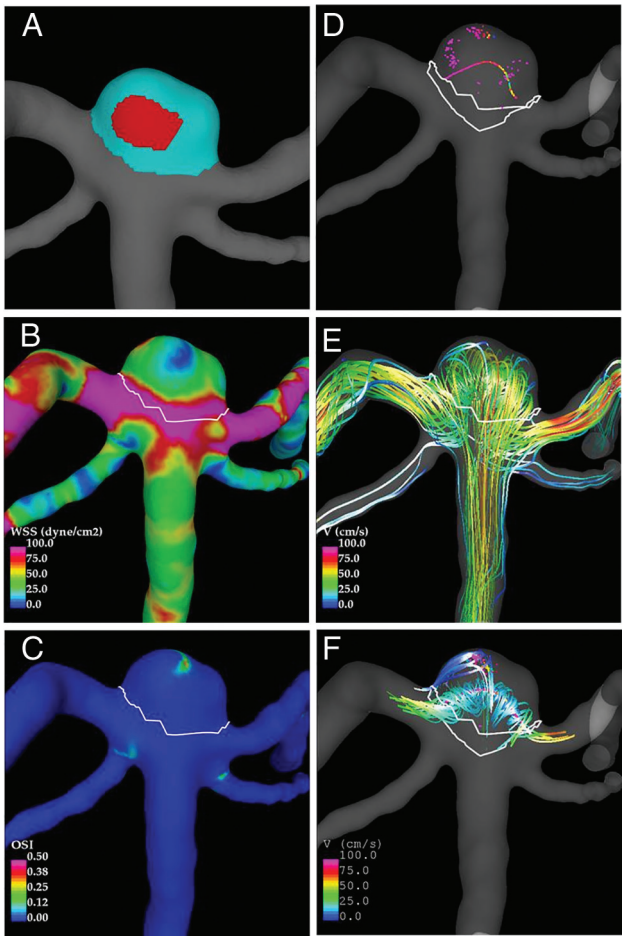
On-line Table 7: Summary of results obtained from prior studies comparing computational fluid dynamics models with the visual appearance of the aneurysm wall during an operation

Study	Data	Findings			Comparison
		Rupture Site	Thin Wall	Atherosclerotic Wall	
Omodaka et al, 2012[28]	6 MCAs (6 R)	Lower WSS impingement (if bleb removed ≥ increased WSS)	–	–	Rupture point vs aneurysm region
Fukazawa et al, 2015[29]	12 MCAs (12 R)	Lower WSS	–	–	Pointwise (rupture vs dome + parent artery)
Sugiyama et al, 2013[30]	30 MCAs (30 U)	–	–	Prolonged RRT (also male sex)	Regional
Kadasi et al, 2013[9]	16 IAs (4 AcomAs + 12 MCAs) (16 U)	–	Lower WSS and WSSG, higher PRE	–	Point cloud comparison (thin vs normal + neck + parent artery)
Sugiyama et al, 2016[31]	3 Patients with multiple IAs (3 atherosclerotic MCAs + 3 MCAs + 2 ICAs) (8 U)	–	–	Lower WSS, prolonged RRT, inflow lower than in nonatherosclerotic IAs	Pointwise
Talari et al, 2016[32]	9 IAs (2 AcomAs + 2 PcomAs + 4 ICAs + 1 MCA) (9 U)	–	Higher PRE	–	Global features; no regional or pointwise comparison
Furukawa et al, 2018[33]	24 IAs (13 MCAs + 9 ICAs + 2 ACAs) (10 R + 14 U)	–	–	Lower WSS and AFI, higher OSI and RRT	Pointwise comparison of hyperplastic vs thin
Cebral et al, 2018, this study	65 IAs (41 MCAs + 10 ICAs + 8 AcomAs + 4 PcomAs + 2 PICAs) (13 R + 52 U)	Lower WSS, higher PRE	Lower RRT, OSI, and GON; higher WSS and PRE	Lower WSS and PRE, prolonged RRT	Regional, normalized

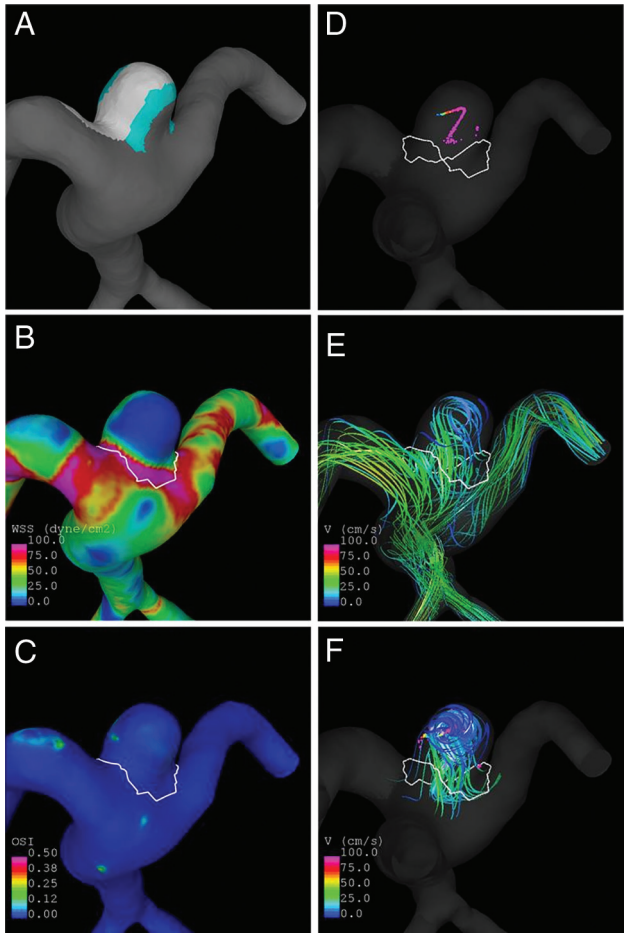
Note:—U indicates unruptured; AFI, aneurysm formation index; ACA, anterior cerebral artery; WSSG, wall shear stress gradient; AcomA, anterior communicating artery; PcomA, posterior communicating artery; R, ruptured.



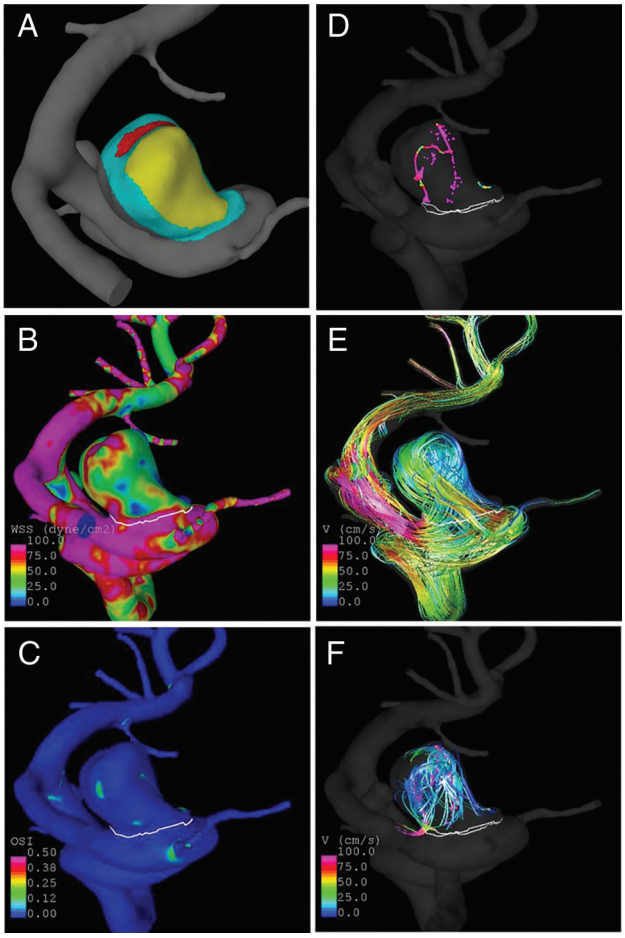
ON-LINE FIG 1. Identification of rupture site. Sample 1: *A*, Hole clearly observed on the side of the aneurysm. *B*, Rupture site marked in gold on the 3D model (views not matched). Sample 2: *C*, Mural hematoma corresponding to the rupture site at the distal end of the fundus. *D*, Rupture site in marked in gold. Sample 3: *E*, Small hematoma observed on aneurysm wall. *F*, Once the hematoma is removed, there is a hole in the aneurysm wall. *G*, Rupture site marked in in gold. Sample 4: *H*, Dome of ruptured aneurysm resected after ligation. *I*, Mural hematoma observed at the distal end of the resected dome. *J*, Rupture site marked in in gold.



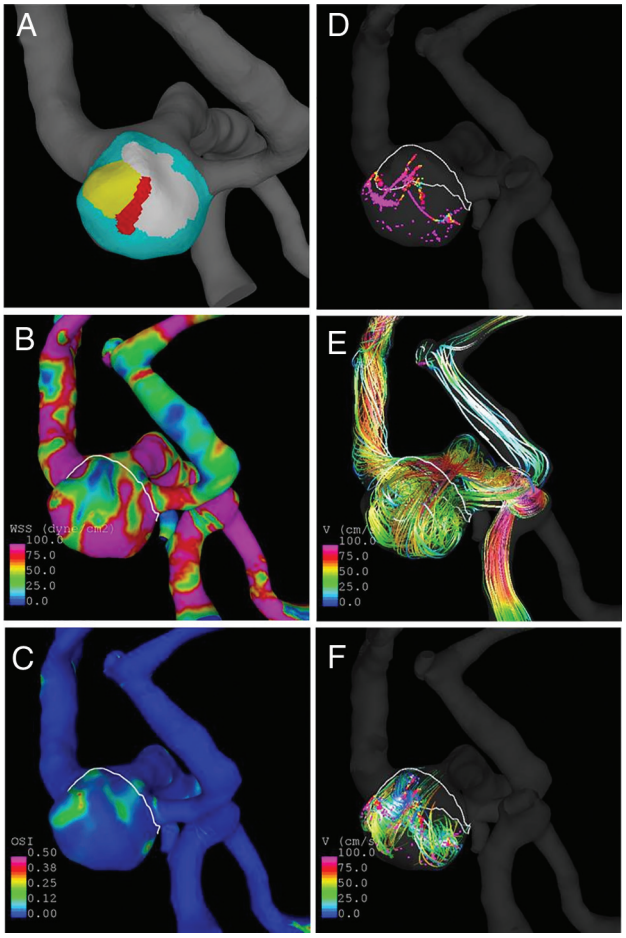
ON-LINE FIG 2. Sample aneurysm with a thin region. *A*, Wall regions (red indicates thin; white, hyperplastic; cyan, normal-appearing). *B*, Wall shear stress. *C*, Oscillatory shear index. *D*, Vortex core lines. *E*, Flow streamlines. *F*, Swirling around vortex core lines.



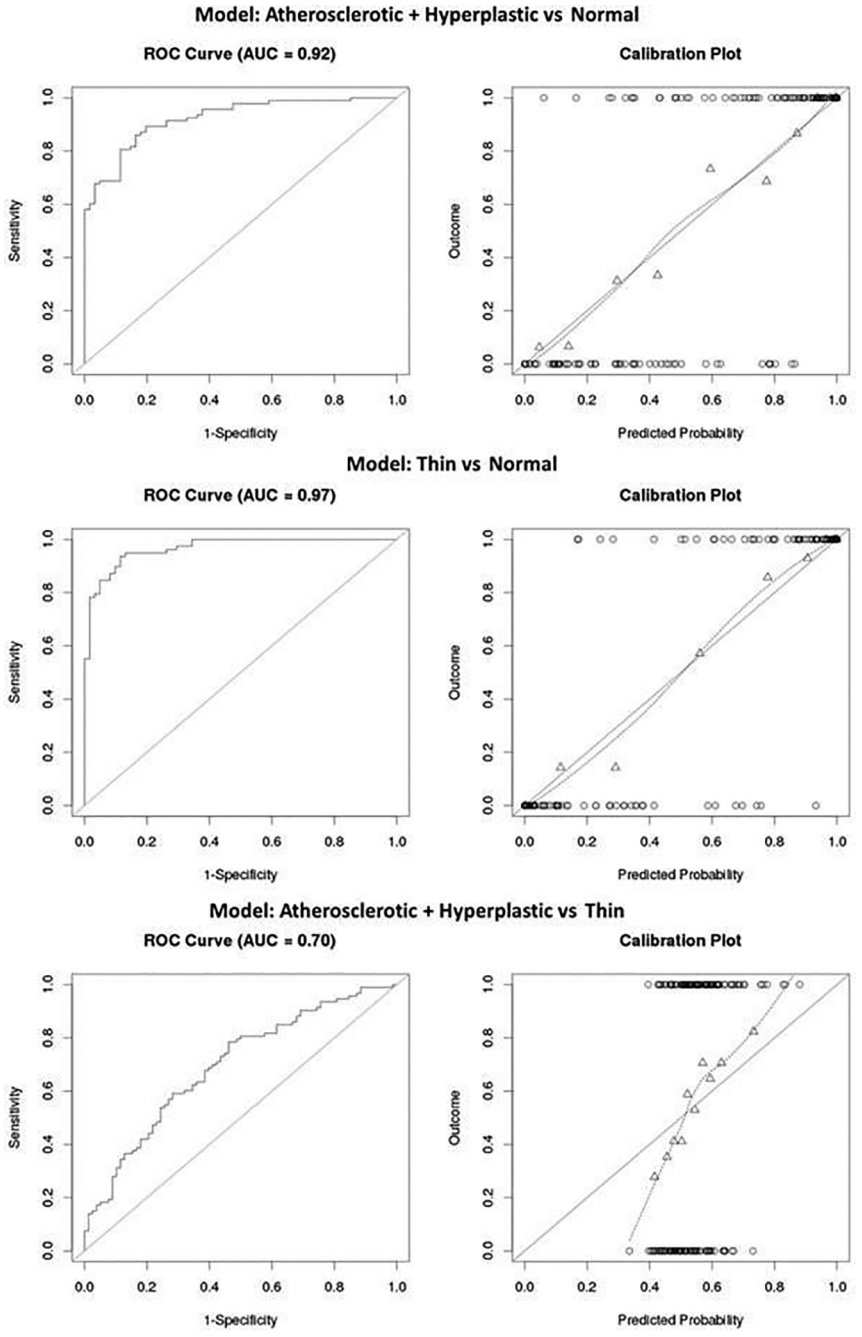
ON-LINE FIG 3. Sample aneurysm with a hyperplastic region. *A*, Wall regions (red indicates thin; white, hyperplastic; cyan, normal-appearing). *B*, Wall shear stress. *C*, Oscillatory shear index. *D*, Vortex core lines. *E*, Flow streamlines. *F*, Swirling around vortex core lines.



ON-LINE FIG 4. Sample aneurysm with thin and atherosclerotic regions. *A*, Wall regions (red indicates thin; yellow, atherosclerotic; cyan, normal-appearing). *B*, Wall shear stress. *C*, Oscillatory shear index. *D*, Vortex core lines. *E*, Flow streamlines. *F*, Swirling around vortex core lines.



ON-LINE FIG 5. Sample aneurysm with thin, hyperplastic, and atherosclerotic regions. *A*, Wall regions (red indicates thin; yellow, atherosclerotic; white, hyperplastic; cyan, normal-appearing). *B*, Wall shear stress. *C*, Oscillatory shear index. *D*, Vortex core lines. *E*, Flow streamlines. *F*, Swirling around the vortex core lines.



ON-LINE FIG 6. Receiver operating characteristic (ROC) curves (left) and calibration plots (right) for 3 multivariate models that discriminate between different regions. *Upper row*, Atherosclerotic and hyperplastic versus normal-appearing regions. *Center row*, Thin versus normal-appearing regions. *Lower row*, Atherosclerotic and hyperplastic versus thin regions.