Clip-Grafts for Aneurysm and Small Vessel Surgery*

Part 1: Repair of Segmental Defects with Clip-Grafts;
Laboratory Studies and Clinical Correlations

Part 2: Clinical Application of Clip-Grafts to Aneurysms;
Technical Considerations

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The introduction of the operating microscope to the field of neurosurgery has opened a new era. Intracranial neurovascular surgery on major vessels seems technically feasible. Yet the necessity for rapid work, the position of these vessels, the friable vessel wall, and uncontrolled bleeding make microsuture techniques most difficult.

The purpose of the clip-graft is to provide the neurosurgeon with a rapid non-suture technique for the repair of diseased major intracranial vessels. It is anticipated that there will be application to endarterectomies, embolectomies, aneurysms, and the repair of major vessels injured in tumor surgery.

The clip-graft utilizes a teflon or dacron graft attached to a circular spring metal clip. The stainless steel metal clip is merely the carrier for the graft and provides a non-suture method of application. This report resolves itself therefore to a study of these fabric grafts in the repair of segmental defects in small arteries of the sizes of the human internal carotid and middle cerebral. The previously reported concept of intraluminal pressure-sealing is utilized.

Construction and Placement of the Prosthesis. The defect was sealed using either dacron fabric #6092 (36 grafts) or teflon fabric #3081 (10 grafts). In general, these grafts were constructed merely by closing a small square of graft material around the circumference of the vessel, thus narrowing the lumen approximately 0.5 mm. A running suture of 7-0 nylon closed the fabric graft, forming a sheath easily movable on the parent vessel. Details of this technique using a venous autograft on a silicone foundation have been described previously. Closing the grafts with a suture rather than the metal clip allowed histological preparations not possible had the metal clip component been used.

Six of the grafts were constructed of both the fabric and the circular metal clip. This was to assure no difference in performance between a graft closed by a running suture and one closed by the circumferential metal clip.

Evaluation of Grafts. Animals were sacrificed at intervals between 1 day and 6 months to evaluate the performance of the grafts. Histological sections were made of representative specimens (Fig. 3).

Results

Patency. Forty-six grafts were placed and followed for periods up to 6 months. All grafts were patent at the time of sacrifice for an over-all patency rate of 100%. There was no difference in the performance between grafts of teflon or dacron, and no difference between those grafts closed with a running suture and those closed with a circumferential stainless steel clip.

Sealing and Bleeding. Those grafts that

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Fitted snugly around the vessel and compromised the lumen 0.5 to 0.75 mm bled only through the pores of the graft. This could be avoided by preclotting the graft. Those grafts which did not fit snugly bled from the ends. This was controlled by the application of gelfoam to the ends and slight pressure for 5 minutes. The gelfoam was then removed by saline irrigations. A properly applied tight-fitting preclotted graft did not bleed (Fig. 2 right).

**Histological Sections.** Endothelium bridging across platelets and fibrin was well-advanced by the end of the third day. This was complete by the seventh day. In no specimens was there evidence of endothelial break-down or necrosis of the supporting tissues to the endothelial lining of
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the graft. There was no evidence of luminal narrowing other than that which was the result of the initial fitting and placement of the graft.

Figure 3 demonstrates the histological appearance of a 6-month-old graft. The section illustrates the edge of the normal vessel wall adjacent to the segmental defect closed by a dacron graft. The thinness of the viable endothelium over this graft can be further appreciated by another 6-month-old graft viewed grossly (Fig. 4).

Superficial to the fabric grafts, an occasional focus of a low-grade inflammatory response has been observed. These have not appeared to be progressive in nature.

Discussion

Engineering Considerations. Figures 1 and 2 show the clip-graft being applied around a vessel with a segmental defect similar to that encountered when an internal carotid-posterior communicating aneurysm tears off at its base. The metal clip serves as a graft carrier and provides a means of application of the graft without suture. This can be applied in the face of uncontrolled bleeding and in deep surgical fields.

The graft slightly compromises the lumen of the parent vessel enabling the vectors of intraluminal pressure to distend the parent arterial walls against the rigidly supported circumferential graft. These vectors provide the primary mechanism for sealing but by no means serve as the sole mechanism of sealing. The normal blood-clotting mechanism seals the pores of the graft and the ends of the graft. Bleeding has been controlled by light pressure on small pledgets of gelfoam and cottonoid held gently in place for 5 minutes. The gelfoam is then removed by saline irrigations.

The work of Tindall, et al., indicates that this degree of luminal compensation does not reduce the blood flow through the vessel.10 Figure 5 shows the 3.5 mm clip-graft in a modified Mayfield clip holder as provided by the manufacturer.* A standard Mayfield clip holder and clip are shown for size

* Kees Surgical Specialty Co., 117 West Main Street, Alexandria, Kentucky.
FIG. 4. A 6-month-old dacron graft is examined by making a longitudinal incision in the artery opposite to the side of the segmental defect. Note the thinness of the endothelial covering of the graft. The true margins of the defect are not well visualized because of traction artifacts.

orientation. The reduction in the size of the clip holder facilitates surgery under the microscope. It has been found that teflon fabric #3081 has had less initial bleeding than the dacron fabric #6092. Accordingly it has been incorporated as the standard graft material for the clip-graft. This fabric is secured to the metal clip by Dow Corning Silastic glue, and the entire unit is autoclaved before use.

The clip-graft is applied with a modified Mayfield clip holder (Fig. 5). The clip-graft should be opened only with the clip holder; digital pressure will deform the spring component and result in a defective clip. Clip-grafts are presently available in diameters of 3.0, 3.5, and 4.0 mm; they are 7 mm long. Additional sizes and configurations are in developmental stages.

Histological Findings. The grafts have retained a thin endothelium with minimal fibrous tissue support. There has been no long-term sub-endothelial proliferation of fibrous tissue or necrosis of supporting tissue. Perhaps this is related to good graft fixation and the proximity of normal vessel wall to the defect area. The fact that moderate bleeding is possible through the graft material indicates that the pore size is probably adequate for long-term survival of the supporting tissues. Flexibility of the graft is not a problem in intracranial struc-

FIG. 5. For size orientation, a clip-graft in a modified Mayfield clip holder is shown next to a Mayfield clip and clip holder.
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Clip-Grafts for Aneurysms and Small Vessels and is, of course, prevented by the metal clip component.

Only an occasional (and minimal) low-grade inflammatory response to the stainless steel clip or fabric was noted.

Clinical Correlations

The degree of patency in this and other small-vessel experimental studies unfortunately cannot be estimated in clinical studies. Most important in the animal studies has been the presence of a normal vessel wall and intima, except for the segmental defect, plus an adequate run-off. Human cases are complicated by many pathological and anatomical factors not present in this experimental preparation.

Aneurysms. Experience with these cases seems sufficient for a detailed report and is presented in Part 2. Suffice it to say at this point that here a distal run-off is present and the patency of clip-grafts has been 100% in eight cases.

Middle Cerebral Endarterectomies and Embolectomies. Six cases have been operated on using a clip-graft of an earlier model; only two cases remained patent. In each of these two cases a back-flow was obtained. The other four cases did not have a back-flow and the vessels thrombosed at the site of endarterectomy within a number of minutes after application of the graft. This was determined by observation through the operating microscope.

All cases were studied postoperatively by arteriograms and, in the case of death, autopsy. Coincidentally or causatively, the two patients in which the flow was re-established died. Portions of these infarcts were hemorrhagic. Two of the four patients without re-established flow also died. Parenthetically, it might be stated that these patients were from a cerebrovascular research group of elderly patients; the mortality for a similar lesion treated without surgery was equal to that in the surgical group. The high mortality in the surgical group was probably the result of a failure to aid the lesion, rather than the result of the stress and trauma of surgery.

Experience with this procedure is developmental, and the problem is infinitely more complex than technical considerations related to small-vessel surgery alone. Consideration must be given to the age of the patient, age of the lesion, alterations in blood-brain barrier, cerebral edema, the small-vessel spasm accompanying an area of ischemia, and thrombosis of major distal vessels if there is complete failure of collateral circulation.

The actual surgical technique with the aid of the operating microscope is quite easy, as bleeding can always be controlled by temporary clips. Endarterectomies at the site of occlusion have been performed under the operating microscope without difficulty. A more formidable difficulty is created by the fact that the distal area of resected intima forms a relatively larger flap than that encountered in cervical carotid endarterectomies. This was also the experience of Scheibert in middle cerebral endarterectomies.

The reported successful embolectomies by Chou and Lougheed in young patients with good collateral circulation serve to stimulate continued interest in this problem. The six patients in our report were all elderly. It is felt that a definite future exists for this procedure, but at present such surgery at this institution is being withheld pending the results of further animal studies and the analysis of other factors beside those inherent in the vessel itself.

Summary

We have described the construction, application, and mechanical action of a clip-graft for non-suture repair of small vessels. We have reviewed experimental results and discussed the differences between the laboratory model and the clinical case. The clip-graft has been designed for aneurysm surgery and for embolectomies and endarterectomies of the middle cerebral artery.

It is hoped the clip-graft will have wide application to intracranial neurovascular surgery as it provides a rapid means for repair of major vessel wall defects or arterioto-mies.

References

Most neurosurgeons have had to witness what happens when an aneurysm arising from the internal carotid artery shears off at its base. The furious bleeding is difficult to control, and all too frequently little or no sac remains to accept a conventional spring clip. Sacrifice of the parent vessel in this situation usually produces a catastrophic neurological deficit.

The clip-graft, described in Part I of this paper and designed to meet this type of emergency, was conceived after such an experience. However, it has also proved to be applicable to many other aneurysmal problems.

Technique

It may be helpful to review the technical considerations applicable to correct placement of the clip-graft.

The internal carotid artery is approached through a small fronto-temporal bone flap hinged on the temporalis muscle. The outer one-third of the sphenoid wing is resected and a small subtemporal craniectomy placed anteriorly. The dura is opened by a Y-shaped incision and the resulting anterior dural flap sutured tightly over the lateral, bleeding surface of the sphenoidal wing and dural sinus. The spinal fluid drainage and urea usually provide ample room without brain retraction to coagulate and divide small bridging veins from the anterior temporal lobe to the sphenoid sinus. This approach, learned from Dr. Matthew Wood, allows one to visualize the major structures adjacent to the carotid artery and tentorium with minimal brain retraction. The sphenoid wing resection provides direct vision through the operating microscope, and it is thereafter necessary to change the angle of the scope only slightly as the operation proceeds.

After bridging veins have been divided and the anterior clinoid identified, the operating microscope is employed. It is considered essential for accurate work, providing both intense illumination and ideal magnification. A 300 mm objective lens and 12.5 X eye pieces are used. The microscope magnification is placed most commonly on 10 or 6 magnifications.

The anterior clinoid and then the optic nerve are identified. The arachnoid lying over the optic nerve and internal carotid artery is incised with a #11 blade. The dissection of these structures is on the surface of the carotid artery away from the aneurysm (Fig. 1). The arachnoid and occasional small veins are incised further posteriory until the bifurcation of the carotid artery is visualized. This is necessary so that when the clip-graft is placed, it is not applied too far distally on the internal carotid artery where it would kink the origin of the A-1 segment (Figs. 2 and 3). This occurred in Case 1.
Fig. 1. View of the surgical field for carotid aneurysms as commonly seen through the operating microscope. The initial dissection is in the arachnoid overlying the optic nerve and internal carotid artery. The view is parallel to the sphenoid wing, not under the temporal lobe.

Fig. 2. Clip-graft being applied to an unruptured aneurysm. The anterior choroidal and posterior communicating arteries are occluded. There is no encroachment on the origins of the anterior and middle cerebral arteries.
With the entire course of the subarachnoid internal carotid artery visualized, the surgeon is in position to apply the clip-graft should the aneurysm rupture. The dissection is then carried laterally to identify the aneurysm and if possible the third nerve. The decision can then be made to use a conventional spring clip or the clip-graft. Figure 2 demonstrates application of the clip-graft to an unruptured aneurysm; Fig. 3 illustrates its application to a ruptured aneurysm. With a light thrusting motion, the clip-graft can be placed around the parent vessel.

Should bleeding occur after the clip-graft has been placed properly around the carotid artery, small pledgets of surgical and gelfoam are placed at the ends of the graft and held in place with cottonoid under light pressure. Bleeding invariably ceases within a few minutes. The gelfoam is then removed with saline irrigations.

It is important to inspect the clip in the dry field after bleeding has ceased to ensure that the clip-graft completely surrounds the internal carotid artery and that it is not applied obliquely, thus compromising or even occluding the vessel. It became necessary (Case 4) to replace one such clip which had been applied in this manner in a field obscured by uncontrolled bleeding. Under these circumstances the surgeon need not remove the clip-graft; he merely applies the clip holder to the clip handle, opens the clip, and advances it further around the vessel.

It should be re-emphasized that kinking...
or occlusion of the A-1 segment of the anterior cerebral or even the middle cerebral may occur if the clip-graft is placed too far distally on the carotid artery. The variations in diameter of carotid arteries make it advisable to have more than one size of clip-graft available. The 4.0 mm diameter clip-graft is suited for the larger vessels, the 3.0 mm for those which appear small. The 3.5 mm diameter clip-graft will fit most vessels and is recommended for general use if the internal carotid artery appears of normal size on arteriography.

We have treated eight aneurysms with clip-grafts (Table 1). The following representative cases illustrate the value of this technique.

**Case Reports**

**Case 7.** A 45-year-old man was admitted to the Baptist Memorial Hospital on December 22, 1966, with a history of severe headache and loss of consciousness 3 hours prior to admission. At the time of admission he was stuporous and disoriented; there were no focal findings. Spinal puncture showed grossly bloody spinal fluid under 400 mm of pressure. Arteriography showed an aneurysm rising from the medial aspect of the right internal carotid artery and projecting medially. On the third day after admission the patient deteriorated markedly and became unresponsive.

**Operation.** On December 26, 1966, surgery was performed under external hypothermia and controlled hypotension. Spinal fluid drainage was employed when the dura was opened; 40 gm of Ureaphil was also administered at this time. The internal carotid artery and its bifurcation were exposed in the manner described. The surgeon was thus in a position to place a clip-graft should the aneurysm rupture before accurate identification. This indeed proved to be the case. During an attempt to dissect away clot between the optic nerve and the internal carotid artery, the aneurysm burst. The origin of the aneurysm had been only partially noted prior to rupture as it was on the medial side of the carotid. The clip-graft was placed circumferentially around the internal carotid artery without complete visualization of the aneurysm. Almost all bleeding ceased. Gelfoam pledgets were placed at the margins to seal the graft. These were then washed free and the position of the clip checked to be certain there was no kinking of the A-1 segment of the anterior cerebral. The wound was then closed in the usual manner.

**Postoperative Course.** A postoperative arteriogram demonstrated occlusion of the aneurysm and a patent internal carotid artery. Over the following 2 weeks the patient improved daily. When discharged, he was able to walk and was neurologically normal except for slight disorientation.

**Case 4.** A 38-year-old woman was admitted with a left third nerve palsy and bloody spinal fluid. Initially she refused surgery and was treated conservatively. Five days after admission the third nerve palsy became more severe and she developed a right hemiparesis. Arteriography demonstrated a large aneurysm arising from the left carotid artery at the site of the origin of the left posterior communicating artery.

**Operation.** An exposure was made in anticipation of application of a Mayfield clip. The aneurysm tore off at its base as the Mayfield clip was placed on the sac. In spite of uncontrolled bleeding it was possible to place a clip-graft. When the bleeding had ceased, inspection of the clip-graft showed that it was obliquely placed across the internal carotid artery. The clip-graft was opened slightly and placed accurately around the vessel; there was slight bleeding during this adjustment.

**Postoperative Course.** The patient had a stormy postoperative course with a fluctuating paresis, but is now neurologically normal except for a third nerve palsy. She has returned to full activity.

**Aneurysms Arising from the Internal Carotid Artery**

**Clinical Application.** The initial clinical trial was necessarily limited to Grade III and IV candidates classified by the method of Botterell. After these clip-grafts were proven patent by postoperative arteriograms, the use was broadened to include better grade candidates. To date, eight aneurysms arising from the internal carotid artery have been treated with the clip-graft. All clip-grafts have been proven...
TABLE 1
Aneurysms treated with clip-grafts

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (yrs)</th>
<th>Patient’s Preop. Grade</th>
<th>Location of Aneurysm</th>
<th>Graft Patency (by Postop. Arteriogram)</th>
<th>Postop. Results</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>68</td>
<td>3</td>
<td>carotid posterior communicating</td>
<td>yes</td>
<td>death</td>
<td>died of pulmonary embolism 14 days after surgery; had monoparesis pre- and postoperatively</td>
</tr>
<tr>
<td>2</td>
<td>65</td>
<td>4</td>
<td>carotid posterior communicating</td>
<td>yes</td>
<td>death</td>
<td>decerebrate before surgery; died 5 wks postoperatively from myocardial infarction</td>
</tr>
<tr>
<td>3</td>
<td>48</td>
<td>2</td>
<td>carotid posterior communicating</td>
<td>yes</td>
<td>death</td>
<td>died of damage from subdural hematoma considered result of error in surgical technique; origin not determined</td>
</tr>
<tr>
<td>4</td>
<td>38</td>
<td>3</td>
<td>carotid posterior communicating</td>
<td>yes</td>
<td>excellent</td>
<td>full employment; no deficit except third nerve palsy</td>
</tr>
<tr>
<td>5</td>
<td>43</td>
<td>1</td>
<td>carotid (proximal to bifurcation, distal to anterior-choroidal)</td>
<td>yes</td>
<td>excellent</td>
<td>full employment; no deficit</td>
</tr>
<tr>
<td>6</td>
<td>48</td>
<td>1</td>
<td>had 3 aneurysms, all arising from carotid artery, 1 treated with Scoville clip; 2 included in single clip-graft</td>
<td>yes</td>
<td>excellent</td>
<td>full employment; surgeon was Dr. James Robertson; surgical technique under operating microscope as were other cases</td>
</tr>
<tr>
<td>7</td>
<td>45</td>
<td>3</td>
<td>carotid aneurysm projecting medially under optic nerve, origin from medial side of vessel</td>
<td>yes</td>
<td>excellent</td>
<td>full employment; has had aneurysm of renal artery since cranial surgery</td>
</tr>
<tr>
<td>8</td>
<td>40</td>
<td>1</td>
<td>anterior cerebral aneurysm with large base projecting posteriorly</td>
<td>yes</td>
<td>excellent</td>
<td>full employment</td>
</tr>
<tr>
<td>9</td>
<td>57</td>
<td>2</td>
<td>carotid aneurysm (proximal to bifurcation, distal to anterior-choroidal)</td>
<td>yes</td>
<td>excellent</td>
<td>full employment</td>
</tr>
</tbody>
</table>

Patent by postoperative arteriograms. There were three deaths in this group: Case 1 died of a pulmonary embolism on the day before discharge from the hospital; Case 2 died of a coronary thrombosis 5 weeks after surgery; Case 3 died as the result of a subdural hematoma. The origin of the hematoma was not proven; it was a convexity mass over the tempoparietal area and did not extend to the site of the clip-graft. It was considered to
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originate from bridging veins arising in the posterior temporal region.

The last five patients have returned to full employment without neurological deficit.

The clip-graft does more than merely occlude the aneurysm sac. It reinforces the parent arterial wall defect which gave rise to the aneurysm. Moreover, it is not possible for a clip-graft to "milk-off" the aneurysm as have spring clips on occasion. The clip-graft is especially applicable to large aneurysms or those that have sheared-off the parent vessel leaving no sac to accept a conventional spring clip. The pre- and postoperative arteriograms of a large aneurysm of a type best served by the clip-graft are shown in Fig. 4. This was a Grade I patient who has made a complete recovery.

Possible Complications. In clipping any aneurysm with a broad base, there is the risk of forcing a clot from the aneurysm into the lumen of the parent vessel. This is true when using a conventional spring clip as well as the clip-graft. We did not encounter this problem, perhaps because the series is small; moreover, in four cases the aneurysm ruptured before the clip-graft was applied, and thus expelled any clot present. The angle of application of the clip-graft and the proximity of the jaws of the clip-graft to the base of the aneurysm, rather than the sac, may reduce this hazard. Nevertheless, it represents a potential risk, and the experienced aneurysm surgeon might prefer to intentionally rupture the aneurysm before applying the clip-graft.

Experimental studies were conducted to determine if some protective effect could be gained from immediate hemodilution with large amounts of concentrated serum albumin in combination with low-molecular-weight dextran. The animal studies were encouraging, but the first clinical case so treated developed a postoperative subdural hematoma (Case 3). The necessity for this treatment is as yet unproven and further use of hemodilution will await proof of its need. Case 3 was the only case treated by this method.

The series is too small to evaluate the potential risk of simultaneous occlusion of the anterior choroidal and the posterior communicating artery. Undoubtedly it will vary depending upon the configuration of the circle of Willis. When there is little or no communication between the basilar artery and the related posterior cerebral artery, occlusion of the posterior communicating artery would, of course, be hazardous. In such a case, the posterior cerebral artery and important collaterals to the anterior choroidal artery could be occluded.

In the seven cases treated thus far, four

Fig. 4. Preoperative arteriogram (left) of an aneurysm rising from the internal carotid artery. It has a broad base, is quite large, and is the kind in which the clip-graft is particularly valuable. Postoperative arteriogram (right) showing the clip-graft in place. The patient (Case 5) returned to full employment.
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Fig. 5. Arteriogram of an aneurysm that would be a poor choice for the clip-graft. The configuration of the circle of Willis is such that the posterior communicating artery serves as the only supply to the posterior cerebral artery. The risk of occluding the posterior communicating artery by the clip-graft would be high in such a case.

An aneurysm that would be a poor choice for clip-grafting is illustrated in Fig. 5. Here there was no filling of the posterior cerebral arteries from the basilar artery, and complications from simultaneous occlusion of the anterior choroidal and posterior communicating arteries would be expected.

Anterior Communicating Aneurysms

The approach used has been described by Pool. The operating microscope was again considered essential. One such case was treated with a 3 mm clip-graft. Here a large aneurysm projected posteriorly from the left anterior cerebral artery just distal to the anterior communicating artery. The clip-graft was proven patent by arteriography. This Grade I candidate has returned to full employment without any neurological deficit except anosmia. Modifications in size and shape of the clip-graft are planned to create additional models which may serve a purpose in this type of aneurysm surgery.

Summary

The clip-graft can be used for most aneurysms arising from the internal carotid artery and selected aneurysms elsewhere. It provides a method of reinforcing the vessel wall at the site of the aneurysm in addition to occluding the sac of the aneurysm. It can be applied rapidly in the face of uncontrolled bleeding. The clip-graft is especially applicable to friable aneurysms with a broad base or those which sheared off at their base when a conventional spring clip was applied.

Wider experience with Grade I and Grade II candidates must be obtained before the risk of simultaneous occlusion of the anterior choroidal and posterior communicating arteries can be assessed. Study of the configuration of the specific circle of Willis under consideration should be an integral part of the preoperative evaluation and will reduce this risk.

The technique for proper application of the clip-graft to aneurysms has been discussed, with emphasis on the essential role of the operating microscope.

Addendum

Clip-grafts are now being produced by the Kees Surgical Specialty Company in diameters of 2.0, 2.5, 3.0, 3.5, and 4.0 mm. At the suggestion of Dr. Charles Drake, various lengths in each size diameter are offered so that there will be wider application to aneurysms in general, and particularly to certain aneurysms with a narrow neck arising from the carotid artery. With these shorter length clips, it will be possible to treat certain carotid artery aneurysms without simultaneous occlusion of the posterior communicating and anterior choroidal arteries, and in the smaller diameter clips, to treat aneurysms elsewhere in the vascular tree with minimal involvement of perforating vessels. Clip-grafts of each diameter will be produced in lengths of 3, 5, and 7 mm.

Each clip is supplied with the graft material attached for autoclaving. It is customary to autoclave the clips for 15 minutes.

Additional cases operated since this article was submitted for publication have included two aneurysms on vessels smaller than the carotid artery. These were treated with 2.5 mm diameter
clip-grafts with patency proven by postoperative arteriograms.

References