

# Experimental Analysis of Intra-luminal Pressure by Contrast Injection during Mechanical Thrombectomy: Simulation of Rupture Risk of Hidden Cerebral Aneurysm in Tandem Occlusion with Blind Alley

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## Abstract

Mechanical thrombectomy using a retrograde approach is performed for tandem occlusion of the internal carotid artery (ICA). In our patient, a guiding catheter was easily passed by the stenosed lesion despite severe stenosis at the ICA origin. Therefore, we aimed to recanalize the occlusion of the terminal ICA without angioplasty for the stenosed lesion. When contrast was injected, a massive extravasation of contrast from the C2 portion of the ICA was observed. It was speculated that the bleeding was caused by rupture of an aneurysm at that site due to increased intra-arterial pressure caused by the contrast injection to a blind alley, which was created by a wedged guiding catheter at severe stenosis at the ICA origin and the occlusion of the terminal ICA. Our simulation experiment using a silicon vascular model in this situation demonstrated that the elevation of intra-arterial pressure in such blind alley reached over 50, 100, and 200 mmHg by injection of contrast from a microcatheter, a 4-Fr inner catheter, and a 9-Fr balloon-guiding catheter, respectively. When a retrograde approach is planned for tandem occlusion of the ICA, even when the proximal lesion is easily passed, prior angioplasty for the proximal lesion should be considered to avoid wedging by catheter.

Key words: mechanical thrombectomy, contrast injection, tandem occlusion, retrograde approach, rupture of aneurysm

## Introduction

The effectiveness of mechanical thrombectomy (MT) for cerebral large vessel occlusion (LVO) has been demonstrated and the use of MT has quickly become the standard treatment for LVO. On the other hand, the prevalence of cerebral aneurysm in the adult population is said to be 3.6–6%;<sup>1)</sup> thus, coexisting cerebral aneurysms in occluded vessels can be encountered during MT. Almost all of these aneurysms are hidden in the occluded vessels and cannot be identified unless the

occlusion is recanalized. There are some reports of the rupture of such hidden aneurysms during MT by withdrawal of stent retriever or during thrombolytic therapy.<sup>2,3)</sup> However, there are no reports in which the contrast injection caused rupture of the hidden aneurysm. Recently, we experienced aneurysmal rupture caused by injection of contrast from a balloon-guiding catheter (BGC) located at the origin of the internal carotid artery (ICA) in a patient with tandem ICA occlusion, in which the ICA origin was wedged guiding catheter, creating a blind alley. Based on this case, we conducted a simulation analysis to evaluate the intra-luminal pressure of the ICA during contrast injection in various situations, particularly focusing on tandem ICA occlusion with wedge of the proximal lesion using a silicon vascular model.

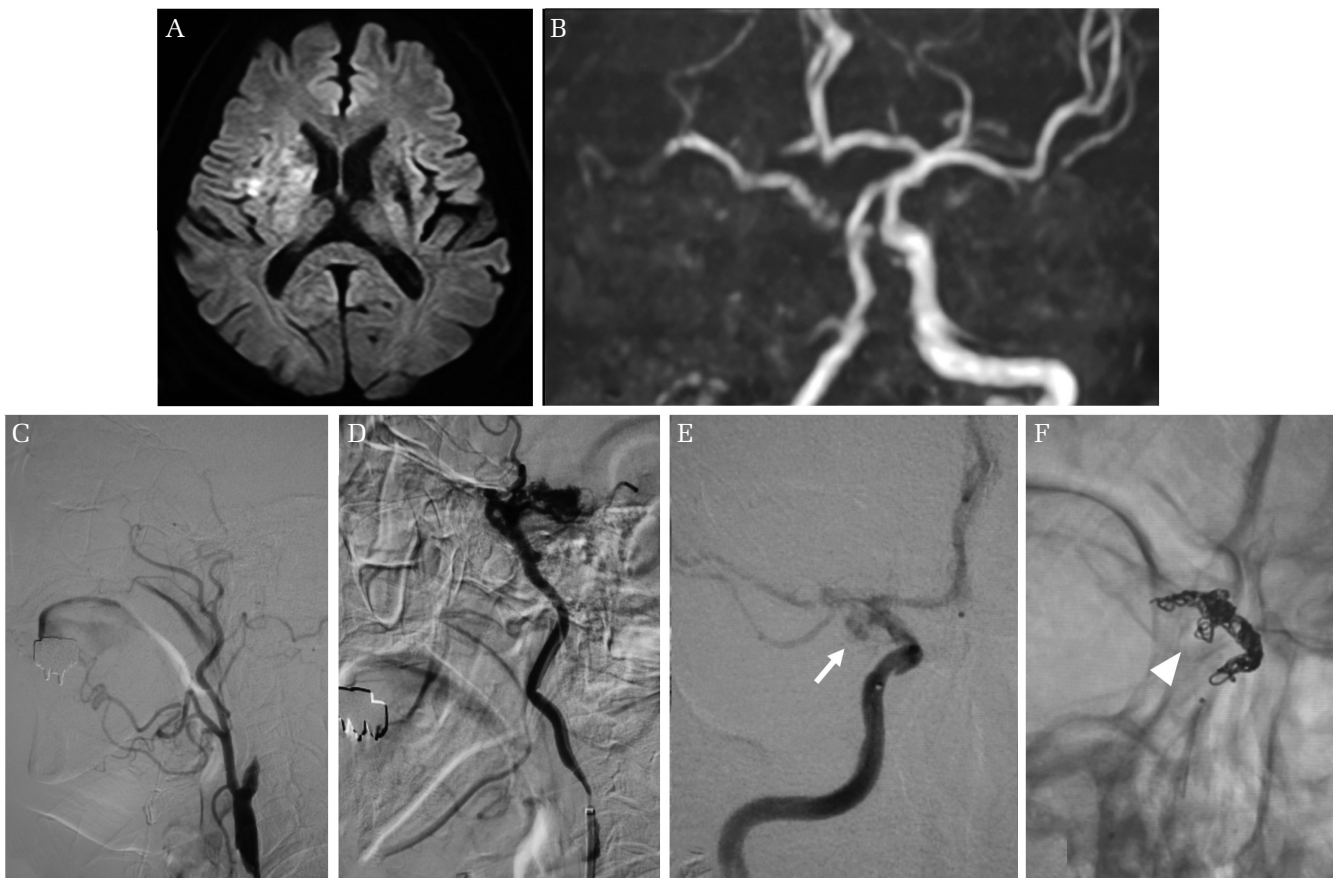
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## Materials and Methods

The case which motivated us to perform the experimental simulation is presented below (Fig. 1). Based on the characteristics of this case, we conducted a simulation analysis using a vascular model of an endovascular surgery training-evaluation-simulator (EVE, FINE-biomedical, Aichi, Japan). We created a pulsatile flow circuit with saline using a pulsatile pump (FINE-biomedical, Aichi, Japan; perfusion pressure: systolic 100 mmHg, diastolic 80 mmHg) from the CCA to the anterior cerebral artery (ACA) and middle cerebral artery (MCA), with intra-luminal pressure monitoring via a transducer set at the posterior communicating artery. Contrast was injected three ways: (a) from a 9-Fr BGC (inner diameter; 0.090 inch, inner volume; 4.2 cc) positioned at the ICA origin, (b) from a 4-Fr inner catheter (inner diameter; 0.048 inch, inner volume; 1.4 cc) positioned

at the proximal portion of the cervical ICA, and (c) from a microcatheter (inner diameter; 0.017 inch, inner volume; 0.41 cc) positioned at the siphon of the ICA (Fig. 2). Intra-luminal pressure during contrast injection was monitored during several situations by combination of a clamp on the ACA and MCA, and balloon occlusion of the ICA origin by the BGC. The simulation models are shown in Fig. 3 and were set as follows. (A) was the control model in which each vessel was open, (B) was the MCA occlusion (MCAO) model in which the MCA was occluded, (C) was the ICA occlusion (ICAO) model in which both the MCA and ACA were occluded, and (D) was the tandem ICAO model in which both the MCA and ACA were occluded and the ICA origin was occluded by the balloon. OYPALOMIN [Fuji Pharma, Toyama, Japan; Iopamidol (iodine concentration 300 mg/mL and osmotic pressure 2.3–2.8 times that of saline)] was used as the contrast. Contrast was injected by auto-injector under



**Fig. 1** Patient imaging findings. (A) Diffusion-weighted magnetic resonance image shows hyper-intensity lesion in the right middle cerebral artery territory. (B) Magnetic resonance angiography shows occlusion of the right internal carotid artery (ICA). (C) The right ICA angiogram shows occlusion at the ICA origin. (D) Injection from the 9-Fr guiding catheter (GC) demonstrates massive extravasation from the terminal ICA. The origin of the ICA is wedged by the GC. (E) The delayed phase of the right ICA angiogram shows aneurysm-like dilatation at the terminal ICA (*arrow*). (F) The plain skull craniogram after parent artery occlusion shows a coil mass distributed at the terminal ICA. Some coil loop is distributed into the aneurysmal-like dilatation (*arrow-head*).

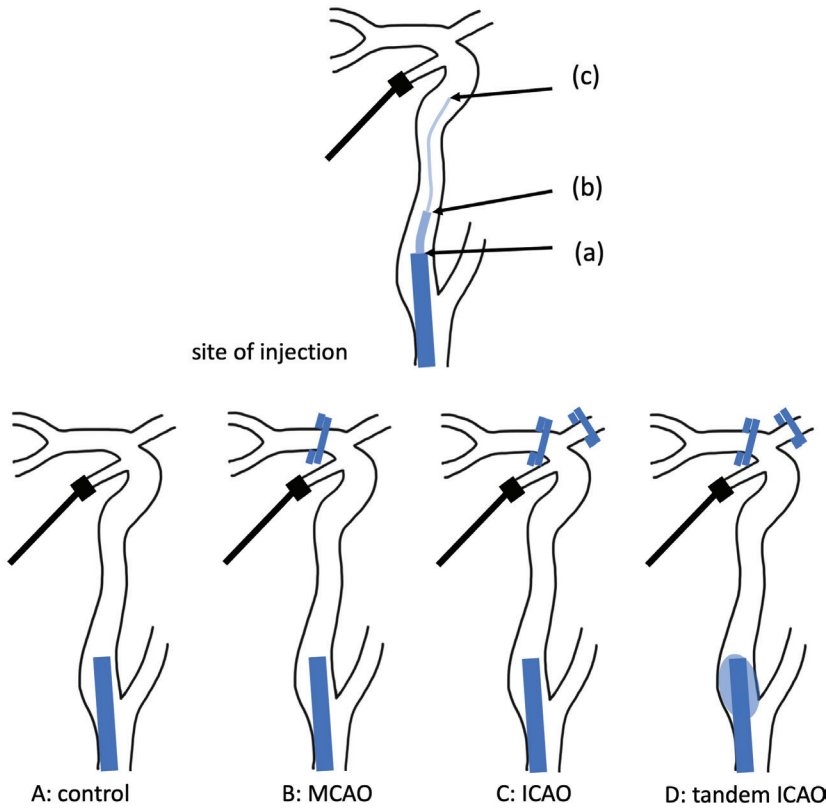


Fig 2 Schematic view of the vascular model. The upper illustration shows the site of injection. A pressure-transducer is placed at the terminal internal carotid artery (ICA). (a) A 9-Fr balloon-guiding catheter is placed at the origin of the right ICA. (b) A 4-Fr inner catheter is placed at the cervical ICA via a 9-Fr balloon-guiding catheter. (c) A microcatheter is placed at the siphon of the ICA via a 4-Fr inner catheter and a 9-Fr balloon-guiding catheter. The lower illustrations show the various models. (A) Control model in which each vessel is opened. (B) MCAO model in which the MCA is occluded by a clip. (C) ICAO model in which both the MCA and ACA are occluded. (D) Tandem ICAO model in which both the middle cerebral artery and the anterior cerebral artery are occluded by a clip and the origin of the ICA is wedged by the balloon.

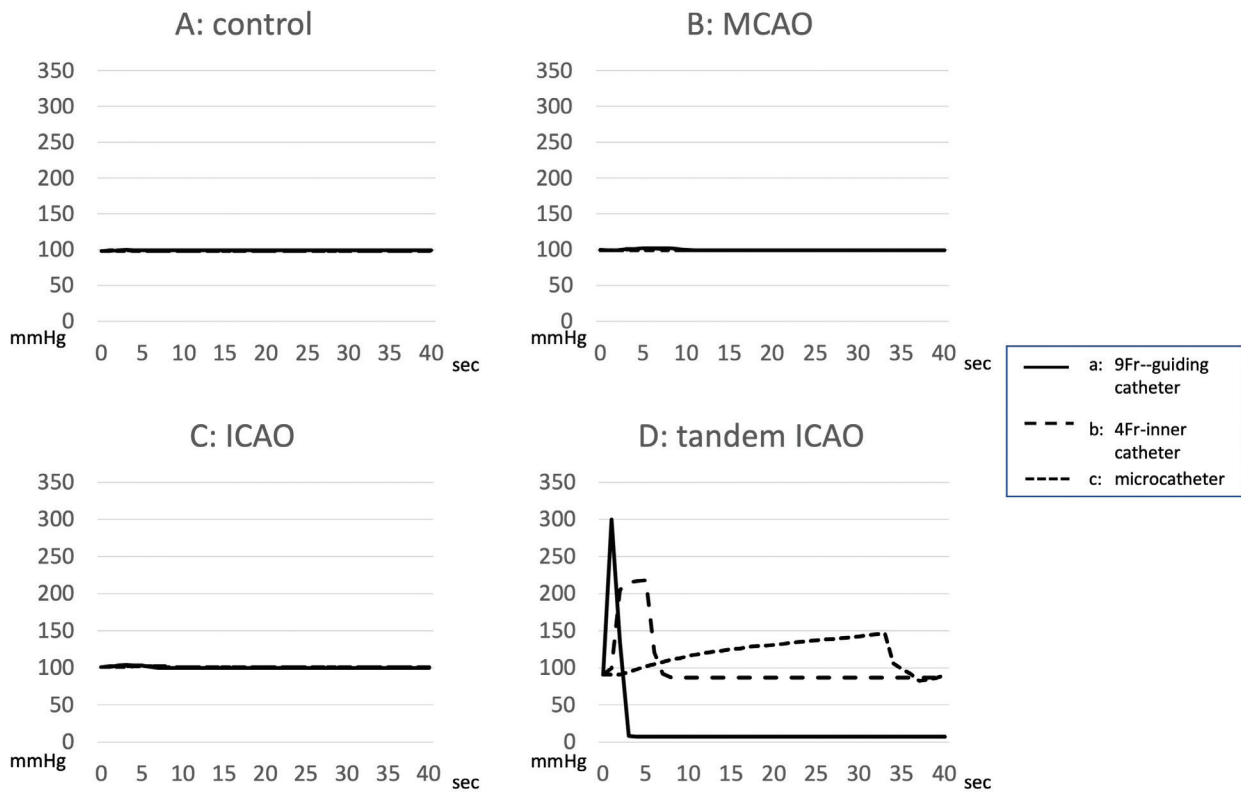


Fig. 3 The change in pressure at the terminal internal carotid artery during contrast injection. (A) Control model. (B) MCAO model. (C) ICAO model. (D) Tandem ICAO model. *Solid line:* injection from 9-Fr-balloon-guiding catheter; *broken line:* injection from 4-Fr inner catheter; *dot line,* injection from microcatheter.

the following conditions, (a) and (b) total amount 7 mL and flow rate 5 mL/s and (c) total amount 1 mL and flow rate 1 mL/s. In each injection, occlusion of the ACA and MCA was released when the pressure reached 150 mmHg, which was the prespecified burst pressure of the silicon vascular model.

## Results

### Part A: case presentation

A 70-year-old male patient was admitted to a previous hospital with dysarthria and mild left hemiparesis. His National Institute of Health Stroke Scale (NIHSS) score was 3. Magnetic resonance imaging showed acute infarction of the white matter of the right cerebral hemisphere on diffusion-weighted images (DWI) (Fig. 1A), and magnetic resonance angiography showed occlusion of the right ICA (Fig. 1B). The patient was transferred to our hospital. After admission, his left hemiparesis worsened, left unilateral spatial neglect appeared, and his NIHSS score had increased to 15. The ischemic core was spread in the right ICA territory and the Alberta Stroke Program Early computed tomography (CT)

score on DWI<sup>4)</sup> was 7. Perfusion CT revealed decreased cerebral blood flow in the right ICA territory. As it was 12 h after the onset and there was a DWI-perfusion mismatch, we intended to perform MT according to the guideline.<sup>5)</sup> A right common carotid angiogram (CCAG) showed tapered occlusion of the right ICA origin (Fig. 1C). A 0.035-inch guide wire easily passed the tapered occlusion. After navigating the guide wire through the lesion, right CCAG demonstrated severe stenosis at the right ICA origin. Therefore, the lesion appeared as a tandem occlusion at the terminal ICA due to artery-to-artery thromboembolism caused by severe stenosis of the ICA origin. The coaxial system of the inner catheter (4–6-Fr JB-2 125 cm; Gadelius Medical, Osaka, Japan) and BGC (9-Fr OPTIMO; Tokai Medical Products, Aichi, Japan; outer diameter 3 mm) was delivered to the right CCA. Both the inner catheter and BGC could pass the stenosis at the ICA origin, and the tip of the BGC was located distal to the stenosis. Thus, we intended to use a retrograde approach<sup>6)</sup> to recanalize the occlusion of the terminal ICA first prior to the treatment of the stenosis at the ICA origin. We injected a small amount (*ca.* 6 mL) of

**Table 1** Raw date of this simulation study

Second	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Control																			
Microcatheter	98	98	98	98	98	98	98	98	98	98	98	98	98	98	98	98	98	98	98
4-Fr inner catheter	98	99	99	99	98	98	98	98	98	98	98	98	98	98	98	98	98	98	98
Guiding catheter	98	98	99	100	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99
MCAO																			
Microcatheter	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99
4-Fr inner catheter	99	99	100	100	101	101	102	101	100	99	99	99	99	99	99	99	99	99	99
Guiding catheter	100	99	99	101	101	102	102	102	102	101	100	99	99	99	99	99	99	99	99
ICAO																			
Microcatheter	101	101	101	101	102	102	102	101	101	101	101	101	101	101	101	101	101	101	101
4-Fr inner catheter	101	102	102	102	103	103	102	102	102	101	101	101	101	101	101	101	101	101	101
Guiding catheter	101	101	103	104	103	103	101	100	100	100	100	100	100	100	100	100	100	100	100
Tandem ICAO																			
Microcatheter	91	91	91	94	98	102	105	108	111	113	116	118	120	122	123	125	126	128	129
4-Fr inner catheter	91	99	205	215	217	218	121	92	87	87	87	87	87	87	87	87	87	87	87
Guiding catheter	91	300	135	8	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7

contrast from the BGC without inflating its balloon, using much gentler manner than a usual internal carotid angiogram. Here, a massive extravasation of contrast was observed at the C2 portion of the ICA (Fig. 1D). At this point, we speculated that a hidden aneurysm at this portion had ruptured due to the sudden increase of intra-luminal pressure caused by contrast injection into the blind alley, which was due to thrombotic occlusion of the terminal ICA and obliteration of the ICA origin by the wedged guiding catheter at the stenosis. We guided a microcatheter to the terminal ICA and occluded ICA with coils including the rupture segment (Figs. 1E and 1F). A diffuse subarachnoid hemorrhage was observed on postoperative brain CT. He presented with dilatation of bilateral pupils and cessation of spontaneous respiration 7 h after surgery despite the administration of medication, and he died on the 3rd hospital day.

**Part B: simulation experiment**

Regardless of the kind of catheter, elevation of pressure was maintained within 10 mmHg in the control, MCAO, and ICAO models by contrast

injection. On the other hand, in the tandem ICAO model, when contrast was injected from the microcatheter, pressure elevated gradually to 150 mmHg and we opened the obstruction. When contrast was injected from a 4-Fr inner catheter in the tandem ICAO, the pressure elevated more rapidly than from the microcatheter up to 150 mmHg and we were able to open the obstruction when the pressure exceeded 200 mmHg. When contrast was injected from a 9-Fr BGC in the tandem ICAO model, the pressure elevated so quickly to over 300 mmHg and the vascular model ruptured without time to open the obstruction (Fig. 3 and Table 1).

**Discussion**

The prevalence of a coexisting aneurysm in target vessels during MT for LVO is reported to be 3.7%.<sup>2)</sup> Most of these aneurysms are hidden in the clot or are distal to the occlusion site. Under these situations, it is unavoidable to perform blind procedure on the occluded vessels during MT, posing the potential risk of rupture of the hidden aneurysm. Previously reported mechanisms behind the rupture of hidden

**Table 1—Continued**

19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
98	98	98	98	98	98	98	98	98	98	98	98	98	98	98	98	98	98	98	98	98
98	98	98	98	98	98	98	98	98	98	98	98	98	98	98	98	98	98	98	98	98
99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99
99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99
99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99
99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99
101	101	101	101	101	101	101	101	101	101	101	101	101	101	101	101	101	101	101	101	101
101	101	101	101	101	101	101	101	101	101	101	101	101	101	101	101	101	101	101	101	101
100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
130	131	132	134	135	136	137	138	139	140	141	142	144	145	146	106	98	92	82	84	86
87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87
7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7

aneurysm are either withdrawal of the stent-retriever<sup>2)</sup> or intra-arterial infusion of thrombolysis.<sup>3)</sup> In our case, rupture of the hidden aneurysm occurred even though we used gentle manual injection of contrast from a guiding catheter. There are no previous reports of such a case. Though we could not confirm the details of the aneurysm because the digital subtraction angiography (DSA) images after the rupture were poor and we did not perform autopsy dissection, we assumed that there was an aneurysm at the C2 portion of the ICA because the DSA showed aneurysmal dilatation at that point and the coil loops distributed to the dilated space during parent artery occlusion.

The retrograde approach, which aims to recanalize the distal occlusion at first, has the benefit of early recanalization of the most important distal blood flow.<sup>6,7)</sup> However, in cases with severely stenosed lesions at proximal of ICA, even if the proximal lesion is easily passed, it could be wedged by cannulated catheter, creating a blind alley. In this situation, we should not inject contrast from guiding catheter, even by gentle manner. We should inject gently from microcatheter. However, in this simulation study, we demonstrated that in the situation of a blind alley, intra-luminal pressure elevates to over 50 mmHg, even when contrast is injected from a microcatheter. If there is an aneurysm in the blind alley, acute elevation of intra-arterial pressure can cause rupture of the aneurysm. So, as a solution of this problem, if the proximal lesion is thought to be wedged by a guiding catheter, not only inject gently from microcatheter but also open the valve of connector of guiding catheter or aspirate the injected contrast from the guiding catheter simultaneously to create a flow outlet.

We could not estimate how high the pressure was elevated when contrast was injected from a 9-Fr BGC because the pressure instantly elevated to over 300 mmHg, resulting in the rupture of the vascular model. The pressure resistance of a normal human cerebral artery is said to be 600 mmHg.<sup>8)</sup> If the intra-luminal pressure had been elevated higher than this in the presented case, the ICA itself could have ruptured, even without the presence of the hidden aneurysm. On the other hand, with other flow outlets such as the ACA, MCA, and external carotid artery, the intra-luminal pressure was not elevated so high.

Through this study, we demonstrated that contrast injection elevates intra-luminal pressure enormously, not only when injected from a large-sized guiding catheter, but also from a microcatheter, in the situation of blind alley caused by a proximal lesion wedged with guiding catheter. In this instance, we

should perform angioplasty first on the proximal lesion to prevent guiding catheter wedge the proximal lesion, even when retrograde approach is selected for tandem occlusion.

This study had some limitations. First, as the elasticity of the silicon vascular model used in this study is different from that of the normal human artery, the changes in intra-luminal pressure may differ from the results of this study. Second, this vascular model did not realize some smaller flow outlets such as the ophthalmic artery, inferolateral trunk, meningohypophyseal trunk, posterior communicating artery, and anterior choroidal artery, which usually exist in the normal human ICA. The presence of these flow outlets may have reduced the elevation of intra-luminal pressure especially when small amount of contrast was injected from a microcatheter. Third, though we used auto-injector to maintain a standard amount of contrast and a standard injection rate, these amounts and injection rate differ from those of the usual manual injection performed in real MT.

In conclusion, while using a retrograde approach for tandem occlusion of the ICA, if the proximal lesion is passed without angioplasty, the proximal lesion can be wedged by catheter creating a blind alley. In this situation, intra-luminal pressure may be elevated enormously by the injection of contrast from any catheter of any size. If there is an aneurysm in the blind alley, it can rupture due to the elevation of intra-luminal pressure. Therefore, even when the proximal lesion can be easily passed, we should perform angioplasty to the proximal lesion first to avoid creating a blind alley and to avoid elevation of pressure in the blind alley.

## Conflicts of Interest Disclosure

The authors declare that they have no conflicts of interest with respect to the research, authorship, and/or publication of this article.

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