On-line Table 1: Hemodynamic parameters most commonly defined in the IA literature

Parameter Abbreviation	Parameter Name	Unit	Definition
WSS or TAWSS	Time-averaged wall shear stress	Pa	$\mathrm{WSS} = \frac{1}{\mathrm{T}}\int_0^{\mathrm{T}} \lvert wss \rvert \, \mathrm{dt}$ *wss,* instantaneous shear stress vector; T, cycle period
Normalized WSS	Time-averaged wall shear stress, normalized by parent vessel WSS[4]	None	$\mathrm{WSS} = \dfrac{\frac{1}{\mathrm{T}}\int_0^{\mathrm{T}} \lvert wss_a \rvert \mathrm{dt}}{\frac{1}{\mathrm{T}}\int_0^{T} \lvert wss_v \rvert \mathrm{dt}}$ wss_a, wss_v, instantaneous shear stress vector for the aneurysm and parent artery; T, cycle period
OSI	Oscillatory shear index[4]	None	$\mathrm{OSI} = \frac{1}{2}\left\{ 1 - \dfrac{\left\lvert \int_0^{\mathrm{T}} wss\mathrm{dt} \right\rvert}{\int_0^{\mathrm{T}} \lvert wss \rvert \mathrm{dt}} \right\}$ *wss,* instantaneous shear stress vector; T, cycle period
WSSG	Wall shear stress gradient[4]	Pa/m	$\mathrm{WSSG} = \frac{1}{\mathrm{T}}\int_0^{\mathrm{T}} \frac{\partial wss}{\partial \mathrm{m}} \mathrm{dt}$ *wss,* instantaneous shear stress vector; m: flow direction
GON	Gradient oscillatory number[60]	None	$\mathrm{GON} = 1 - \dfrac{\lvert \int_0^{\mathrm{T}} WSSG\mathrm{dt} \rvert}{\int_0^{\mathrm{T}} \lvert WSSG \rvert \mathrm{dt}}$ *WSSG*, instantaneous wall shear stress gradient vector; T, cycle period
MWSS	Maximum time-averaged aneurysmal wall shear stress[5]	Pa	$\mathrm{MWSS} = \max_{\mathrm{A_a}}\left(\frac{1}{\mathrm{T}}\int_0^{\mathrm{T}} \lvert wss_a \rvert \mathrm{dt} \right)$ A_a, aneurysmal area
Normalized MWSS	Maximum time-averaged wall shear stress, normalized by parent vessel WSS[4]	None	$\mathrm{MWSS} = \max_{\mathrm{A_a}}\left(\dfrac{\frac{1}{\mathrm{T}}\int_0^{\mathrm{T}} \lvert wss_a \rvert \mathrm{dt}}{\frac{1}{\mathrm{T}}\int_0^{\mathrm{T}} \lvert wss_v \rvert \mathrm{dt}} \right)$ A_a, aneurysmal area
LSA	Low shear-stress area percentage	None	$\mathrm{LSA} = \mathrm{A_l}/\mathrm{A_a}$ A_l, low WSS aneurysmal area $<10\%$[4,13] or 1 standard deviation[5] of parent vessel WSS, or <0.4 Pa[30]
RRT	Relative residence time[4]	Pa^{-1}	$\mathrm{RRT} = \dfrac{1}{\frac{1}{\mathrm{T}}\left\lvert \int_0^{\mathrm{T}} wss\mathrm{dt} \right\rvert}$ *wss,* instantaneous shear stress vector; T, cycle period

On-line Table 1: Continued

Parameter Abbreviation	Parameter Name	Unit	Definition
NV	Number of vortices[4]	None	Count on the velocity field of the representative cross-sectional plane
ICI	Inflow concentration index[5]	None	$ICI = \frac{Q_{in}/Q_v}{A_{in}/A_o}$ Q_{in}, inflow rate to aneurysm; Q_v, vessel flow rate; A_{in}, area of inflow region; A_o, area of ostium surface
SCI	Shear concentration index[5]	None	$SCI = \frac{F_h/F_a}{A_h/A_a}$ F_h and F_a, shear forces over high WSS (A_h, >1 standard deviation of parent vessel WSS) and entire aneurysm (A_a)
VDR	Viscous dissipation ratio[5]	None	$VDS = \frac{\int_{V_a} 2\mu/\rho(e_{ij}e_{ij})dV/V_a}{\int_{V_{near}} 2\mu/\rho(e_{ij}e_{ij})dV/V_{near}}$ e_{ij}, strain rate tensor; V_a, aneurysm volume; V_{near}, near vessel volume
KER	Kinetic energy ratio[5]	None	$KER = \frac{\int_{V_a} 1/2 \cdot u^2dV/V_a}{\int_{V_{near}} 1/2 \cdot u^2dV/V_{near}}$ V_a, aneurysm volume; V_{near}, near vessel volume; u, velocity
LSI	Low shear index[5]	None	$LSI = \frac{F_l \cdot A_l}{F_a \cdot A_a}$ F_l and F_a, shear forces over high WSS (A_l, >1 standard deviation of parent vessel WSS) and entire aneurysm (A_a)
EL	Energy loss[28,31]	Pa/s	$EL = \frac{v_{in}A_{in} \cdot \left\{\left(\frac{1}{2}\rho v_{in}^2 + P_{in}\right) - \left(\frac{1}{2}\rho v_{out}^2 + P_{out}\right)\right\}}{V_m}$ v_{in} and v_{out}, inlet and outlet vessel velocity; A_{in} and A_{out}, inlet and outlet vessel area
PLc	Pressure loss coefficient[28,31]	None	$PLc = \frac{\left(\frac{1}{2}\rho v_{in}^2 + P_{in}\right) - \left(\frac{1}{2}\rho v_{out}^2 + P_{out}\right)}{\frac{1}{2}\rho v_{in}^2}$ v_{in} and v_{out}, inlet and outlet vessel velocity; P_{in} and P_{out}, inlet and outlet pressure

On-line Table 2: Summary of literature investigating the relationship between aneurysmal hemodynamics and aneurysm growth

First Author	Year	No. of Aneurysms (Total: Growing + Stable)	Location	Follow-Up Time	Inlet Boundary Condition	Parameters	Definition of Growth and Analytic Method	Main Findings
Jou[1]	2005	2 Fusiform: 1 + 1	BA	2 y	Patient-specific inflow	WSS, pressure	Plot histograms of WSS area at different WSS level	Growth at very low WSS (<0.1 Pa) No change in flow pattern with time Pressure uniformly distributed
Acevedo-Bolton[2]	2006	1 Growing fusiform	BA	5 y	Patient-specific inflow	WSS		Altering flow ratio of 2 vertebral arteries reduces low WSS in the growth region CFD validated in vivo and in vitro
Boussel[17]	2008	7 Growing	BA: 3 ICA: 3 MCA: 1	1~3 y	Patient-specific inflow	TAWSS	>0.3 mm during followed time	Significant relationship between WSS and surface displacement Growth probably occurs at low WSS
Sugiyama[3]	2011	2 Growing	PICA	1 y	Patient-specific inflow	TAWSS		Growing aneurysms could be in the high WSS impact zone and also low WSS and high OSI region
Sforza[19]	2012	25: 7 + 18			Typical pulsatile inflow	WSS	>0.5 mm/y	3 Growing aneurysms in high WSS regions; 2 in lower region and the remaining 2 with the same WSS as non-growth region

Note:—BA indicates basilar artery; PICA, posterior inferior cerebellar artery.

On-line Table 3: Summary of literature investigating the relationship between aneurysmal hemodynamics and aneurysm rupture

First Author	Year	No. of Aneurysms (Total: Ruptured + Unruptured)	Location	Inlet Boundary Condition	Parameters	Statistical Methods	Main Findings
Shojima[12]	2004	20: 3 + 17	MCA	Pulsatile, same mean flow velocity: 0.6 m/s	MWSS and mean WSS at peak systole	*t* Test	Maximum WSS at neck region, higher than vessel value Mean aneurysmal WSS significantly lower than vessel value Mean WSS at peak: significantly higher for ruptured IAs Tip of ruptured IAs with recirculating flow and markedly low WSS (<0.5 Pa), compared with unruptured tip (1.7 Pa)
Shojima[33]	2005	29: 14 + 15	ICA, MCA, ACA	Pulsatile, same mean flow velocity	Pressure at peak systole	*t* Test, ANOVA	Pressure elevation at the area of flow impact constituted 1~2% of systolic pressure Pressure: No significant difference between ruptured and unruptured IAs, also for different locations Pressure elevation has less contribution to rupture
Cebral[20]	2005	62: 25 + 34		Pulsatile, same mean flow rate	Flow complexity, stability, inflow concentration, impingement	Multiple logistic regression	Rupture IAs found with complex, unstable, small impingement, and small jet Only impingement size achieved significance
Hassan[21]	2005	68: 45 + 23	MCA, ACA, AcomA	Pulsatile	WSS at peak systole		Wide-neck IAs: high flow Narrow-neck sidewall IAs: high pressure and flow stasis
Valencia[34]	2008	34: 15 + 14	Not specified	Pulsatile, same mean flow velocity: 0.37 m/s	Vortex, pressure, spatial mean WSS over peak systole		Highest WSS occurred at neck Very low WSS found in the ruptured IAs WSS correlated with aneurysm-inlet vessel area ratio in both ruptured and unruptured

On-line Table 3: Continued

First Author	Year	No. of Aneurysms (Total: Ruptured + Unruptured)	Location	Inlet Boundary Condition	Parameters	Statistical Methods	Main Findings
Jou[13]	2008	26: 8 + 18	ICA	Pulsatile, same inlet flow rate (diastole 2.6 mL/s)	Normalized WSS, MWSS, low WSS area% (<10% vessel WSS) at the end of diastole	Rank sum test	Similar MWSS (26 versus 23 Pa) for ruptured and unruptured Ruptured IAs have larger low WSS area (27% versus 11%, $P = .03$) Low WSS found at dome, high WSS found at distal neck Small mean WSS in ruptured IAs, not significant
Chien[61]	2008	6: 2 + 4	Small ICA	Pulsatile, same WSS inlet BC	Normalized WSS, absolute WSS at peak systole	Significant test	Low WSS in aneurysm compared with parent artery Highest WSS at neck region Absolute aneurysmal WSS value not significant, parent vessel WSS not significant, normalized WSS significant for ruptured and unruptured IAs
Castro[23]	2009	26: 8 + 18	AcomA	Pulsatile, same inlet WSS (1.5 Pa)	MWSS at systolic peak	Wilcoxon rank sum test	Higher MWSS in ruptured IAs, $P = .1$ High WSS found in dome
Castro[22]	2009	42: 25 + 17	AcomA, MCA, BA tip, ICA terminus, ACA	Pulsatile, same inlet WSS (1.5 Pa for ICA inlet and 1 Pa for BA inlet)	MWSS at systolic peak	*t* Test	MWSS significant in ruptured IAs, with $P = .04$
Chien[25]	2009	8: 4 + 4	Small ICA	Pulsatile, same WSS inlet BC	WSS in aneurysmal neck, body and dome circumference at peak systole	Significant test	WSS in aneurysmal sac lower than parent artery WSS Higher WSS in ruptured IAs, compared with unruptured IAs
Chien[24]	2009	24	MCA, ICA, BA, AcomA	Pulsatile, same WSS inlet BC	WSS at peak systole	Spearman rank correlation	Lower WSS in aneurysm sac than parent vessel Different aneurysm locations with different WSS
Cebral[26]	2010	20	MCA, AcomA, PcomA, ICA, BA	Pulsatile, same inlet WSS (1.5 Pa)	WSS	*z* Test	80% Blebs occurred at highest WSS regions Once blebs were formed, 90% progressed to low WSS 77% Blebs located at inflow jet

On-line Table 3: Continued

First Author	Year	No. of Aneurysms (Total: Ruptured + Unruptured)	Location	Inlet Boundary Condition	Parameters	Statistical Methods	Main Findings
Xiang[4]	2011	119: 38 + 81	ICA, MCA, PcomA, PCA, AcomA, ACA, BA, PICA, VA	Pulsatile, same flow rate 4.6 mL/s for ICA, aneurysmal WSS normalized by parent vessel WSS	Time and spatial mean WSS further normalized by parent vessel WSS, MWSS, LSA, WSSG, OSI, RRT, NV	*t* Test, receiver operating characteristic, and multivariate logistic regression	Most ruptured IAs had complex flow and multiple vortices Significantly smaller WSS, MWSS and larger OSI, RRT, LSA, NV in ruptured IAs Normalized TAWSS and OSI were the only independently significant variables in the hemodynamics rupture risk model
Lu[27]	2011	18: 9 + 9	ICA, MCA, ACA	Pulsatile, same mean velocity	WSS at peak systole, low WSS area % (<1.5 Pa), OSI	Wilcoxon test	Larger low WSS area in ruptured IAs (P = .012) Lower WSS in ruptured IAs Higher OSI in ruptured IAs (P = .008) No difference between parent vessel WSS in both groups
Zhang[29]	2011	54:43 + 11	ICA, PcomA, AcomA, MCA, BA	Pulsatile	WSS, OSI at peak systole	χ^2 significant test	Daughter blebs have significantly lower WSS and higher OSI than primary aneurysms Ruptured IAs had lower WSS
Cebral[43]	2011	210	Not specified	Pulsatile, same inlet WSS (1.5 Pa)	Flow complexity, stability, inflow concentration, impingement	χ^2 significant test	Rupture IAs were more likely to have complex flow patterns (P < .001), stable flow patterns (P = .0018), concentrated inflow (P < .0001), and small impingement regions (P = .0006)
Cebral[5]	2011	210	Not specified	Pulsatile and steady, same inlet WSS, 1.5 Pa with different heart rates	Time-averaged MWSS, SCI, VDR, LSA	Student *t* test	Significant: higher MWSS, ICI, and SCI and lower VDR Not significant: LSA, KER, LSI

On-line Table 3: Continued

First Author	Year	No. of Aneurysms (Total: Ruptured + Unruptured)	Location	Inlet Boundary Condition	Parameters	Statistical Methods	Main Findings
Goubergrits[30]	2012	22: 7 + 15	MCA	Pulsatile, same flow rate 3.7 mL/s	Time and spatial mean WSS, low WSS% (<0.4 Pa), statistical WSS map	Mann-Whitney *U* test	WSS: no significant difference Statistical WSS map: larger continuous area of higher WSS in the dome; larger areas of low WSS; overall significant low WSS with ruptured IAs
Qian[28]	2011	30: 4 + 26	ICA-PcomA	Pulsatile, same inlet flow rate 4.23 mL/s	EL, WSS at peak systole	Significant test	Significantly higher EL in ruptured IAs Mean WSS: no significant difference
Tako[31]	2012	100: 13 + 87	ICA, MCA	Pulsatile, same inlet flow rate	Time mean WSS, MWSS, minimum WSS, EL, PLc, OSIMAX, OSIAVE	*t* Test or rank sum test, Bonferroni method	ICA: minimum WSS significantly lower in ruptured IAs Higher EL in ruptured IAs, not significant PLc significant in both ICA and MCA IAs
Omodaka[35]	2012	6: 6 + 0	MCA	Pulsatile, same inlet flow rate 3.08 mL/s	Time-averaged WSS, OSI	Wilcoxon *t* test	TAWSS at rupture point was significantly lower than that at the aneurysm wall without rupture point ($P = .031$) OSI at rupture point was lower than that at the aneurysm wall without rupture point ($P = .156$)
Kawaguchi[62]	2012	150: 13 + 137	MCA, ICA, AcomA, ACA, VA, BA	Pulsatile	Time-averaged WSS, OSI	Student *t* test	Aneurysm blebs in both ruptured and unruptured aneurysm manifested low WSS and high OSI WSS was significantly lower in ruptured than in unruptured blebs
Miura[37]	2013	106: 43 + 63	MCA	Pulsatile	WSS, Normalized WSS, OSI, WSSG, GON	Wilcoxon *t* test, multivariate logistic regression	Significant parameters: WSS, Normalized WSS, OSI, WSSG WSS is the only independently significant parameter
Xu[38]	2013	16: 8 + 8	Mirrored PcomA	Pulsatile	Normalized WSS, OSI	Wilcoxon test	Significant parameters: normalized WSS

ACA indicates anterior cerebral artery; AcomA, anterior communicating artery; BA, basilar artery; LSA, low shear-stress area; PcomA, posterior communicating artery; PICA, posterior inferior cerebellar artery; VA, vertebral artery; WSSG, WSS gradient; PCA, posterior cerebral artery; BC, boundary condition; OSIMAX, maximum oscillatory shear index; OISAVE, average oscillatory shear index; PLc, pressure loss coefficient; RRT, relative residence time; NV, number of vortices; ICI, inflow concentration index; SCI, shear concentration index; VDR, viscous dissipation ratio; KER, kinetic energy ratio; LSI, low shear index; EL; energy loss.