Nonpenetrating Clips Successfully Replacing Sutures in Base of Skull Surgery

Abstract—Reconstructive challenges engendered by skull base surgery are critical determinants of outcome. A novel nonpenetrating, arcuate-legged clip has proven to be both technically and biologically effective for management of these difficult closures. Clips have facilitated reconstructions associated with the surgical management of eight skull base cases: leiomyosarcoma of the orbit, middle fossa, pterygopalatine fossa, two meningiomas (petrotemporal, cavernous sinus), vagus nerve paraganglioma, complex traumatic orbital dural tear, and one basilar and two vertebral artery aneurysms. (Skull Base Surgery, 3(4):171–181, 1993)

Exquisite surgical demands are imposed by manipulations within the anatomic confines of the skull base. Vital structures must be precisely and confidently dissected, then rejoined under conditions of limited exposure. These circumstances can make conventional needle and suture approximation cumbersome and dangerous, particularly for attenuated dura, venous channels, and arteries. Thus, skull base reconstructions merit trials of alternative, nonsuture methods for tissue approximation. The Loma Linda University (and Jerry L. Pettis Memorial Veterans’ Medical Center) Minimal Invasive Surgical Laboratory has pioneered a new system for tissue approximation in skull base surgery, consisting of nonpenetrating, arcuate-legged clips applied in an interrupted fashion to symmetrically everted tissue. This system has proven to be at least equivalent and in many cases technically and biologically superior to needle-and-suture closure. Conclusions are drawn from experimental and clinical studies extending over several years.1-4

Surgical advances have generated the need for alternative nonsuture systems that provide reliable tissue approximation at remote or microscopic sites. The fields of skull base surgery, microsurgery, endolaparoscopy, and arthroscopy are prime examples of surgery’s enlarging scope. Nonpenetrating arcuate-legged clips successfully replace sutures by creating an elastomeric, flanged, nonpenetrated anastomosis with remarkable physical and biologic properties.5,6 Clips are clearly preferable to sutures for certain venous reconstructions, such as venous valves.7 This report describes their application in the course of managing eight skull base cases.

The clips, their special applicators, and the surgical technique for their use have been extensively described in previous publications.1-6,8 Although four different sized clips have been used (Fig. 1), only two (the mezzo and macro) have wide clinical application. Clips consist of arcuate arms, blunted tips, interconnected by a bridge attached to a frangible tang. The tips compress without penetrating intima or mucosa when applied to everted tissue.

A perceived need to facilitate the microsurgical anastomoses of the superficial temporal arterial to middle cerebral cortical artery branches ("EC-IC bypass") for brain ischemia stimulated clip development. The initial clips (microclips) were successfully tested on rat femoral arteries and veins.8 The problem of unambiguous loading
of a 400 μm long clip ("microclip") into the special slotted applier was solved by incorporating a frangible 2 mm tang onto the clip shoulder. Tangs serve a dual purpose; facilitating clip loading and mediating clip closure (Fig. 2). Microclips are designed for anastomosis of vessels 1 mm or less in diameter with wall thickness ranging from 100 to 150 μm. In practice, a microclip was found to small and the mezzoclip too large for the adult human EC-IC bypass, so an intermediate clip (the miniclip) was developed for vessels 2 to 3 mm in diameter and wall thickness less than 400 μm. All of the dural, sinus, and arterial reconstructions reported in this article were done with silver mezzo and macro clips (vessels or structure about 8 to 10 mm diameter, wall thickness 1.0 to 2.0 mm).

Figure 1. Dimensions and configurations of the four different sized clips. The microclips are 150 μm thick, whereas mini, mezzo, and macro are 300 μm thick. These sizes have proven applicable to all experimental and clinical tissue approximations so far encountered to include human dural closure and severely atherosclerotic human arteries.

Figure 2. The surgical technique for clip-mediated vascular anastomosis. Not shown are the critical everting forceps that allow tissue to be picked up and symmetrically everted prior to clip application. Traction of the tangent forces the clip shoulders against the jaws producing a bending moment that is a function of the distance of the contact points from the midline. As the clip closes, this distance becomes smaller until all energy is dissipated into fracturing the tangent. The novel mechanical features of the clip as well as a description of the special appliers, everting forceps, clip removers, and surgical technique have been extensively described and illustrated by Kirsch et al.1-4
DESCRIPTION OF CASES

Case 1: Leiomyosarcoma at the Skull Base

A 47-year-old woman with an invasive leiomyosarcoma (right middle fossa, orbit, and maxilla) underwent radical tumor resection after unsuccessful tumor control with local irradiation and chemotherapy. The surgical defect included the right hemimaxilla with palate, nasal septum, right orbital contents to include orbital floor, right zygomatic body and arch, right pterygoid processes, and right pterygoid portion of the floor of the middle cranial fossa (Fig. 3). Reconstruction was accomplished by procurement and microvascular transfer of a segmented right serratus anterior osteocutaneous free flap (Fig. 4). The seventh rib was included for bony reconstruction. The microvascular anastomoses consisted of facial artery to thoracodorsal artery (end-to-side with 18 mezzo clips) and thoracodorsal vein to facial vein (end-to-end with 12 mezzo clips).

The right external carotid arterial system, to include the facial artery, was ectatic and atherosclerotic secondary to local irradiation. A facial artery endarterectomy provided adequate arterial blood flow, but resulted in a lumen surrounded by friable adventitia. The recipient thoracodorsal artery, vein, and common facial vein appeared normal. Despite a significant arterial and venous luminal and wall thickness mismatch, blood-tight clipped arterial and venous anastomoses were done in 20 and 8 minutes, respectively. Immediate pulsative flow was attained and reconstructed veins filled immediately (Fig. 5). The flap remained viable with demonstrable perfusion by magnetic resonance angiography 6 months postoperative (Fig. 6). The patient died 20 months later of pulmonary and hepatic metastases, without evidence of skull base tumor recur-

Figure 3. The extensive resectional defect of case 1 with the acrylic palatal prosthesis visible. The procedure was performed in a previously irradiated field.

Figure 4. Harvesting of a right serratus anterior, bilobed free-flap with thoracodorsal artery and vein.
Figure 5. The clipped arterial and venous anastomosis of the transposed serratus anterior free flap. The end-to-end venous anastomosis required 8 minutes, and the end-to-side arterial connection, despite a diseased facial artery, required 15 minutes. Anastomoses were blood tight at the outset.

rence. She was free of facial pain with a gratifying cosmetic and functional result (Fig. 7).

Comment

Microvascular, composite, free tissue transfer is considered inadvisable in the presence of a compromised donor arterial supply. Even though the donor arterial supply in this case was compromised by radiation-induced atherosclerosis, clips enabled the rapid construction of a blood-tight patent anastomosis. This anastomosis would have been very difficult with needle and suture.

Case 2: Meningioma of the Cavernous Sinus

A 37-year-old woman with a medial sphenoid wing meningioma invasive to the right cavernous sinus had the latter structure entered during the course of tumor dissection. Sinus bleeding was controlled by application of three macro clips to everted sinus walls. The dura was closed with interrupted macro clips. Complete return of third and fifth nerve function on the right occurred within weeks after surgery. The patient subsequently had proton beam irradiation to residual tumor with magnetic resonance imaging evidence of significant tumor regression. She is asymptomatic 3 years after surgery.

Figure 6. This magnetic resonance angiogram demonstrates patency of the end-to-side facial to thoracodorsal artery anastomosis 1 year postoperative.
Comment

The cavernous sinus was purposely entered in order to resect tumor, since bleeding could be readily controlled by the application of clips after eversion of the sinus edges. Confidence in the clips' ability to control sinus bleeding guided our aggressive strategy for tumor resection from the cavernous sinus.

Case 3: Vagus Paraganglioma

A 46-year-old woman with a right vagal nerve paraganglioma adherent to hypoglossal nerve and internal carotid artery presented with dysphagia, neck pain, and transient ischemic episodes (Fig. 8). The rostral internal carotid artery was inadvertently torn during the course of tumor removal and promptly repaired with 16 macro clips, resulting in an immediate blood-tight closure and a patent reconstruction (Figs. 9, 10). The tumor mass was subtotally removed from the hypoglossal nerve and internal carotid artery. The right vagus nerve was invaded by tumor and taken. Postoperatively, the patient has noted improved swallowing and has been free of recurrent transient ischemic attacks and pain for the past 2 years. She has mild hoarseness secondary to right vocal cord paralysis.
nal carotid artery at the skull base is difficult. The clipped arterial tear has healed without aneurysm or stricture.

Case 4: Left Petrotentorial Meningioma

A 48-year-old woman with a 4 cm diameter, left-sided petrotentorial meningioma compressing both sigmoid and transverse sinuses underwent tumor resection. The left sigmoid sinus was entered during the course of tumor removal, but hemostasis was achieved by the application of a single mezzo clip. A complete tumor resection was accomplished and a watertight dural closure was secured with a deantigenized pericardial patch graft (BioGuard) and mezzo clips. The patient is asymptomatic 3 years after surgery.

Comment

During the course of tumor resection of a petroten- torial meningioma, a small tear was made in the left sigmoid sinus. Special everting forceps enabled eversion and approximation of the sinus walls, with a single mezzo clip providing hemostasis. Control of an open intracranial venous sinus may be problematic with either suturing or packing.

Case 5: Orbital Dural Tear, Recurrent Sinusitis, Meningitis

A 39-year-old man experienced recurrent sinusitis and meningitis subsequent to a basilar skull fracture and right orbital exenteration 11 years previously. At surgery, a purulent frontal sinusitis was found in continuity with a right orbital encephalocele. The optic nerve stump was visible through the attenuated encephalocele sac (Figs. 11,
12). The orbital dura was reconstituted with 10 mezzo clips and a deantigenized pericardial patch. The attenuated encephalocele sac was too fragile to suture, but could be clipped without rupture. The repair has healed without incident and there have been no subsequent episodes of sinusitis or meningitis over the past 3 years.

Comment

The problem of dural closure was solved by clipping deantigenized pericardium to the attenuated encephalocele sac. Pericardium is an excellent dural substitute. Needle and suture would have lacerated the encephalocele sac and resulted in a cerebrospinal fluid leak. The non-penetrated dura has healed and the patient has been asymptomatic for the past 3 years. Clips and deantigenized pericardium provide rapid and reliable watertight dural closure. Clips have been used to secure pericardium to the inner table of bone in cases of attenuated dura with excellent dural regeneration. Deantigenized pericardium and clips have been used without complication in 52 cases (cranial and spinal).

Case 6: Intraoperative Basilar Aneurysm Rupture and Repair

A 40-year-old woman had a sessile basilar tip aneurysm torn at its base after applying a 790 Yasargil aneurysm clip. Control of intraoperative bleeding was accomplished by the application of 15 macro clips to both P1 segments of the posterior cerebral arteries. Complete hemostasis was secured 4 minutes and 5 seconds after the tear, with preservation of the rostral basilar artery and posterior circle of Willis (Fig. 13). The patient made a complete neurologic recovery, to include the preoperative right third nerve palsy. The patient, a known cocaine addict, committed suicide 4 years after surgery.

Comment

Intraoperative rupture of a basilar aneurysm can be a catastrophic event. Conventional aneurysm clips have bulky handles that obscure visualization, whereas the loaded arcuate clip applier functions as a dissecting fork.
and enables precise application. Applied clips do not obscure visualization nor do they occlude vessels to achieve hemostasis. Despite the single fire system, clips were applied at a rate of 3 per minute. A multiple firing clip application system is under current development.

Case 7: Plication of a Dissecting Aneurysm; Right Vertebral Artery

A 37-year-old man bled three times within 1 month from a right vertebral artery dissecting aneurysm. Each ictus led to a worsening neurologic status. Angiograms demonstrated the point of proximal arterial dissection immediately distal to the origin of the right posterior inferior cerebellar artery (PICA), with the aneurysm extending ventrally to the medulla oblongata (Figs. 14, 15). At surgery, focal atherosclerosis was found at the site of proximal dissection. Control of the dissection was accomplished by plicating the region of focal atherosclerosis and proximal dissection with a 1 cm wide investing pericardial band secured firmly by two macro clips. Prompt deflation of the dissection occurred and intraoperative angiography confirmed control. The patient,

Figure 14. Intraoperative angiogram demonstrating right vertebral artery dissecting aneurysm just prior to plication with clips. The site of proximal dissection is immediately distal to the origin of the large PICA.

Figure 15. Diagram of plication. The pericardial band was firmly secured after tightening with two macro clips. The dotted line indicated the prompt appearance of the right vertebral artery after plication and intraoperative angiography. This maneuver has resulted in resolution of the dissection and no further hemorrhages. Postoperative angiography demonstrates complete patency without compromise of the vascular lumen.
now 5 years postoperative, has made a complete neurologic recovery.

Comment

The point of proximal dissection of this vertebral artery aneurysm was identifiable just prior to the arteries course anterior to the medulla. In view of the interposed PICA, and ventral extension of the dissection arteries to the medulla, "trapping" was impossible. Control of the dissection was obtained by clip-mediated plication and confirmed with intraoperative angiography.

Case 8: Plication of a Vertebral Aneurysm

A 77-year-old man with progressive quadriplegia, hoarseness, and dysphagia was found to have a giant left vertebral artery aneurysm markedly deforming the pons and medulla (Fig. 16). Decompression of the brainstem was attempted by debulking the aneurysm after trapping. Temporary occluding clips were placed rostrally above the PICA and inferiorly above the origin of the left anterior spinal artery. Despite temporary arterial occluding clips, brisk bleeding occurred after debulking the opened aneurysm. Hemostasis could not be secured by passage of inflatable balloons, conventional aneurysm clips, or suturing. Finally, a pericardial patch was clipped to the open calcified vertebral artery wall, and plication with ten macro clips achieved immediate hemostasis. The patient never regained consciousness after surgery and died 1 month later. The surgical reconstruction was examined postmortem and the clips found to be in place (Figs. 17, 18).

Comment

This patient with compromised pontine and medullary function died from brainstem ischemia associated with "back bleeding" from the opened aneurysm. Bleeding could not be controlled by intravascular balloons, suture, or conventional aneurysm clip, but was eventually achieved by clip application of a pericardial patch. The mass of the left-sided vertebral artery aneurysm actually obscured a smaller mirror aneurysm on the right vertebral artery.

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Figure 16. Sagittal MRI demonstrating a large left vertebral artery aneurysm markedly deforming and dorsally displacing the medulla. The flow void within the aneurysm represents the residual left vertebral artery.

Figure 17. This postoperative angiogram demonstrates the trapping of the giant left vertebral artery aneurysm utilizing clips and a pericardial patch. Despite trapping, persistent back bleeding could not be controlled by balloon catheters or conventional clips. Back bleeding was eventually controlled by clip application of a pericardial patch to the opened aneurysm wall.
Figure 18. Postmortem examination of the clipped pericardial patch of the opened and calcified vertebral artery aneurysm. The clips are clearly visible.

DISCUSSION

The outcome of these skull base cases has been tabulated according to the recommendations of Ojemann (Table 1). Clips expedited the free tissue transfer necessary for craniofacial reconstruction in case 1 and enabled the rapid repair of the cavernous sinus and proximal internal carotid artery in cases 2 and 3. The quality of dural closure in case 4 would have been severely compromised by suture. Clips were essential for reconstruction of the posterior circle of Willis in case 5, enabled the control of the dissection in case 6, and achieved hemostasis when all other modalities failed in case 8. In summary, the arcuate-legged clips have been very helpful for tissue and vascular reconstructions in anatomically confined regions and certainly accelerated the procedure.

We have found the clip to be practical for dural reconstructions, particularly in confined and attenuated circumstances, in combination with deantigenized pericardium. Watertight dural closures have been achieved. The key principle in surgical application of the clip is the ability to evert tissue, and special everting forceps facilitate this maneuver. The nonpenetrating arcuate-legged clip confers technical advantages to the surgeon engaged in skull base surgery. The clip provides the capability of improved dural reconstructions, rapid and reliable blood-tight vascular anastomoses, and the capability of controlling hemorrhage from arterial, venous, and sinus sources.
### Table 1. Summary Statement of Skull Base Surgical Cases and Clip Utilization

<table>
<thead>
<tr>
<th>Indications for Therapy</th>
<th>Immediate Results: Clip Application</th>
<th>Long-Term Results</th>
<th>Response to Radiotherapy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Facial pain secondary to leiomyosarcoma of right middle fossa, orbit, and maxilla</td>
<td>Tumor ablation, relief of facial pain, and cosmetic reconstruction of face. Clips used for microvascular anastomosis in free flap transfer</td>
<td>Died at home 20 months later of metastatic pulmonary and hepatic leiomyosarcoma</td>
<td>No tumor response to local radiation (2500 rads brachytherapy Ir beads)</td>
</tr>
<tr>
<td>Headache and cranial nerve deficits of III and V secondary to cavernous sinus meningioma, medial wing of sphenoid</td>
<td>Normalization of extraocular movements, return of facial sensations, and relief of headaches. Clips used for closure of cavernous sinus</td>
<td>Asymptomatic 3 years with no signs of residual tumor growth</td>
<td>Residual tumor controlled by heavy particle (proton irradiation)</td>
</tr>
<tr>
<td>Dysphagia, hoarseness, cervical discomfort, right glomus vagale tumor</td>
<td>Improved swallowing, discomfort relieved, hoarseness persists with paralyzed right vocal cord. Clips used for repair of high internal carotid artery entered during the course of tumor removal</td>
<td>No discomfort, mild hoarseness, improved swallowing, no evidence of tumor recurrence 2 years after surgery</td>
<td>None given</td>
</tr>
<tr>
<td>Headache, recurrent meningitis, chronic sinusitis</td>
<td>No further headache, cosmetic restoration of forehead. Clips used to repair attenuated dura and optic encephalocele</td>
<td>No further headache or meningitis 3 years postoperative. Cosmetic facial improvement</td>
<td>None given</td>
</tr>
<tr>
<td>Recurrent subarachnoid hemorrhages, basilar artery aneurysm</td>
<td>Rapid and progressive neurologic improvement with immediate right III nerve palsy. Clips used to repair posterior circle of Willis after intraoperative aneurysm repair</td>
<td>Neurologically intact with recovery of III nerve palsy. Committed suicide 4 years postsurgery, narcotic addiction</td>
<td>None given</td>
</tr>
<tr>
<td>Recurrent subarachnoid hemorrhages, right vertebral dissecting aneurysm</td>
<td>Rapid and progressive neurologic improvement. Clips used to control point of arterial dissection</td>
<td>Neurologically intact 5 years postoperation</td>
<td>None given</td>
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<tr>
<td>Mass effects of giant vertebral artery aneurysm on medulla and high cervical cord</td>
<td>Immediate postoperative worsening, coma, and death 1 month postoperative. Clips used to obtain hemostasis from left vertebral artery after &quot;trapping&quot; and balloon occlusion failed</td>
<td>Death 1 month postoperative</td>
<td>None given</td>
</tr>
<tr>
<td>Mass effects of left petrotemporal meningioma</td>
<td>Steady postoperative improvement. Clips used to control bleeding from transverse sinus. Dural closure.</td>
<td>Neurologically intact 3 years postoperative</td>
<td>None given</td>
</tr>
</tbody>
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### REFERENCES