Clinical and Laboratory Experience With Heparin-Impregnated Silicone Shunts for Carotid Endarterectomy

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Our experience with use of a Silastic shunt for carotid endarterectomy is reviewed briefly, and the complication of shunt thrombosis despite intraoperative administration of heparin is noted. Of obvious importance are the reduction of blood flow and the possibility of embolization caused by accumulating thrombus. Shunt thrombosis has been abolished by the use of heparin-impregnated Silastic shunts. In experiments in dogs, such heparin-treated shunts showed greater thromboresistance than did untreated shunts.

OUR experience with intraoperative electroencephalographic (EEG) and cerebral blood flow (CBF) monitoring during carotid endarterectomy has enabled us to establish relatively definite criteria for the use of a shunt in this procedure. These have been discussed previously.[11,13] This communication presents some of the early difficulties caused by thrombotic occlusion of and embolization from these shunts, the resolution of these difficulties by the use of heparin-impregnated shunts, and the results of laboratory investigations comparing heparin-impregnated and untreated shunts in dogs.

Clinical Studies

From January 1970 to December 1975, we performed 515 carotid endarterectomies for stenotic or ulcerative carotid artery disease. Silicone elastomer shunts, designed specifically for carotid endarterectomy (Fig. 1),* were used in 183 or approximately one-third of these cases. Surgical and anesthetic techniques have been reported previously.[10,13] All patients were anticoagulated intraoperatively with 5,000 to 10,000 U of heparin administered intravenously just before carotid clamping. Each shunt was used only once. Approximately 270 of these procedures were done from January 1970 to October 1973, during which time we routinely found thrombus deposition within the lumen of the shunt after removal, particularly at the proximal and distal orifices. On several occasions we documented thrombotic occlusion of the shunt with resultant acute deterioration of the EEG pattern and reduction of CBF, as measured by intra-arterial injections of xenon-133. One patient with a shunt in place suffered a permanent neurologic deficit from emboli, possibly arising from thrombus accumulating within the shunt itself. The following case report is illustrative.

Case Report

A 71-year-old man with multiple, recent, right middle cerebral artery transient ischemic attacks and angiographic evidence of a high-grade stenotic and ulcerated plaque in the right cervical internal carotid artery underwent right carotid endarterectomy. Intraoperative baseline CBF was 35 ml/100 g of cerebral tissue and the EEG tracing was normal. After intravenous administration of 7,000 U of heparin, the right common, internal, and external carotid arteries were occluded to isolate the lesion, at which time there was a prompt, marked deterioration of the EEG pattern with severe reduction of the amplitude and slowing over the right hemisphere. CBF at this time

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* Sundt Carotid Endarterectomy Shunt, manufactured by Heyer-Schulte Corp., 600 Pine Ave., P.O. Box 946, Goleta, CA 93017.

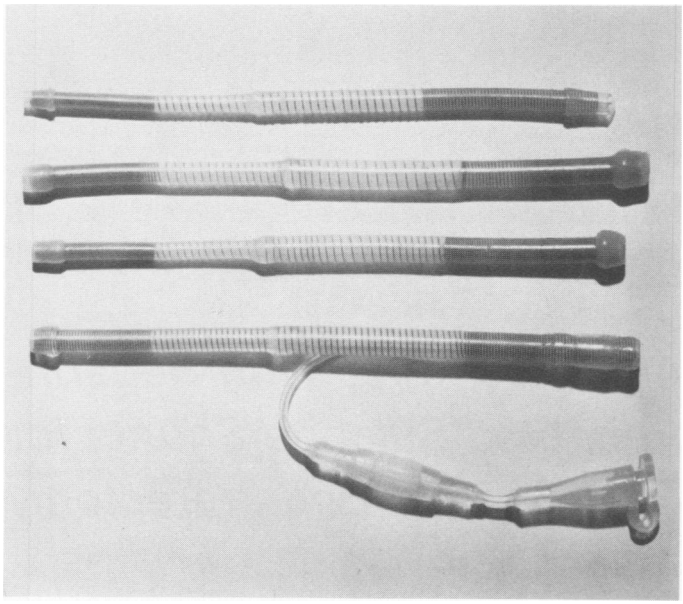

FIG. 1. Silastic shunts for carotid endarterectomy in three sizes (above) and with inflatable proximal balloon (below).

was too low to be calculated. Because of the reduced diameter of the internal carotid artery distal to the plaque, only a small Silastic shunt could be inserted, but restoration of flow slowly improved the EEG pattern, with return to normal after 10 minutes. CBF with the shunt in place was 23. A highly stenotic and ulcerated plaque was then meticulously removed from the internal carotid artery, and repair of the arteriotomy site with a saphenous vein patch graft was begun. As repair was nearing completion (30 minutes after placement of the shunt), the EEG pattern on the right progressively deteriorated, and CBF was found to be reduced to 19. The shunt was removed, repair quickly completed, and flow restored, with prompt return of the EEG tracing to normal. CBF was 40 after the repair. Inspection of the shunt revealed a large thrombus at the distal orifice with the lumen almost occluded, undoubtedly the cause for the reduction of CBF to a critical level and deterioration of the EEG pattern.[13]

Comment. This case emphasizes the importance of intraoperative monitoring techniques, the critical relationship between CBF and cerebral function as monitored by the EEG, and the thrombogenicity of a Silastic shunt despite systemic heparin anticoagulation.

As a result of these difficulties and with reports of heparin-impregnated nonthrombogenic surfaces being developed for intravascular prostheses[14] and great-vessel shunting,[5] we began to use heparin-coated shunts in October 1973. Shunts were processed at Battelle Laboratories, Columbus, Ohio. Heparin is impregnated by steeping the shunts in a 2% solution of the heparin complex of tridodecylmethylammonium chloride (TDMAC).[6] TDMAC is a quaternary ammonium salt that forms an ionic bond with heparin and attaches firmly to the polymer surface.[4]

Shunts should be autoclaved immediately before operation, though chemical or gas sterilization may be used without loss of thromboresistance.[7] Usually, shunts are not used more than once clinically.

Since adopting the use of heparin-treated shunts in October 1973 and through December 1975, we have done 244 carotid endarterectomies, using a shunt in approximately one-third of these cases. In none have we had problems caused by thrombotic occlusion of the shunt nor have we identified any thrombus deposition within the shunt lumen. Because most of our endarterectomy repairs are done with placement of a saphenous vein graft, closure is somewhat prolonged. The shunt remains in place an average of 40 minutes. The results of all carotid endarterectomies done between January 1970 and July 1974, as well as a preoperative assessment of risks, have been published elsewhere.[12]

Experimental Studies

Materials and Methods. Using pentobarbital anesthesia, we exposed the cervical carotid arteries of 10 large mongrel dogs bilaterally, performed an arteriotomy, and inserted a heparin-impregnated intra-arterial endarterectomy shunt on the right and an untreated shunt on the left.

After 1 hour, the shunts were removed and inspected

TABLE 1. *Thrombus Formation in Untreated and in Heparin-Impregnated Silastic Endarterectomy Shunts in Dogs Without and With Systemic Heparin Anticoagulation*

Type of Shunt	Animal No. 1	2	3	4	5	6	7	8	9	10	Mean Thrombogenicity Index*
Untreated shunts											
Without anticoagulation	4	4	4	4	4	4	4	4	4	4	4
With anticoagulation	3	3	2	2	2	2	1	1	2	3	2.1
Treated shunts											
Without anticoagulation	1	0	0	0	0	0	0	0	0	1	0.2
With anticoagulation	0	0	0	0	0	0	0	0	0	0	0

* Thrombogenicity index: **0** = No fibrin strands, thrombus, or platelet aggregates; **1** = Fibrin strands or platelet aggregates; **2** = Small thrombus; **3** = Moderate thrombus; **4** = Massive thrombus occluding shunt lumen.

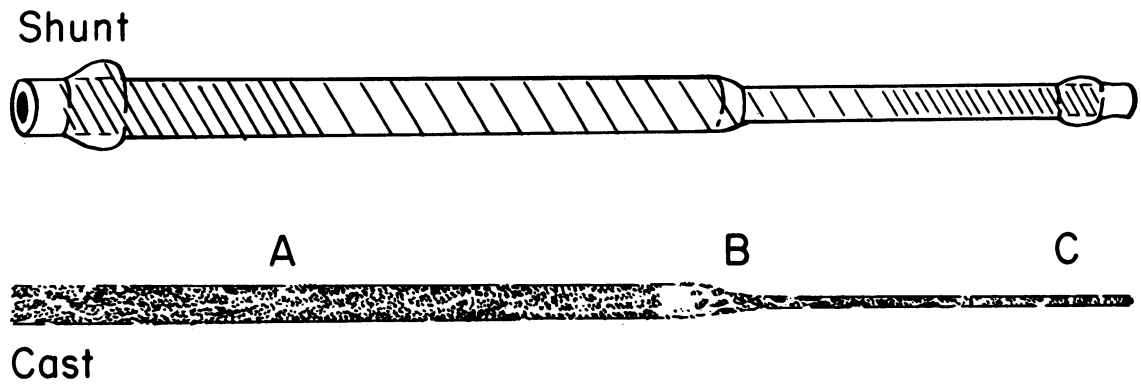

FIG. 2. Diagram of untreated Silastic endarterectomy shunt (above) and thrombus cast that formed within this shunt after 1 hour in a dog without anticoagulation (below). See text for details.

for thrombus. The dogs were then anticoagulated with intravenously administered heparin (Panheprin, Abbott, 100 U/ml) in a dose of 100 U/kg of body weight. After a thorough cleansing with isotonic saline, the heparin-impregnated and untreated shunts were repositioned in the arteries of the anticoagulated dogs for another 60 minutes, then removed and again inspected for thrombus. Thrombus specimens were saved for light microscope and scanning electron microscope examinations.

Results

Thrombus accumulation within the shunts was determined by careful inspection and graded in degree to arrive at a thrombogenic index[1] (Table 1). Thrombus occluded each of the untreated shunts after 1 hour in the dogs without anticoagulation. Even with systemic anticoagulation, the untreated shunts showed mild to moderate thrombus deposition. The heparin-impregnated shunts showed a high degree of thromboresistance.

An occluding thrombus in an untreated shunt from a dog without anticoagulation formed a cast of the lumen of the shunt (Fig. 2). Interestingly, a white thrombus typically formed at the point where the shunt begins to narrow (area B in Fig. 2). Proximal to this and filling the larger diameter of the shunt (area A) was found a red thrombus assumed to be a propagated clot, and distally in the narrower portion of the shunt (area C) was a mixed red and white thrombus.

Scanning electron microscope examination of a cast

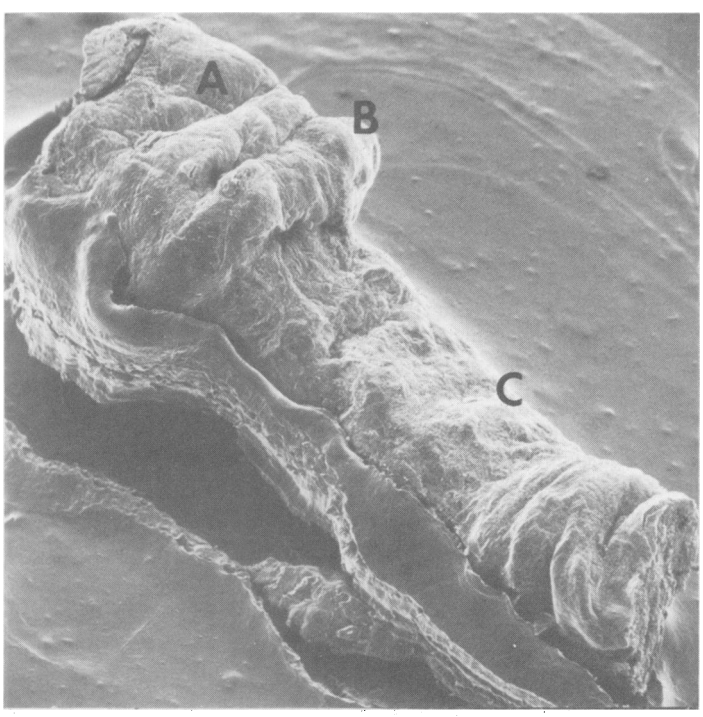

FIG. 3a. Scanning electron microscope view of segment of thrombus cast formed within untreated endarterectomy shunt after 1 hour in artery of dog without systemic anticoagulation (×320). Region of shunt narrowing (B); areas proximal (A) and distal (C) to this, as diagrammed in Figure 2.

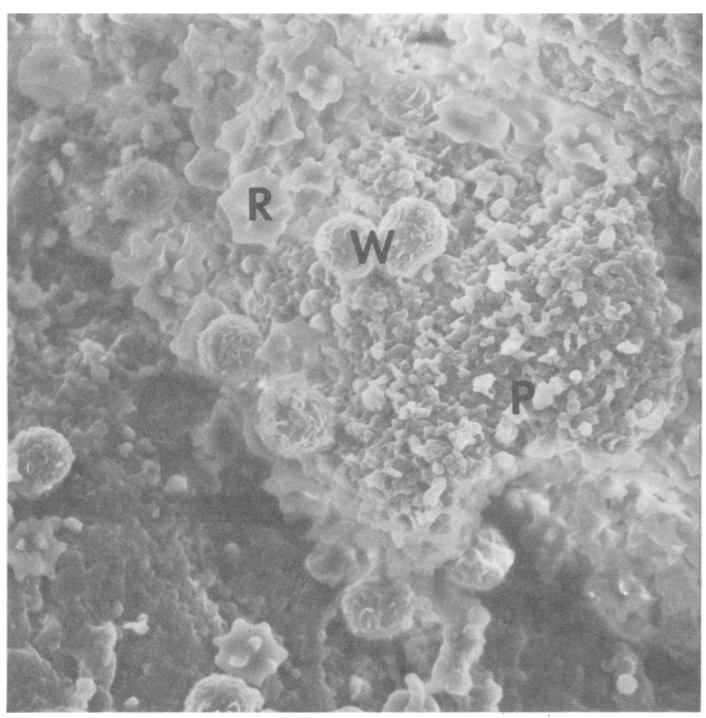

FIG. 3b. High-power view of region B, showing masses of platelet aggregates (P), crenated red cells (R), and several white cells (W) (×1,800).

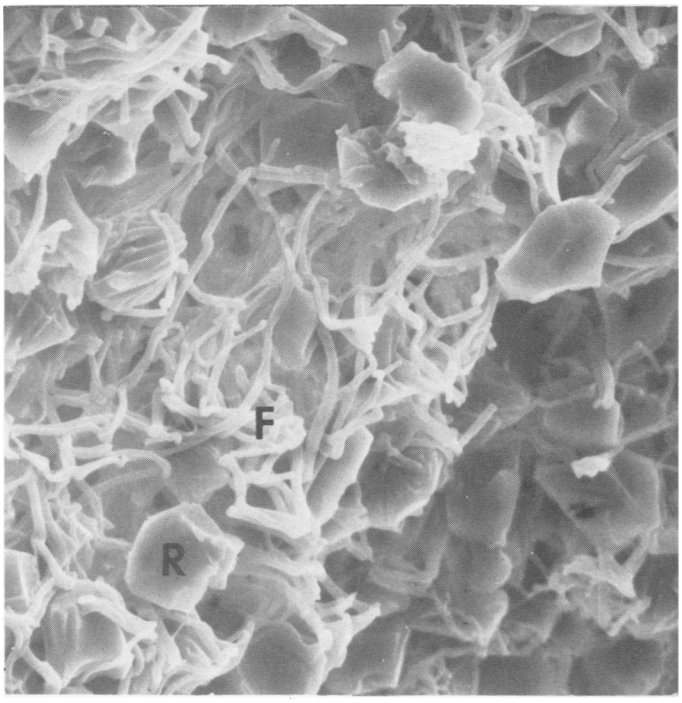

FIG. 3c. Field of the thrombus at part C, showing numerous trapped red cells (R) and fibrin strands (F) but no platelets (×3,000).

showed it to be composed of a fibrin meshwork, platelets, and red blood cells. As suggested by gross examination, there was a difference in the makeup of the thrombus at the site of shunt narrowing, the platelets predominating in this region compared with the proximal and distal areas of the thrombus where there were fewer platelets but relatively increased fibrin and trapped red cells (Fig. 3).

Discussion

Impregnation of polymer surfaces with the TDMAC-heparin complex effectively retards surface-induced thrombosis[7] and has been used successfully in permanent intravascular prostheses[8] and temporary shunts.[1,5] In our clinical experience with carotid endarterectomy shunts, the preexistent problem of shunt thrombosis has been virtually eliminated by the routine use of heparin-impregnated Silastic shunts.

Comparative studies using both untreated and heparin-impregnated shunts in dogs confirmed a high degree of thromboresistance in the heparin-impregnated shunts and virtually no thrombogenicity when used with systemic heparin anticoagulation. During carotid endarterectomy, we routinely give heparin intravenously just before vessel clamping; this provides additional protection if a shunt is required and protects the occluded vessels if a shunt is not required. In approximately two-thirds of our patients, a shunt is not required; we believe a shunt should not be used unless indicated.[11]

The shunts we use have been designed to be placed in the common and internal carotid arteries with minimal trauma to the arterial wall. Such a design with distal narrowing of the lumen undoubtedly produces some turbulent flow—which is known to enhance thrombus formation[9] and may explain our finding of solid platelet thrombus at the site of narrowing of the untreated shunts in dogs without anticoagulation: We found no predilection for thrombus accumulation at this site in the heparin-impregnated shunts.

Although we routinely use a shunt only once clinically, heparin-impregnated shunts have been reused many times in animals (up to 5 hours of exposure) without apparent loss of thromboresistance. Prolonged exposure of the heparinized surface to high blood flow results in some elution of the bonded heparin,[6,7] though nonthrombogenicity has been shown to be retained despite large heparin loss on other heparin-coated surfaces.[3] Although adsorption of thrombin to certain heparinized surfaces has been documented and may reduce the surface thromboresistance,[2] it has not been shown to be a factor in intra-arterial Silastic shunts impregnated with a TDMAC-heparin complex.

Addendum

Since this manuscript was submitted for publication, Battelle Laboratories has discontinued their service of heparinizing our shunts and we now carry out this relatively simple process in our laboratories.

Acknowledgment

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References

1. Brenner, W. I., Engelman, R. M., Williams, C. D., et al.: Nonthrombogenic Aortic and Vena Caval Bypass Using Heparin-Coated Tubes. Am. J. Surg., 127:555, 1974.
2. Falb, R. D., Takahashi, M. T., Grode, G. A. and Leininger, R. I.: Studies on the Stability and Protein Adsorption Characteristics of Heparinized Polymer Surfaces by Radioisotope Labeling Techniques. J. Biomed. Mater. Res., 1:239, 1967.
3. Gott, V. L., Whiffen, J. D. and Dutton, R. C.: Heparin Bonding on Colloidal Graphite Surfaces. Science, 142:1297, 1963.
4. Grode, G. A., Falb, R. D. and Crowley, J. P.: Biocompatible Materials for Use in the Vascular System (Biomedical Materials Symposium No. 3). J. Biomed. Mater. Res., 6:77, 1972.
5. Krause, A. H., Ferguson, T. B. and Weldon, C. S.: Thoracic Aneurysmectomy Utilizing the TDMAC-Heparin Shunt. Ann. Thorac. Surg., 14:123, 1972.
6. Leininger, R. I.: Personal Communication.
7. Leininger, R. I., Crowley, J. P., Falb, R. D. and Grode, G. A.: Three Years' Experience In Vivo and In Vitro With Sur-

faces and Devices Treated by the Heparin Complex Method. Trans. Am. Soc. Artif. Intern. Organs, 18:312, 1972.

8. Mobin-Uddin, K., Utley, J. R., Bryant, L. R., et al.: Experimental and Clinical Evaluation of Heparin-Impregnated Cloth-Covered Cardiac Valves Used Without Systemic Anticoagulation. Ann. Thorac. Surg., 17:351, 1974.
9. Mustard, J. F.: Hemostasis and Thrombosis. Semin. Hematol., 5:91, 1968.
10. Sharbrough, F. W., Messick, J. M., Jr. and Sundt, T. M., Jr.: Correlation of Continuous Electroencephalograms With Cerebral Blood Flow Measurements During Carotid Endarterectomy. Stroke, 4:674, 1973.
11. Sundt, T. M., Jr.: Advances in the Surgical Treatment of Patients With Extracranial Cerebral Vascular Disease. MCVQ. Med. Coll. Va. Q., 10:128, 1974.
12. Sundt, T. M., Jr., Sandok, B. A. and Whisnant, J. P.: Carotid Endarterectomy: Complications and Preoperative Assessment of Risk. Mayo Clin. Proc., 50:301, 1975.
13. Sundt, T. M., Jr., Sharbrough, F. W., Anderson, R. E. and Michenfelder, J. D.: Cerebral Blood Flow Measurements and Electroencephalograms During Carotid Endarterectomy. J. Neurosurg., 41:310, 1974.
14. Whiffen, J. D., Dutton, R., Young, W. P. and Gott, V. L.: Heparin Application to Graphite-Coated Intravascular Prostheses. Surgery, 56:404, 1964.