Hemodynamic Changes in Drainage Systems Following Treatment of Cerebral Arteriovenous Malformations

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Summary

The authors studied 61 patients undergoing effective embolization for cerebral arteriovenous malformations (AVMs) and analyzed the hemodynamic changes in their drainage systems following embolization.

The changes were classified into following 5 types: type A, disappearance of all the draining veins; type B, disappearance of a part of the cortical veins; type C, disappearance of a part of the deep-seated veins; type D, combined type B and C patterns; type E, disappearance of reflux into normal cortical veins. Each case was evaluated on the basis of these criteria from comparing pre- and post-embolization angiograms.

The delay and reduction of shunt were observed in all cases. Forty-nine of them showed obvious hemodynamic changes in the draining systems including type A change in 9, type B in 19, C in 5, D in 3 and E in 13 cases, respectively. Two cases showed a spontaneous shift in the dominance of the main drainers. Thirteen of 15 cases showing successful results in subsequent radiosurgery exhibited various changes in draining pattern.

Changes in drainage systems may be affected by the compartmentalization of the nidus, reduction in shunt flow, and spontaneous or progressive thromboses. These can be promoted by embolization and may be regarded as one of the indicators of successful pretreatment for radiosurgery.

Introduction

Cerebral arteriovenous malformations (AVMs) usually have abnormally expanded draining veins distal to the nidus, and their location, flow direction, morphology and hemodynamics affect the clinical manifestation as with focal ischemia and convulsion. In particular, the hypertension of the draining veins due to the convergence of shunt flow or an occlusive lesion in their exit may be an important risk factor for bleeding¹⁻³. The hemodynamic change after AVM treatment has been studied from the standpoint of the increased pressure of feeding arteries or the influence on the normal circulation as in hyperemia⁴ or normal perfusion pressure breakthrough⁵. Therefore, we focused on the AVM draining system and evaluated the significance of their changes following endovascular treatments to clarify the influence on the treatment to follow.

Material and Methods

Out of 70 patients treated by embolization over 5 years, 61 patients were selected using the following criteria. All of them underwent successful embolization with more than 70% reduction in size and marked hemodynamic improvement, and their angiographic images should have sufficient resolution to be evaluated. Comparing the angiograms before and after embolization, the changes in drainage pattern

were classified into the following 5 types. Type A includes the cases with disappearance of all draining veins due to total or nearly total embolization. In cases of type B, part of the cortical veins disappears after the embolization, and similarly in type C, part of the deep-seated drainers disappear. Type D is the combination of type B and C. Cases of Type E have no reflux into the normal veins from the main drainers.

Results

Embolization caused a the delay in early opacification and remarkable size reduction of drainers in all cases. Forty-nine cases showed obvious changes in the draining systems, including type A in 9, type B in 19, type C in 5, type D in 3 and type E in 13 cases (figures 1-5). Of these, some peculiar changes were observed; 1 was the spontaneous shift in dominance of the

main draining system (figure 6). Two patients revealed this interesting phenomenon.

Table shows how the changes in drainage can influence the postoperative features. These results indicate that a complete cure due to the delayed spontaneous thrombosis of the nidus can be expected in cases with a marked reduction in drainage flow as in type A change. The partial disappearance of cortical drainage in type B and improvement of reflux in type E may be effective in further reducing the size and successful results of radiosurgery, but changes in deep-seated drainers in type C did not always carry out the good results. However, no change group showed a lower rate of further size reduction than the groups with drainage changes.

Discussion

The AVM draining system is very important to determine the clinical features. The risk of hemorrhage is closely related with the characteristics of draining systems. Miyasaka et al¹ indicated that AVM with one draining vein, impaired venous drainage or deep venous drainage alone has a high risk of hemorrhage. Nataf et al³ pointed out exclusively deep drainage, venous stenoses, venous reflux and the ratio of afferent to efferent systems as the exclusive unfavorable factors promoting hemorrhage. The flow stagnation of drainers occasionally causes venous congestion in normal circulation. One patient (figure 6) with left rolandic AVM, which was incidentally found 6 years ago, suddenly presented with convulsion, and the angiogram at that moment showed a different draining pattern from the previous one. Therefore, this new symptom may be induced by focal ischemia due to the change in flow pattern. Such a thrombosis of drainers may be related to spontaneous regression of AVM⁶.

Moreover, acute occlusion of a high-flow shunt following aggressive embolization may promote the extended drainer thrombosis⁷, resulting in venous infarction (figure 7).

However, the disappearance or normalization of abnormal veins should generally indicate the decline of AVM hemodynamics. Particularly type A change in our classification usually results from proper and sufficient nidus embolization, and early or delayed complete occlusion is very probable. On the other hand,

Figure 1 Type A change in drainage. Left carotid angiogram showing a middle-sized, compacted AVM at the left trigone (A). After embolization, drainers were no longer opacified due to complete occlusion of nidus (B).

Figure 2 Type B change in a large rolandic AVM with multiple cortical drainage via a large main drainer (A,B). Postembolization angiogram (C,D) showing that part of them (arrows) disappeared and some changed in the direction of drainage flow.

abrupt disappearance of all the draining veins in the early stage of embolization is rather a warning sign of postoperative bleeding due to the nidus hypertension. Type B, C, and D changes, on the other hand, suggest a reduction

in drainer pressure; type E change, the normalization of recruited cortical veins for AVM, may show the redistribution of stolen blood to the normal brain. This phenomenon is occasionally related with prenidial hypervascular

Figure 3 Type C change in a large thalamic AVM with multiple drainers coming into the straight sinus via bilateral basal veins (A,B). Effective embolization resulted in the disappearance of deep drainage and no reflux into the contralateral basal vein (arrow) (C,D).

network⁸ observed in the early phase of angiography immediately after embolization. In our study such a hemodynamic remodelling brought about positive effects for further reduction in size before radiosurgery except for type C change. Since type C change in deep-seated drainers is mostly seen in the nuclear AVMs, numerous perforators serve to supply them. This is why the temporary flow reduction does not cause the delayed effects, and rather the other remnant feeders may redistribute, and AVM hemodynamics may return to the preembolization state.

Two factors may play a role in the mechanism of such a change in the drainage system. One is the compartmentalization of the nidus with a proper draining system. Figure 8 shows a case of basal ganglia AVM with compartmentalized nidus split by hematoma. The superselective angiogram clearly shows the anterior and posterior parts of the nidus both have their own feeders and drainers.

Other factors include changes in the hemodynamic pattern, which may be the main mechanism in most cases: first, the angiographic absence of draining veins because of the

Figure 4 Type D change in a large frontal AVM with a tortuous drainage complex draining in multiple directions (A,B). Postembolization angiogram shows the marked reduction in size as well as shunt flow (C,D). Most of the drainage complex was no longer opacified, and very stagnated flow was found through only one ascending cortical drainer. Normal antegrade drainage was found to recover (arrows) rather than other cortical and deep drainage. Please note this case shows further reduction in size on the angiogram for planning of radiosurgery (E).

Figure 5 Type E change in a case of a small Rolandic AVM with single cortical drainage (A,B). There is a reflux into an adjacent cortical vein in the very late phase (arrow). This reflux disappeared on the postembolization angiogram, and normal cortical drainage is seen using this vein (C,D).

competition or balance against the inflow from other drainers or normal draining systems; second, a far slower shunt, which can be visualized in very late phase; third, the release from the

AVM shunt flow occupying the veins, which results in transformation to normal drainage; and fourth, spontaneous or progressive thrombosis due to the stagnation of drainage flow.

Figure 6 A case of spontaneous drainage change. The initial angiogram shows a left rolandic AVM draining into the superior sagittal sinus (A), but it was not treated. A follow-up angiogram obtained 5 years later shows a small cortical drain developed in addition to the main drainage (B). An angiogram obtained 6 years later at the time of the first convulsion attack shows complete changes in the drainage direction (C,D). There are no main cortical drainers (arrow), and drainage flow was divided into two cortical veins that developed (double arrow). This case may suggest a serial change in the drainage system including the impairment of main drainage flow and development of collateral channels. This patient was successfully treated by embolization and radiosurgery (E).

Figure 7 A case with peculiar hemodynamic changes causing thrombosis of drainers and catastrophic venous congestion. This patient has a ruptured, large, high-flow AVM in the left temporal region (A,B). After the 2 sessions of embolization, shunt flow was remarkably decreased and normal cerebral arteries could be visualized (C,D). But 2 weeks later the patient fell into the epileptic status, and an angiogram at the time shows extensive thrombosis of several cortical veins (arrows) (E). An MR image demonstrated the cortical venous infarction (F).

Figure 8 A case of basal ganglia AVM with compartmentalized nidus divided by hematoma (A). The anterior part of the nidus with intranidal aneurysm drains into the basal vein (arrow) (B), and the posterior part mainly drains into internal cerebral vein (double arrow)(C). These were identified on the superselective angiograms.

Table 1 Postoperative feature by each type of change in drainage

	size change before radiosurgery				almost total extirpation	surgical
	further reduction	equal	recurrence	obstruction		
type A	(9)	5	3	1	7	0
type B	(19)	9	4	2	5	4
type C	(5)	1	2	2	0	0
type D	(3)	2	1	0	1	0
type E	(13)	6	4	1	3	3
no change	(12)	3	6	3	1	3
<i>the rate of further reduction</i>						
	group with drainage change		53,5%			
	group w/o drainage change		25,0%			

Embolization plays an important role in making treatment to follow easier and safer⁹⁻¹¹. From this point of view, promoting the further reduction in size and flow would have a favorable effect. Our study suggests that drainage changes are involved in postembolization phenomena and may serve to predict the effects and complications. If the relationship between the AVM drainage change and abnormality in draining routes or pressure and flow analysis of each drainer is clarified, the evaluation of pre- and postembolization drainage change should be one of the useful indicators of the effects of embolization.

Conclusion

The changes in drainage patterns following the embolization of AVM may be caused by the compartmentalization of the nidus, reduction in shunt flow and spontaneous or progressive thrombosis. These can be promoted by nidus embolization. Some of these changes may affect the postoperative features and therapeutic effects, and may encourage the spontaneous regression in certain cases, but occasionally cause thrombotic complications extending into normal venous systems. Their evaluation will be a useful indicator of the success of embolization.

References

- 1 Miyasaka Y, Yada K et Al: An analysis of the venous drainage system as a factor in hemorrhage from arteriovenous malformations. *J Neurosurg* 76: 239-243, 1992.
- 2 Albert P, Sagado H et Al: A study on the venous drainage of 150 cerebral arteriovenous malformations as related to haemorrhagic risks and size of the lesion. *Acta Neurochir* 103: 30-34, 1990.
- 3 Nataf F, Meder JF et Al: Angioarchitecture associated with haemorrhage in cerebral arteriovenous malformations: a prognostic statistical model. *Neuroradiology* 39: 52-58, 1997.
- 4 Al-Rodhan NRF, Sundt TM et Al: Occlusive hyperemia: a theory for the hemodynamic complications following resection of intracerebral arteriovenous malformations. *J Neurosurg* 78: 167-175, 1993.
- 5 Spetzler RF, Wilson CB et Al: Normal perfusion pressure breakthrough theory. *Clin Neurosurg* 25: 651-672, 1978.
- 6 Marconi F, Parenti G et Al: Spontaneous regression of intracranial arteriovenous malformation. *Surg Neurol* 39: 385-391, 1993.
- 7 Miyasaka Y, Kurata A et Al: The significance of retrograde thrombosis following removal of arteriovenous malformations in elderly patients. *Surg Neurol* 49: 399-405, 1998.
- 8 Takemae T, Kobayashi S, Sugita K: Perinidal hypervascular network on immediate postoperative angiogram after removal of large arteriovenous malformations located distant from the arterial circle of Willis. *Neurosurgery* 33: 400-406, 1993.
- 9 Miyachi S, Tanaka T et Al: Embolization of cerebral arteriovenous malformations to enhance the success of subsequent radiosurgery. *Interventional Neuroradiology* 4 (Suppl 1): 121-126, 1998.
- 10 Miyachi S, Negoro M et Al: Effectiveness and pitfall of embolization of cerebral arteriovenous malformations. *Interventional Neuroradiology* 5 (Suppl 1): 151-156, 1999.
- 11 Wallace RC, Flom RA et Al: The safety and effectiveness of brain arteriovenous malformation embolization using acrylic and particles: The experiences of a single institution. *Neurosurgery* 37: 606-618, 1995.

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