Advances in Vertebral Artery Surgery at the Skull Base

Andrew L. Carney, M.D.,* Evelyn M. Anderson, M.D.,* and Daniel M. Martinez, M.D.†

Between July 1975 and May 1985, 219 procedures were performed on the vertebral system; two were intracranial, 118 were at the skull base and 99 were at the neck base. Of the 108 patients operated on at the skull base, procedures were multiple in five and bilateral in two.

Bypass to the vertebral artery between the transverse process of C1 and C2 was performed 91 times. The blood supply for the bypass was the common carotid (70), the external carotid (9), the internal carotid (9), the subclavian (3), and the occipital artery (3). Decompression was performed in three patients, segmental resection in seven, and ligation in two.

The primary objective was to increase the flow capacity of the vertebral artery. This flow to the Circle of Willis supplies the forebrain and the hindbrain if the internal carotid artery is obstructed and the posterior communicating artery is patent, or it may supply only the hindbrain when no communication exists. The pathologic processes include atherosclerosis, thrombosis, dissection, compression, and vasospasm.

The male:female ratio is 2:3. Long-term mortality is 19% for the male and 4.6% for the female. Hindbrain symptoms in the male predates cardiac symptoms by 2 to 4 years. Operative mortality and stroke rate is less than 3% combined. Long-term graft patency is 87%.

Vertebral artery surgery at the skull base produces results superior to those following proximal segment reconstruction when measured by dynamic computerized tomographic scanning, neurofunctional testing, and symptom relief. Success following reconstruction depends on careful patient selection and surgical expertise. The techniques of reconstruction are well established and results have been durable for over a decade.

DYNAMIC COMPUTERIZED tomographic scanning and vertebral artery surgery at the skull base are major developments in the field of neurovascular surgery. This type of scanning permits a hemodynamic approach to brain ischemia because its diagnostic capability is not limited to the cerebral hemispheres, but extends into the brainstem.

From *Mercy Hospital and the University of Illinois, Chicago; and †Presbyterian Hospital, Southwest Medical School, Dallas, Texas.

Address for reprints: Andrew L. Carney, M.D., Box 2009, 222 Forest Avenue, Oak Park, Illinois 60302.
and the cerebellum. The hindbrain is sensory, homeostatic and works in conjunction with the organs of special sense. The ability to distinguish central ischemia from peripheral dysfunction is critical. Cortical blindness and central deafness can be distinguished from end-organ dysfunction.\(^1\)

Vertebral artery surgery at the skull base addresses the complexity of anatomy, pathology, and motion at the skull base and recognizes the importance of the vertebral artery to brain hemodynamics.\(^2,3\) Vertebral artery surgery at the skull base has produced results superior to that performed on more proximal segments when measured by the criteria of dynamic computerized tomography, neurofunctional testing, and symptom relief. Success following reconstruction depends on careful case selection and surgical expertise. The techniques of vertebral artery reconstruction at the skull base are established and the results are durable.\(^4\)

**PATIENTS AND METHODS**

Between July 1975 and May 1985, 219 procedures were performed on the vertebral system: two were intracranial, 118 were at the skull base, and 99 were at the neck base. Of the 108 patients operated on at the skull base, procedures were multiple in five and bilateral in two.

Bypass to the vertebral artery between the transverse process of C1 and C2 was performed 91 times. The blood supply for the bypass was the common carotid artery in 70 cases, the external carotid artery in nine cases, the internal carotid artery in nine cases, the subclavian artery in three cases, and the occipital artery in three cases. Decompression was performed as the sole procedure in three cases, and segmental resection with end-to-end anastomosis in seven cases. The vertebral artery was ligated without reconstruction in two cases because of dissection. Sympathetic denervation was accomplished in two cases: (1) by superior cervical gangliectomy, and (2) by perivascular denervation.\(^1\)

The male to female ratio was 2:3. Long-term mortality was 19% in the males and 4.6% in the females. Hindbrain symptoms in the male predated cardiac symptoms by 2 to 4 years. Operative mortality and stroke rate were less then 3% when combined. Long-term graft patency was 87%.

**CASE REPORTS**

**Case 1**

**Common Carotid to Distal Vertebral Artery Bypass\(^5\)**

On August 29, 1977, a 77-year-old man presented with transient right hemiparesis, confusion, slurred speech and the inability to swallow. A computerized tomographic scan revealed a watershed infarction in the left parietal-occipital region. Angiography disclosed total occlusion of the left internal carotid artery. Injection of the dominant left vertebral artery showed sharply-angled dynamic obstructions at the origin of the proximal segment within the cervical spine, and at the level of C2. The right internal carotid artery did not supply the forebrain on the left side.

On October 5, 1977, a vein bypass from the common carotid artery to the distal vertebral artery between C1 and C2 was performed. This bypass resulted in increased flow and pressure to the forebrain and hindbrain by increasing the flow capacity of the vertebral artery and the posterior communicating artery. Comparison of his preoperative and postoperative angiograms revealed marked increase in the number and size of the visualized secondary vessels. Despite dramatic improvement, the patient died within a year of coronary artery disease.

**Comment**

Carotid obstruction proximal to the circle of Willis will result in the diversion of blood flow from the hindbrain into the forebrain if the posterior communicating artery is large.\(^6\) If the vascular bed exceeds the capacity of the vertebral artery, though its flow be great, the ischemia will be maximal in the parietal-occipital watershed. If the carotid is stenotic, endarterectomy will relieve symptoms by restoring normal flow to the carotid artery and reducing the demand on the vertebral system.

However, if the internal carotid artery is occluded, then the vertebral artery must
supply an overextended vascular bed, the forebrain and hindbrain. Only by increasing the flow capacity of the vertebral artery can the blood flow be increased and improve brain perfusion. Dynamic arterial obstructions decrease flow capacity. Bypass to the vertebral artery at the skull base increases flow capacity (Fig. 1).

![Diagram of brain hemodynamics]

**Fig. 1 Brain hemodynamics.** The circle of Willis, including the vertebral arteries, is the anatomical basis for competitive flow within the system. McDonald and Potter define the “deadpoint” as the point of no flow where pressures are balanced. Occlusion of a single vessel results in the rapid redistribution of blood flow within the circle of Willis and may affect a vascular bed remote from the occluded vessel. (Reprinted from Carney AL: Advances in Neurology, by permission of Raven Press, New York, N.Y.).

**Case 2**

**Subclavian to Distal Vertebral Artery Bypass**

A 65-year-old male, who was a retired cement worker, presented with dramatic loss of strength precipitated by head rotation. Noninvasive evaluation revealed a marked reduction in right carotid blood flow. Angiography disclosed total occlusion of the right external carotid artery, but no apparent obstruction of the common or internal carotid artery. Left carotid compression was not tolerated. There were dynamic obstructions of the dominant left vertebral artery.

On May 5, 1978, a vein bypass was performed between the subclavian artery and the vertebral artery between C1 and C2 on the left side. The subclavian artery was selected by necessity. Left carotid compression was not tolerated. Subsequently, the patient was dramatically relieved of his symptoms.

Postoperatively, dynamic computerized tomographic scanning was done with the bypass occluded and open. This revealed that the contralateral right frontal lobe was ischemic when the bypass was closed, and perfusion was normal when the subclavian: distal vertebral artery bypass was open. High flow through the left vertebral artery was necessary to restore perfusion of the right frontal lobe to normal.

The patient died 4 years later in 1982 from progressive pulmonary fibrosis.

**Comment**

Obstruction of a single pre-circle artery, internal carotid artery or vertebral artery may result in ischemia in a portion of the brain that is well tolerated. When flow is further reduced by obstruction of a second pre-circle vessel, the impact can be catastrophic.

In this patient, the right carotid angiogram revealed no apparent obstruction of the internal carotid artery, but the blood flow was reduced by noninvasive testing, and the right frontal lobe was ischemic. Occlusion of neither the left common carotid artery nor the left vertebral artery could be tolerated. Postoperative angiograms disclosed filling of the distal external carotid artery segment on the right side. Thus the left vertebral artery now contributed to the perfusion of the right frontal lobe and increased the flow to the right external carotid artery (Fig. 2).

**Case 3**

**Segmental Resection at C1-C2**

A 39-year-old woman presented with recurring syncope precipitated by head hyperextension. The carotid arteries were normal. Both vertebral arteries were extremely redundant and acutely angled at the level of C2, but much worse on the right.
On July 31, 1975, a segmental resection of the vertebral artery between C1 and C2 was performed with primary end-to-end repair. Her symptoms have been relieved for the 10 years of follow-up without requiring contralateral surgery.

Comment

Head motion at the skull base has a tremendous range. Stressed head positions normally result in obstruction of one or two vessels. If cardiac output is adequate, if the circle of Willis is complete, and if the primary vessels to the circle of Willis are patent, there are no symptoms. If the flow capacity of patent vessels is decreased, the dynamic occlusion of the vertebral artery can be catastrophic. Head rotation primarily compromises vertebral artery flow between C1 and C2, but it may occur within the cervical spine. Head extension can result in obstruction in the proximal segment within the cervical spine, and posteriorly between the arch of the atlas and the skull base.

In this patient, head hyperextension resulted in the obstruction of both vertebral arteries at the level of C2. Reconstruction of the worst vessel resulted in the relief of symptoms.
Case 4
CC-DVA Bypass to a Hypoplastic Vertebral Artery

(CC = common carotid; DVA = the vertebral artery between C1 and C2)

In 1977, a 59-year-old mechanic suffered a brainstem stroke that resulted in painful dysaesthesias and difficulty in walking. The carotid arteries were normal but the carotid injection filled the basilar artery to its midportion. The vertebral system was hypoplastic.

On April 11, 1979, a vein bypass was performed from the left common carotid artery to the 2.0 mm vertebral artery between C1 and C2. His symptoms were markedly improved, and his recovery was uneventful. Two years later, in 1981, he underwent coronary bypass for progressive left ventricular dysfunction and did not experience any neurologic complications. Angiograms performed in April 1985, 6 years after surgery, revealed continued patency of the vein bypass.

Comment
When the carotid vascular bed is large, the vertebral bed is correspondingly smaller. Ordinarily the internal carotid artery supplies the anterior cerebral artery and middle cerebral artery. When it also supplies both posterior cerebral arteries, the basilar artery ends with the superior cerebellar arteries, and the vertebral artery is smaller in diameter, resulting in an increase of high resistance. A reduction of cardiac output can cause hindbrain ischemia or brain infarction in this vulnerable territory.

Coronary insufficiency may first be manifested by symptoms of hindbrain ischemia. These symptoms may precede manifest cardiac disability by 2 to 4 years, and carry a serious prognosis for males.

Hypoplastic vertebral systems have high resistance, and any reduction of cardiac output or perfusion pressure can result in severe ischemic damage to this vulnerable territory. If a hypoplastic vertebral artery does not communicate with the circle of Willis and terminates in the end posterior inferior cerebellar artery, extracranial vertebral artery occlusion can result in brainstem and cerebellar infarction.

Case 5
Carotid Distal Vertebral Artery Bypass

In 1978, a 63-year-old woman came into our institution with dysequilibrium, ataxia and syncope. The carotid arteries were normal. Mild sinus bradycardia was present. On March 7, 1978, a vein bypass was performed from the common carotid to the vertebral artery between C1 and C2. A year later, in 1979, a physiologic pacemaker was implanted for worsening bradycardia. Angiography performed 7 years after surgery demonstrated continued satisfactory function.

Comment
Hypertension and bradycardia are common findings in patients with hindbrain ischemia. The control of hypertension is often successful in controlling symptoms, but vertebral artery surgery and cardiac pacing may also be required. Ventricular pacing should not be used if sinus rhythm is present, because symptoms may be severely aggravated.

Over the course of 5 years, one-third of the patients undergoing vertebral artery surgery will require pacemakers. Physiologic pacemakers are preferable. If the bradycardia is profound, initial pacemaker implantation is employed. However, if the patient fails to respond, then vertebral artery reconstruction may be necessary. Vertebral artery reconstruction does not prevent the necessity of cardiac pacing at a later date.

Case 6
ICA Ligation; ICA:DVA Anastomosis, End-to-Side

(ICA = internal carotid artery; DVA = the vertebral artery between C1 and C2)

A 63-year-old man, blinded by ocular enucleation, presented with severe dizziness, ataxia, and confusion. He had functioned as a skilled cabinet maker using power tools and was dependent upon his seeing-eye dog. The symptoms and the death of his dog destroyed his well-being. He was not considered eligible for a dog because of his symptoms. Angiography revealed severe internal carotid artery siphon stenosis, which was bilaterally worse on the right, stenosis of the right internal carotid artery at the bifurcation, and bilateral vertebral artery stenosis at the origin from the subclavian artery.
On November 11, 1984, the right carotid bifurcation was endarterectomized and the distal internal carotid artery ligated and divided at the level of C1. The divided end of the internal carotid artery was then anastomosed end-to-side to the vertebral artery between C1 and C2. The postoperative angiogram revealed good filling of the carotid siphon through the posterior communicating artery.

The patency of the internal carotid artery is assured and no other procedure appears warranted at this time. The patient obtained a seeing-eye dog and is doing well.

Comment
Eighty-five percent of superficial temporal artery-middle cerebral artery bypasses are done for internal carotid occlusion or inaccessable stenosis. In the 5-year cooperative study by Barnett and Peerless, this procedure was deemed of no benefit or detriment.8 The anastomosis of the superficial temporal artery to the middle cerebral artery is associated with the postoperative occlusion of the proximal middle cerebral artery. The point where the reversed flow in the middle cerebral artery encounters the circle of Willis becomes a dead-point, a watershed where pressures are balanced, stasis is produced, and thrombosis enhanced. A similar phenomenon is observed with coronary bypass.

The same competition for flow occurs between the CC-DVA bypass and the internal carotid artery. If the internal carotid artery siphon stenosis is severe, then the internal carotid artery will occlude — and has occluded following a CC-DVA bypass. An artery is a better conduit than a vein. Utilizing the internal carotid artery as a conduit to the DVA requires the bold stroke of dividing the distal internal carotid artery at the skull base and anastomosing it to the DVA. Because of the adequate posterior communicating artery in this patient, the procedure was well tolerated and produced a satisfactory result.

Case 7
Suboccipital Denervation of the Vertebral Artery

A 44-year-old motorcyclist exhibited a history of severe migraine headaches, which incapacitated him from work. The headache was localized on the side of a hypoplastic vertebral artery. Intense medical therapy for 6 years proved to be both expensive and fruitless. Selective angiography of the right vertebral artery precipitated a typical migraine headache. Magnification angiography of the right skull base revealed prominence of occipital artery and spasm of the posterior meningeal artery.

On April 5, 1985, the vertebral artery between the occiput, dura and foramen transversarium was denervated. Postoperatively, he was able to work without limitation. The headaches that occurred were more easily controlled and appeared related to muscle spasm in the flap. The migraine headaches have been controlled since surgery.

Comment
Neurovascular access to the posterior skull base requires access to a blood supply. Only by combining the lateral with the posterior approach is this possible. In 1954, Hauge9 showed that contrast injection into the vertebral system results in sensory disturbances. It can, in fact, reproduce the clinical manifestations of hindbrain ischemia. Following surgery, the relief of the severe migraine headache in this patient was astounding. Long-term follow-up is required to satisfactorily evaluate this approach.

DISCUSSION

Clinical symptoms of hindbrain ischemia cannot localize the arterial lesions, identify the vascular system involved, nor distinguish end-organ from central hindbrain dysfunction, Preoccupation with the end organ may result in missing the central pathology. In respiratory arrest, for example, attention is usually directed to the lung, but not to the respiratory center in the brainstem or the vertebral artery which perfuses it. Distinguishing dysfunction of the brain stem from that of the vestibular apparatus is commonly done, but identifying ischemia as the pathologic mechanism is uncommon. Dynamic computerized tomographic scanning permits the qualitative measurement of focal tissue perfusion with high resolution in the cerebral hemispheres as well as the brainstem.3
The structure of the brain and regional perfusion must be considered separately from vascular anatomy. Brain structure is constant; arterial supply is variable. Hindbrain perfusion studies cannot identify the site, the side, nor the obstructed artery, which, when repaired, will improve flow. Dynamic computerized tomographic studies can only document the presence and location of brain ischemia preoperatively and the changes in perfusion that result following arterial reconstruction.

The selection of surgical therapy requires a careful evaluation of vascular anatomy, brain hemodynamics, and risk. The objective of surgery is to maximize the flow capacity of the vertebral artery. The integrity of the circle of Willis, especially the posterior communicating artery, influences the risk of stroke. The procedures are multiple and varied, depending upon the anatomy and lesions.

In the presence of adequate posterior communicating arteries, the internal carotid artery obstruction will markedly increase the size of the intracranial vascular bed supplied by the vertebral artery. Flow demand is increased because the vertebral artery now supplies the forebrain, the frontal, and the parietal lobes. A large caliber vein bypass to the dominant vertebral artery at the skull base can enhance flow capacity by dilating the system, enhancing arterial flow, and normalizing the perfusion of the forebrain, the hindbrain, or both.

In the absence of the posterior communicating arteries, the vascular bed of the hindbrain is limited to the occipital and temporal lobes, the brainstem and cerebellum. In the hypoplastic vertebral system, two vertebral arteries supply the brainstem and cerebellum. The asymmetrical hypoplastic vertebral artery may end in the posterior inferior cerebellar artery, supplying one side of the brainstem and cerebellum. When a single vertebral artery supplies a vascular bed without obvious collateral, the risk of brain infarction during surgical occlusion is increased. The case process requires careful clinical judgment.

Vertebral artery surgery at the skull base has led to a better understanding of the dynamic anatomy and pathology in this region, and to an appreciation of the sensory nature of the hindbrain. The primary manifestation of hindbrain ischemia is disability due to dysfunction of the sensory, the sensory integrating, or the autonomic homeostatic systems. Relief of disability is the primary indication for surgery.

The vertebral system is very sensitive to reductions of cardiac output. Symptoms of hindbrain ischemia are particularly ominous for males and may antedate cardiac crisis by 2 to 4 years in our cases. Vertebral artery surgery was associated with a 19% mortality in males over the period of follow-up (a four-fold increase over females). Brain ischemia may also antedate symptoms by as much as 2 years. Progressive brain ischemia appears associated with a falling cardiac output.

Cardiac surgeons have aggressively corrected carotid stenosis without significantly reducing the incidence of neurologic complications. We propose several questions: How do patients with hindbrain ischemia tolerate cardiopulmonary bypass? Should the hindbrain and the vertebral artery be more carefully considered and aggressively pursued prior to heart surgery? We find that cardiopulmonary bypass has been well tolerated by the patients who have had vertebral artery reconstruction at the skull base as the initial procedure.

Ischemia of the hindbrain is a central hemodynamic problem of the central nervous system, with peripheral neurologic manifestations. Only a hemodynamic approach encompassing brain hemodynamics and vertebral artery surgery will resolve the issue. The diagnostic instrumentation, the surgical technique, and the knowledge are available. The cost of disability should be factored into clinical decisions because stroke and death are not reliable indicators of sensory or cognitive defects.

**REFERENCES**