Point-wise investigation of the effects of ICA flow variability on aneurysmal haemodynamics

When studying complex flows patterns induced by the IA morphology and the systemic flow conditions, it is important to characterize the local shear stresses which subsequently drive region-specific endothelial cell (EC) phenotypes. To provide more intuition into the effects of parent vessel flow waveform variability, we illustrated the results for five manually selected representative points on the aneurysm sacs. For both cases, the selected points correspond to the maximum and minimum TAWSS on the sac (points 1 and 5, respectively) and other locations where flow was impinging on the wall (point 2 on aneurysm 2), or where flow was highly multidirectional (all other points). For these five points, Fig. 1 shows the ranges of variation of OSI and rTransWSS over the virtual population. As depicted, both OSI and rTransWSS are at their minimums at point 1 where shear stresses are high and almost unidirectional. Effects of ICA flow waveform variations on both directionality measures are very limited at this point on both aneurysms. However, the effects are greater at other points with maximums occurring at point 5 where the shear stresses are small and multidirectional. Mohamied et al. [1] showed that both OSI and rTransWSS are required to capture the time-varying directionality aspect of WSS vectors. Similarly, on the aneurysms in this study, there are locations where the directionality could not be captured by neither OSI nor rTransWSS alone. For example, at point 4 in both patients, blood flow is not oscillatory (very low OSI) but moderately multidirectional (higher rTransWSS). At points 2 and 3 on aneurysm 1, OSI values are far above the half range, which indicates highly oscillatory flow at this points; in contrast, rTransWSS shows moderate directionality at these points. Xiang et al. [2] showed a linear correlation between parent vessel flow pulsatility index and space-averaged OSI over the aneurysm sac and suggested that parent vessel's waveform influences space-averaged aneurysmal OSI mainly through pulsatility of the flow waveform. To investigate if the same applies on the regional directionality of WSS vectors, we examined any possible correlation between local aneurysmal WSS directionality (OSI and rTransWSS) and flow pulsatility index (PI) in the parent vessel. In Table 1, Pearson's correlation co efficient and p-values are reported for correlation tests between parent vessel flow PI and both OSI and rTransWSS at each of the 5 points on the aneurysm sacs. In Patient 1, where flow is generally more regular than in patient 2, strong correlations were observed at points 1 and 4 (Pearson $r = 0.93$ and 0.94 for OSI and Pearson $r = 0.85$ and 0.86 for rTransWSS, respectively). Moderate or weak correlations were observed at other points on the aneurysms.

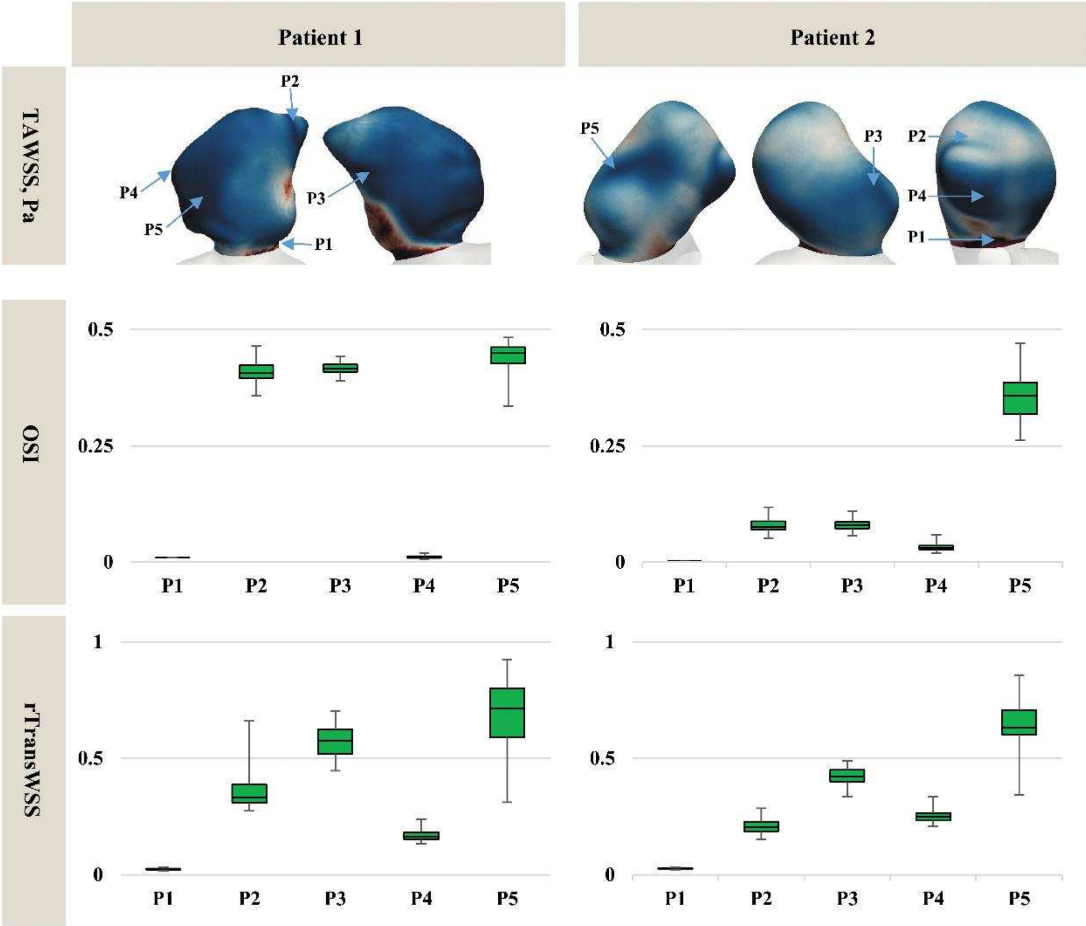

Figure 1. Aneurysmal population mean TAWSS maps with the manually selected points shown by arrows (first row) and the effect of parent vessel flow waveform variability on oscillatory shear index (OSI) and relative transverse WSS (rTransWSS) at each point.

Table 1. Pearson correlation coefficients and p-values for pairwise comparisons between each flow waveform PI and the corresponding OSI and rTransWSS at each of the 5 points on the aneurysm sacs.

	Patient 1				**Patient 2**			
	PI vs OSI		PI vs rTransWSS		PI vs OSI		PI vs rTransWSS	
	r	*p-value*	*r*	*p-value*	*r*	*p-value*	*r*	*p-value*
P1	0.93**	< 0.001	0.85**	< 0.001	0.64**	< 0.001	0.63**	< 0.001
P2	-0.58**	< 0.001	0.71**	< 0.001	-0.05	0.73	0.28*	0.05
P3	0.01	0.93	-0.10	0.48	0.49**	< 0.001	0.46**	< 0.001
P4	0.94**	< 0.001	0.86**	< 0.001	0.38*	0.007	0.41*	0.003
P5	-0.72**	< 0.001	-0.15	0.29	0.11	0.45	-0.03	0.83

References

[1] Y. Mohamied, E. M. Rowland, E. L. Bailey, S. J. Sherwin, M. A. Schwartz, P. D. Weinberg, Change of direction in the biomechanics of atherosclerosis, Ann. Biomed. Eng. 43(1) (2015) 16–25.

[2] J. Xiang, A. Siddiqui, H. Meng, The effect of inlet waveforms on computational hemodynamics of patient-specific intracranial aneurysms, J. Biomech. 47(16) (2014) 3882–3890.