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Balloon Embolization of Experimentally Created Aneurysms: An Animal Training Model

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The intravascular treatment of aneurysms and vascular malformations with detachable balloons has become an increasingly popular alternative to conventional surgery. The critical nature of these procedures and the variability in the material, size, shape, and ease of detachability of commercially available balloons have led us to develop an animal model that provides the operator with experience in using detachable balloons and affords an opportunity to study the resultant pathologic changes. Creating experimental saccular aneurysms in dogs and ablating them via intravascular balloon occlusion techniques affords experience with an animal model that can to some extent be extrapolated to the human situation and thereby serve as a valuable training vehicle.

Materials and Methods

Aneurysm Creation

Adult mongrel dogs weighing 20–30 kg were anesthetized with sodium pentobarbital (Nembutal), 30 mg/kg IV, endotracheally intubated, and the ventral lateral portions of their necks antiseptically prepped. A 5–7-cm longitudinal incision was made in the cervical portion of the neck between the right common carotid artery, exposing both vessels. The aneurysms were created on the carotid artery by using a modification of the technique first described by German and Black [1]. A 5–7-cm length of right external jugular vein was isolated, adventitially stripped, and cranially and caudally triple ligated with 2-0 silk (Fig. 1). A 2-cm length of vein was measured for the most proximal ligature. The external jugular vein was then transected at the 2-cm dimension and further transected from the parent vein between the second and third ligatures. The double ligation of the end-of-the-vein pouch segment obviated suture transfixion closure. The vein-graft pouch segments were then placed in isotonic saline while the right common carotid artery was prepared. A 5-cm segment of the right common carotid artery was isolated, adventitially stripped, and occluded cranially and caudally with pediatric vascular occluding clamps. A 0.5–0.6-cm arteriotomy was performed with one cut of a

microvascular scissors, resulting in an arterial defect with a longitudinal dimension of 0.6 cm and a transverse mid-positional dimension of approximately 0.2 cm. A venoarterial anastomosis was made with 6.0 nonabsorbable monofilament suture in a running, continuous fashion using a quadrant technique. Bleeding from needle punctations was minimal and controlled with sponge tamponade. The wound was closed with 3-0 absorbable suture in the soft tissues and 5-0 absorbable suture in a running subcuticular fashion.

One to three aneurysms can be created along the carotid artery during one procedure. Since we began balloon embolization of aneurysms, we have created two aneurysms per dog along a single carotid artery. The size and neck of the aneurysm can be controlled by varying the length of the vein segment and the size of the arteriotomy, respectively.

Aneurysm Embolization Technique

Many different balloon/catheter systems are available for intravascular occlusive procedures [2–5]. We describe the technique and materials we use most often.

With the animal under general anesthesia and intubated as described above, we cut down to the femoral artery. A small incision is made in the femoral artery between a distal permanent suture and a proximal slipknot. A 7.5-French sheath (Cook, Inc., Bloomington, IN) is inserted into the femoral artery and advanced through the slipknot, which is then tightened over the sheath. A 5-French catheter is inserted through the sheath, and under fluoroscopy the appropriate carotid artery is catheterized (Fig. 2). The 5-French catheter is then removed over an exchange guidewire (260 cm) and replaced with a 5.0/7.3-French coaxial catheter system (Interventional Therapeutics, San Francisco). The 5-French inner catheter is removed. The inner lumen of the 7.3-French catheter is constantly perfused with heparinized saline by use of a side-arm adapter attached to a pressure pack.

On a separate table, the detachable balloon (Interventional Therapeutics) is affixed to the tip of a 2-French catheter, which lies within a 4.0-French catheter in coaxial fashion. The coaxial system (Cook, Inc.) with balloon affixed is then passed into the carotid artery through the 7.3-French introducer catheter. The 2-French catheter and balloon

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are then advanced and positioned in the aneurysm. The balloon is inflated with contrast medium. Contrast injection through the side port is necessary in order to evaluate patency of the carotid artery prior to balloon detachment (Fig. 3).

After the balloon is detached the entire system is removed (Fig. 4). The femoral artery is ligated proximally without ill effect. We have found it preferable to ligate the femoral artery rather than compress it because of the difficulty in obtaining adequate hemostasis at the puncture site by compression alone.

In most cases, balloon embolization of each of the two aneurysms was attempted at one sitting. When embolization of the second aneurysm was performed on a different day (dogs 5, 7, 8, and 10), the opposite unligated femoral artery was used for sheath introduction.

Results

We created a total of 22 aneurysms in 11 adult mongrel dogs (Table 1). Initially, aneurysms measuring 1.5 cm in length \times 0.5–0.6 cm in diameter were made. The diameter of the aneurysm depended on the native diameter of the dog's external jugular vein. The arteriotomy length was 0.5 cm. Ten aneurysms with these dimensions were created in five dogs. All 10 aneurysms remained patent without angiographic evidence of thrombosis. To simulate an aneurysm with a narrow neck, a smaller arteriotomy, 0.3–0.4 cm, was made in the two aneurysms created in dog 6. At the time of angiography, 32 days later, one aneurysm was not seen and the other was about 80% ablated. This result, which was due to thrombus formation, was confirmed by the gross pathologic specimen. Since then we have made the arteriotomy length 0.6 cm and increased the aneurysm length to 2.0 cm. With the exception of dog 6 there was no angiographic evidence of thrombosis within any other aneurysm. Table 1 reveals the interval of time (days) between when the aneurysms were created and when they were identified angiographically for balloon embolization. The longest interval occurred with the second aneurysm in dog 8: embolization was performed 128 days after creation of this aneurysm.

In most cases, the balloon was successfully detached within the aneurysm while total patency of the native carotid artery was maintained. However, there were several cases in which the balloon extended partially into the carotid artery after detachment. Successful embolization of these aneurysms depends on several factors, one of which is operator experience. As an individual became more experienced with the technique, he or she was more successful at optimal placement of the balloon. Also important was the mode of detachment. Better results were obtained when the 4-French outer catheter was advanced coaxially over the 2-French inner catheter to the base of the balloon while the 2-French inner catheter was simultaneously withdrawn. Unintentional occlusion of the carotid artery occurred in a single case and was caused by the extreme amount of traction that was needed on the 2-French catheter to detach the balloon. During de-

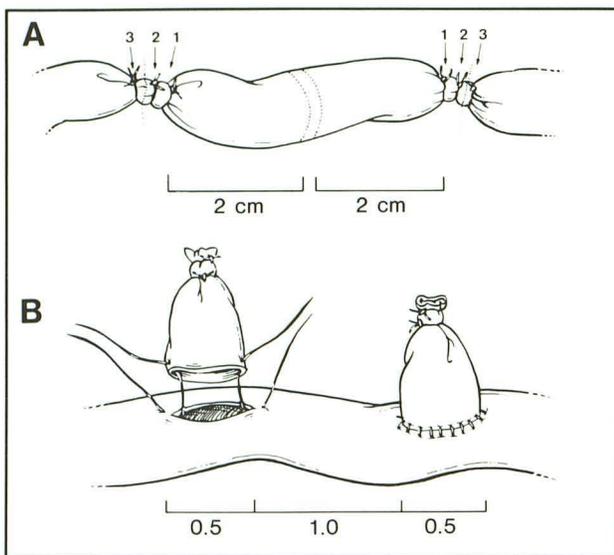


Fig. 1.—A, A 5-cm length of external jugular vein was triple ligated at both ends and transected 2 cm from the ligatures. (1, 2, and 3 = first, second, and third ligatures.)
B, The jugular vein segments are anastomosed to the carotid artery to create the aneurysms.

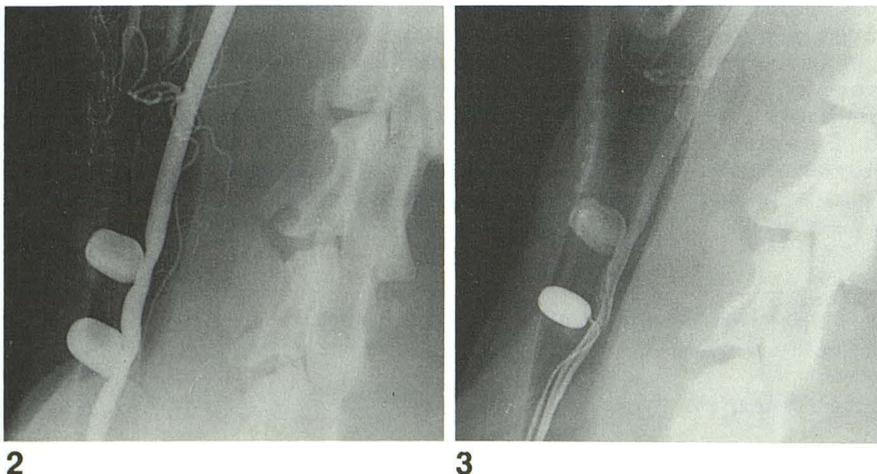


Fig. 2.—Arteriogram obtained through 5-French catheter in right common carotid artery shows the two aneurysms created in dog 8.

Fig. 3.—Arteriogram shows contrast-filled balloon attached to 2-French catheter inflated within proximal aneurysm.

Fig. 4.—After balloon detachment (arrows) within aneurysm there is continued patency of the carotid artery.

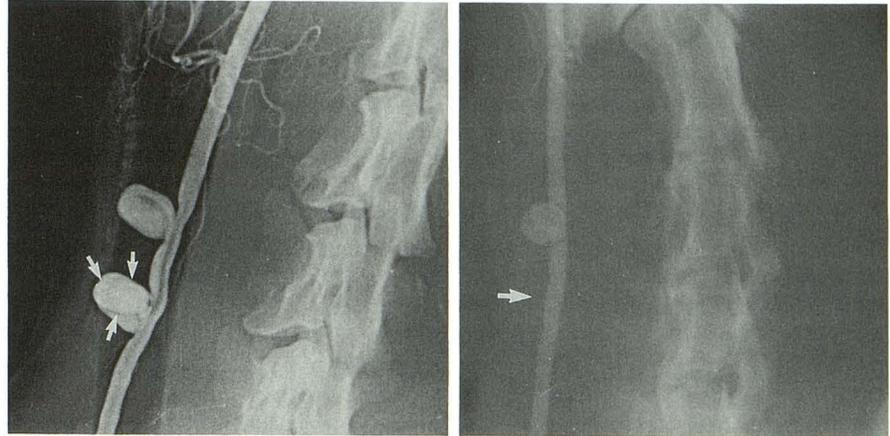


Fig. 5.—Follow-up angiogram obtained 110 days after balloon embolization shows nearly complete ablation of proximal aneurysm pouch (arrow). The distal aneurysm is widely patent 128 days after its creation (same dog as in Figs. 2-4).

TABLE 1: Aneurysm Patency Rate with Reference to Aneurysm Size, Arteriotomy Length, and Interval of Time Between Its Creation and Endovascular Embolization

Dog No.	Weight (lbs)	Aneurysm Size (cm)	Arteriotomy Length (cm)	Interval (Days) Between Aneurysm Creation and Angiography with Attempted Aneurysm Ablation	Aneurysm Patency (%)
1	47	1.5 × 0.5-0.6	0.5	58	100
		1.5 × 0.5-0.6	0.5	58	100
2	35	1.5 × 0.5-0.6	0.5	30	100
		1.5 × 0.5-0.6	0.5	30	100
3	59	1.5 × 0.5-0.6	0.5	11	100
		1.5 × 0.5-0.6	0.5	11	100
4	50	1.5 × 0.5-0.6	0.5	51	100
		1.5 × 0.5-0.6	0.5	51	100
5	39	1.5 × 0.5-0.6	0.5	3	100
		1.5 × 0.5-0.6	0.5	16	100
6	55	1.5 × 0.5-0.6	0.3-0.4	32	0
		1.5 × 0.5-0.6	0.3-0.4	32	20
7	54	2.0 × 0.5-0.6	0.6	11	100
		2.0 × 0.5-0.6	0.6	45	100
8	44	2.0 × 0.5-0.6	0.6	28	100
		2.0 × 0.5-0.6	0.6	138	100
9	54	2.0 × 0.5-0.6	0.6	23	100
		2.0 × 0.5-0.6	0.6	23	100
10	56	2.0 × 0.5-0.6	0.6	13	100
		2.0 × 0.5-0.6	0.6	34	100
11	54	2.0 × 0.5-0.6	0.6	13	100
		2.0 × 0.5-0.6	0.6	13	100

tachment of the 2-French catheter from the valve, the balloon dislodged from the aneurysm, extended into the carotid artery, and occluded it. We believe this was due to a faulty valve mechanism.

In no case did we induce rupture of an aneurysm (venous sac).

Discussion

Two (9%) of the 22 created aneurysms had either completely or partially thrombosed at the time of arteriography 32 days after their creation. Both occurred in dog 6. The smaller arteriotomy size, 0.3-0.4 cm, in these two aneurysms prob-

ably was the reason for their spontaneous ablation. The small orifice may have minimized flow effects within the aneurysm pouch leading to stasis and subsequent thrombosis formation and propagation. The remaining 20 aneurysms (91%) were patent without evidence of thrombosis on angiography. Thus, our model, which is a modification of German and Black's, had an aneurysm patency rate that was acceptable to us. In the original model, described over 30 years ago [1], German and Black reported favorable patency results in five created aneurysms of varying sizes. Their first experimental aneurysm was not only patent after 5 months but was believed to have increased in size as seen by angiography. On angiography, their smallest aneurysm was patent 1 week after its creation

but was not identified 7 weeks later. The size of this aneurysm was not given.

Success or failure of balloon embolization of these aneurysms was dependent on several factors. One of these was operator experience. An "ideal" embolization outcome was most likely after an individual had had some experience with the particular balloons and catheters used. Another factor was type of balloon used in a given procedure. We used several different types of balloons and most of these were designed only for experimentation and were not sold or made available for clinical use in humans. Thus, we cannot comment on the reliability of any given balloon since these were non-uniform and of inferior quality as compared with balloons used in humans. We believe that the single case of carotid occlusion due to balloon displacement from the aneurysm into the carotid lumen was caused by a faulty valve. This balloon was a prototype meant to be used only in the laboratory. It is our belief that an experienced operator using a balloon system with which he or she is familiar should expect to be able to optimally place the balloon within the aneurysm.

A limitation of this model is that a single type of aneurysm was created. In humans there is greater variability—aneurysms of different size, shape, neck configuration, and wall thickness are encountered. Creation of a single model including all of these possible variations would be impossible. In addition, this is not a true arterial aneurysm but a venous pouch physically simulating a true aneurysm. Also, flow effects would be different in our model as compared with the human condition. Our "aneurysm" is a blind pouch extending off a virtually uninterrupted long vessel segment. True arterial aneurysms generally arise at bifurcations or branching points off the native vessel.

Follow-up angiography after balloon embolization of an aneurysm was performed in several cases (Fig. 5). Although these showed good results, we do not have a significant number of cases with any single balloon, nor is it our intention in this report to comment on the efficacy of balloon embolization for the treatment of aneurysms in an animal model.

Our model proved suitable for practicing detachable balloon techniques and for studying the pathologic consequences of this mode of treatment in an animal model. The advantage of this model is that the catheters and balloon systems used are nearly identical to those used in the treatment of human cerebral conditions via the femoral approach.

While experience gained with this animal model is not a substitute for appropriate training in the clinical uses of detachable balloons, it does provide a practical method for gaining familiarity with an increasing variety of detachable balloons and their delivery systems in a noncritical situation.

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