High pressure in virtual post-coiling model is a predictor of internal carotid artery aneurysm recurrence after coiling

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Introduction

Hemodynamic factors may play a crucial role in the recurrence of intracranial aneurysms after coiling. However, the strongest factor for predicting recurrence remains unclear because each risk factor has been investigated and reported separately.We clarified the strongest predictor of recurrence with computational fluid dynamics (CFD).

Methods

Using pre-treatment patient-specific three-dimensional rotational angiography data of 50 internal carotid artery aneurysms (7 recanalized and 43 stable) treated with endovascular coiling (Table 1), we created a pre-coiling model and a virtual post-coiling model produced by manually cutting the aneurysm by the flat plane corresponding to the virtual coil surface (Figure 1).

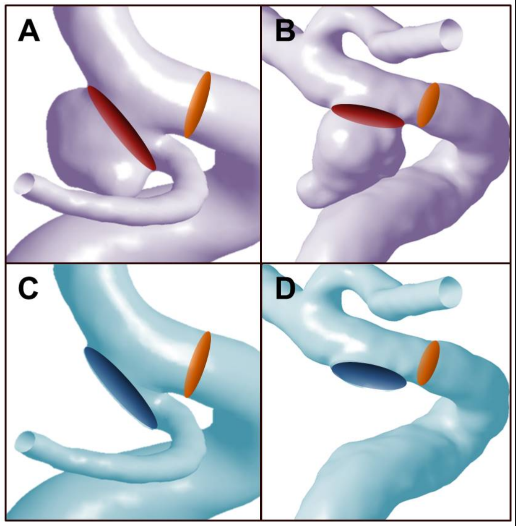
Table 1: Patients and morphological characteristics

Variable	Recanalized n=7	Stable n=43	p value
Age	65±14	58±13	0.203
Female (%)	5 (71.4)	40 (93.0)	0.138
Ruptured (%)	5 (71.4)	10 (23.3)	0.020
Maximum size, mm	11.5±2.6	8.3±2.5	0.010
Neck width, mm	6.8±2.1	5.0±1.5	0.052
Aspect ratio	1.29±0.61	1.25±0.33	0.665
Bottleneck factor	1.70±0.66	1.54±0.35	0.706
Size ratio	2.48±0.55	2.33±0.83	0.476
VER, %	22.5±3.5	24.8±4.5	0.158

Hemodynamic models

The fluid domains of both pre-coiling and virtual post-coiling model were meshed using the ANSYS ICEM CFD software. Blood was modeled as a Newtonian fluid with a density of 1100 kg/m3 and a viscosity of 0.0036 Pa·s. A rigid-wall no-slip boundary condition was implemented at the vessel walls. We performed a pulsatile-flow simulation with ANSYS CFX (version 16.2, ANSYS Inc., Canonsburg Pennsylvania). Zero pressure was imposed at the outlets. Calculations were performed for 2 cardiac cycles, and the result of the second cycle was used for analysis.

Figure 1



A and B: The pre-coiling model shows the neck plane (red) and the inlet plane (orange). C and D: The virtual post-coiling model shows the coil plane (blue) and the inlet plane (orange).

We investigated inflow dynamics in the pre-coiling model including inflow area, neck area, inflow rate ratio, and velocity ratio. We also examined pressure difference and wall shear stress on the virtual coil plane.

Pressure difference was defined as the degree of pressure elevation at the coil plane from the inlet plane. This value was divided by the dynamic pressure at the inlet plane for normalization. These values were analyzed at peak systole.

Equation

$$Inflow\ rate\ ratio = \frac{Inflow\ rate\ (neck)}{Flow\ rate\ (inlet)}$$

$$Velocity\ ratio = \frac{Max\ Velocity\ (neck)}{Ave\ Veclocity\ (inlet)}$$

$$Pressure\ differece = \frac{Max\ P\ (coil) - Ave\ P\ (inlet)}{\frac{1}{2}\rho V\ (inlet)^2}$$

P: pressure, V: velocity
ρ: density, $1100\ kg/m^3$

We compared hemodynamic parameters in the two models between recanalized and stable aneurysms.

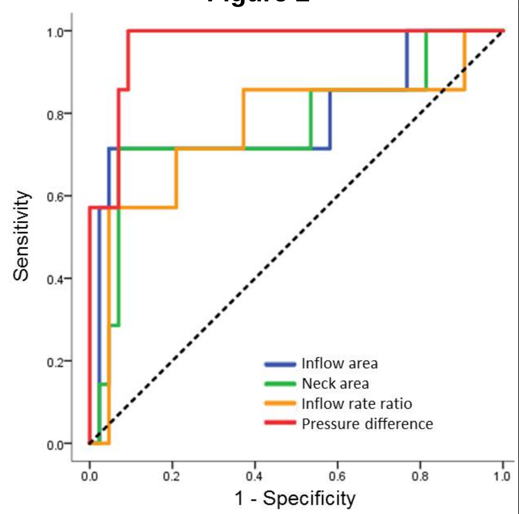
Results

Compared with stable aneurysms, recanalized aneurysms showed significantly larger inflow area and higher inflow rate ratio in the pre-coiling model ($p = 0.016, 0.028$) and higher pressure difference at the coil plane in the post-coiling model ($p < 0.001$)(Table 2). The receiver-operating characteristics analysis showed that the area under the curve value for the pressure difference (0.967) was superior to other evaluated parameters (Figure 2).

Table 2: Hemodynamic characteristics

	Parameter	Recurrence n=7	Stable n=43	p value
Pre-coiling model	Inflow area at neck plane, mm^2	15.0±7.1	7.6±4.5	0.016
	Area of neck plane, mm^2	40.1±19.1	21.2±13.8	0.024
	Inflow rate ratio	0.70±0.35	0.38±0.25	0.028
	Velocity ratio	1.86±0.32	1.78±0.27	0.409
Post-coiling model	Average wall shear stress, Pa	14.0±5.6	14.9±7.9	0.834
	Maximum wall shear stress, Pa	60.1±21.8	56.5±28.4	0.476
	Pressure difference	3.60±0.78	2.15±0.64	< 0.001

Figure 2



The ROC curve for pressure difference (red line) at the coil plane shows that the AUC was 0.967 (95% CI: 0.920-1.000) with the cut-off value of 2.83 having a sensitivity of 100% and specificity of 90.7%.

Conclusions

The virtual post-coiling model makes it easy to evaluate hemodynamic strength on the virtual coil surface before actual coiling. Pressure difference in the virtual post-coiling model may be a strong predictor of recurrence after coiling. The results of this study suggest that a tight packing density should be achieved and careful follow-up is necessary when treating ICA aneurysms with a high pressure difference at the virtual coil surface.