

## Microvascular decompression of cranial nerves: lessons learned after 4400 operations

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**Object.** Microvascular decompression has become an accepted surgical technique for the treatment of trigeminal neuralgia, hemifacial spasm, glossopharyngeal neuralgia, and other cranial nerve rhizopathies. The senior author (P.J.J.) began performing this procedure in 1969 and has performed more than 4400 operations. The purpose of this article is to review some of the nuances of the technical aspects of this procedure.

**Methods.** A review of 4415 operations shows that numerous modifications to the technique of microvascular decompression have occurred during the last 29 years. Of the 2420 operations performed for trigeminal neuralgia, hemifacial spasm, and glossopharyngeal neuralgia before 1990, cerebellar injury occurred in 21 cases (0.87%), hearing loss in 48 (1.98%), and cerebrospinal fluid (CSF) leakage in 59 cases (2.44%). Of the 1995 operations performed since 1990, cerebellar injuries declined to nine cases (0.45%), hearing loss to 16 (0.8%), and CSF leakage to 37 (1.85%  $p < 0.01$ , test for equality of distributions). The authors describe slight variations made to maximize surgical exposure and minimize potential complications in each of the six principal steps of this operation. These modifications have led to decreasing complication rates in recent years.

**Conclusions.** Using the techniques described in this report, microvascular decompression is an extremely safe and effective treatment for many cranial nerve rhizopathies.

**KEY WORDS** • microvascular decompression • trigeminal neuralgia • hemifacial spasm • glossopharyngeal nerve

VASCULAR arterial contacts with the dorsal root of the trigeminal nerve were first described in 1929 by Dandy.<sup>5</sup> Although he characterized these findings in subsequent communications,<sup>4,6</sup> it was not until the 1950s that Gardner and Miklos<sup>8</sup> and Taarnhøj<sup>12</sup> reported the beneficial effects of decompressing the trigeminal nerve for tic douloureux. Similar observations of vascular compression of the seventh cranial nerve in patients with hemifacial spasm were first reported by Campbell and Keedy<sup>3</sup> in 1947 and by Laine and Nayrac<sup>10</sup> in 1948. Gardner and Sava<sup>9</sup> later extended these descriptions and proposed decompression of the facial nerve for hemifacial spasm in 1962. Despite these seminal observations, it took another 10 to 15 years before microvascular decompression became an accepted treatment for cranial nerve syndromes.

Early posterior fossa surgery was performed without the aid of magnification or adequate lighting and produced high rates of morbidity and mortality. Initially, procedures were performed with the patient prone, with planned partial or complete nerve section. Over the years, the goals of the operation changed and technological advances, combined with surgical innovations, helped to make this procedure safer and more effective. We review the senior author's (P.J.J.) 29 years of experience in performing this operation, and we detail many of the techni-

cal aspects that have contributed to minimize complications.

We propose a six-step method of performing microvascular decompression and describe six surgical "pearls" that make this operation safer and more effective. Important modifications of the initial procedure include patient positioning and the overall goal of surgery. The patient is now surgically treated while in the lateral or park-bench position, and the goal of the surgery is nerve decompression rather than nerve section. Such modifications, in addition to many others described herein, have greatly reduced the attendant risks of operative morbidity and have improved outcome.

### Operative Technique

#### *Step 1. Positioning of the Patient*

"Vertex position dictates cranial nerve exposure" (P.J.J.).

It has been said that the most important part of a surgical procedure occurs before the skin incision, and much of the ease or difficulty of the microvascular decompression procedure is determined by patient positioning. The patient is placed on the operating room table with the head at the foot of the bed to maximize the surgeon's comfort

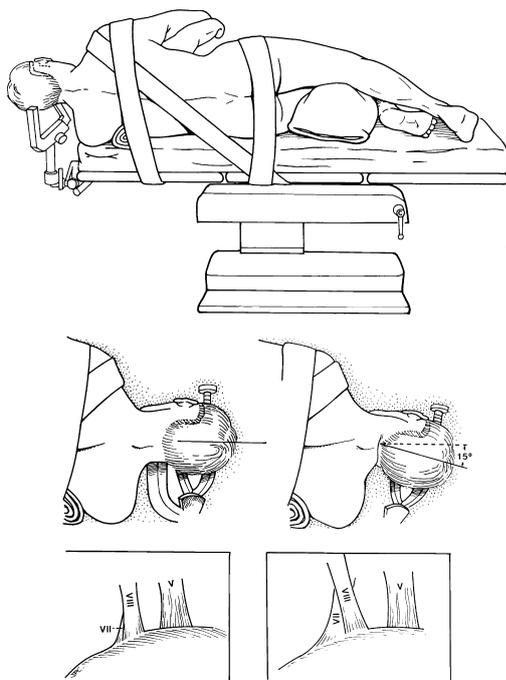


FIG. 1. *Upper:* Drawing showing the patient's head placed at the foot of the operating table to allow more leg room for the surgeon during the microsurgical portion of the procedure. The head is secured with three-point fixation and the patient is turned in the lateral decubitus position. The head is rotated slightly away from the affected side and flexed to approximately two finger breadths from the sternum. *Lower:* Drawings showing how the angle of the vertex is tailored depending on the cranial nerve approach. For trigeminal or cochlear nerve approaches, the vertex of the head is kept parallel to the floor to keep the seventh–eighth nerve complex at a more inferior position with respect to the trigeminal nerve. For a seventh or lower cranial nerve approach, the vertex is dropped 15° toward the floor to rotate and expose the proximal aspect of the seventh nerve and to rotate the vestibulocochlear complex more cephalad.

during the microsurgical portion of the procedure. Following induction of anesthesia and intubation, a three-point head-fixation device is applied and the patient is placed in the lateral decubitus position with appropriate padding of pressure points and an axillary roll. The neck is flexed slightly with the chin approximately two finger breadths from the sternum (Fig. 1 *upper*). The head is rotated approximately 10° away from the affected side. If a trigeminal or cochlear approach is planned, the vertex is kept parallel to the floor to keep the seventh–eighth cranial nerve complex at a more inferior position in relation to the trigeminal nerve. If a facial nerve or lower brainstem approach is planned, the vertex is dropped 15° toward the floor to expose the proximal aspect of the seventh nerve and rotate the vestibulocochlear complex more cephalad (Fig. 1 *lower*). The head holder is secured in the proper position. The patient is taped securely to the table at the hips and chest to allow rotation of the table during the operation. Finally, the patient's shoulder is taped down and placed out of the way.

### Step 2. Surgical Incision

“The placement of the incision is variable depending on the size and thickness of the patient's neck” (P.J.J.).

A 3 × 3-cm area behind the ear is shaved and bone landmarks are identified by palpation before the patient is prepared for surgery. The mastoid eminence, digastric groove, andinion should be identified and an inimeatal line drawn to define the transverse sinus. Laterally, over the digastric groove a second line is drawn. The intersection of these lines reveals the junction of the transverse and sigmoid sinuses. This allows the surgeon a “mind's eye” view of optimal burr hole placement. These external landmarks guide the surgeon to minimize the length of the incision and to allow adequate exposure for burr hole placement (Fig. 2 *upper*). A vertical incision is drawn 3 to 5 cm long, approximately 0.5 cm posterior (medial) and parallel to the hair line. Identical incisions are used for both upper and lower cranial nerve exposures. A slightly shorter incision is required for thin- and long-necked patients. For short- and thick-necked patients, the incision should be slightly longer with the inferior aspect angled more posteriorly (medially). This angled incision requires slightly more extensive muscle dissection over the mastoid and digastric groove, but positions the thicker neck musculature posteriorly (medially), allowing freer movement of the surgeon's hands and instruments while performing the microsurgery (Fig. 2 *lower*). Three-quarters of the incision should be drawn inferior to the junction of the transverse and sigmoid sinuses and one-quarter should be above. The area is prepared and draped in the usual fashion and the incision is made down to the occipital bone by using monopolar cautery. The soft tissues are dissected using a periosteal elevator and electrocautery where necessary. The initial periosteal dissection should proceed anteriorly (laterally) before completing the posterior (medial) dissection. This provides better fixation with the Weitlaner retractor. The anterior (lateral) and inferior aspects of the mastoid eminence must be cleared of soft tissue. The nuchal muscles are dissected with electrocautery and the transverse occipital artery is identified, ligated, and divided. The mastoid emissary vein is usually identified and must be waxed in its fossa. An angled Weitlaner cerebellar retractor is put in place. In thin-necked patients a straight Weitlaner retractor often gives adequate exposure and takes up less room within the incisional opening.

### Step 3. Bone Removal

“The junction of the transverse and sigmoid sinuses must be visualized before the dural opening” (P.J.J.).

Before burr hole placement, bone landmarks should be well exposed. The digastric groove should be clearly visualized and the soft tissue should be dissected slightly anterior to this landmark. Often the external aspect of the emissary vein does not lie directly over the sinus; rather, the vein meanders in a rostralateral direction before entering the proximal sigmoid sinus. Therefore, the mastoid emissary vein is a good landmark for the underlying junction of the transverse and sigmoid sinuses. The asterion location is variable and, thus, is not a reliable landmark for the sinus junction.<sup>7</sup> The burr hole should be placed over

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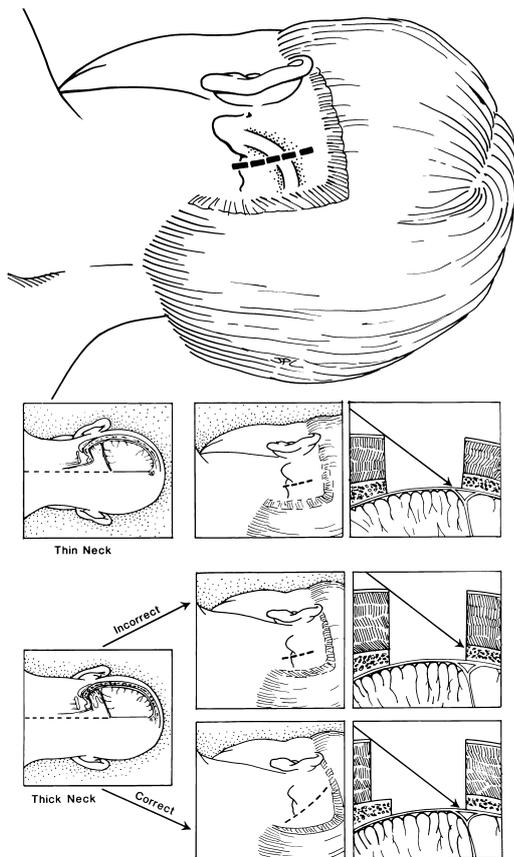


FIG. 2. *Upper:* Drawing depicting how the intersection of the digastric groove and the inionmeatal line defines the junction of the transverse and sigmoid sinuses. With a “mind’s eye” view of optimal burr hole placement and craniectomy, an incision is drawn centered over the planned craniectomy. *Lower:* Drawings showing different surgical incisions based on the size of the patient’s neck. Short and thick-necked patients require a more posteriorly (medially) directed incision. This angled incision positions the thicker neck musculature more posteriorly (medially) and out of the operative field. This small adjustment is critical in allowing freer movement of the surgeon’s hands and instruments while performing the microsurgery.

the mastoid emissary vein by using a perforator or high-speed drill. The goal of bone exposure should be to identify the edge of the junction of the transverse and sigmoid sinuses first. A small craniectomy can then be tailored according to the cranial nerve approach desired (Fig. 3). For a trigeminal or cochlear nerve approach, the craniectomy should be shaped as an isosceles triangle with the apex at the junction of the transverse and sigmoid sinuses. For a facial or lower cranial nerve approach, the apex of the triangle should be at the edge of the jugular bulb.

It is important to remove a portion of the posterior mastoid air cells and to bevel the craniectomy outward so that no bone overhang will limit the dural opening. Mastoid air cells should be thoroughly waxed. Either a curvilinear or T-shaped incision is made in the dura mater. This incision must expose the most superior and lateral corner of the dura adjacent to the junction of the transverse and sigmoid

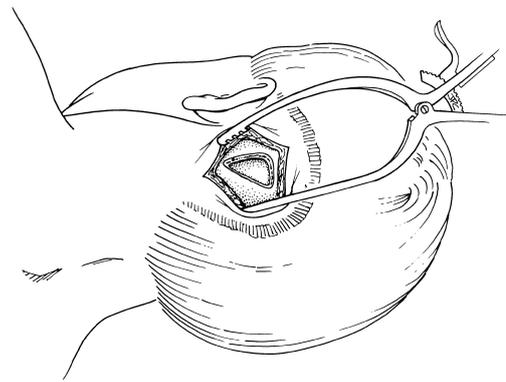


FIG. 3. Drawing depicting how bone exposure should demonstrate the junction of the transverse and sigmoid sinuses. Surgical exposure can then be tailored according to the cranial nerve approach desired.

sinuses to allow a direct corridor along the petro-tentorial bone. The bone work must be anterior (lateral) enough (usually into mastoid air cells) to allow dural incision and reflection.

### Step 4. Turning the Corner

“Turning the corner is the most dangerous stage of the operation and must be executed with patience and the utmost care” (P.J.J.).

After the dura is sutured back, an operative microscope with a 250-mm objective lens is brought into the field. “Turning the corner” or exposing the cerebellopontine angle may be difficult and hazardous. The surgeon should allow some drainage of cerebrospinal fluid (CSF) before placing the microretractor. Occasionally, gentle advancement of a cottonoid with a rubber dam is required to drain CSF from the cerebellopontine angle before placement of a retractor. All cottonoids are moistened with saline and are paired with an appropriately sized (0.5 × 2-in) piece of latex cut from a sterile glove. The latex prevents adhesion to the cerebellum and allows easy advancement of cottonoids medially to the cerebellopontine angle. If there is adequate CSF egress, a lumbar drain is not necessary. After the CSF has been drained, the cerebellum should begin to fall away from the petro-tentorial junction. A tapered retractor blade, bent proximally to a 60° angle, is placed over the previously placed rubber dam/cottonoid combination. The retractor should be no longer than necessary (approximately 6 in) because an overly prominent retractor can be bumped accidentally.

For trigeminal and cochlear nerve approaches, the blade and cottonoid are placed over the superolateral aspect of the cerebellar surface and the ala of the cerebellum is gently elevated. The goal of retraction for all approaches in this region is always to elevate the cerebellum slightly toward the surgeon and not simply to compress it medially. This facilitates more CSF drainage, thereby minimizing the need for cerebellar retraction. The petrosal vein complex is identified and placed on gentle traction with the retractor. Using microbipolar electrocautery, the vein complex is coagulated and partially divided to verify adequate hemostasis. The complex is then coagulated a sec-

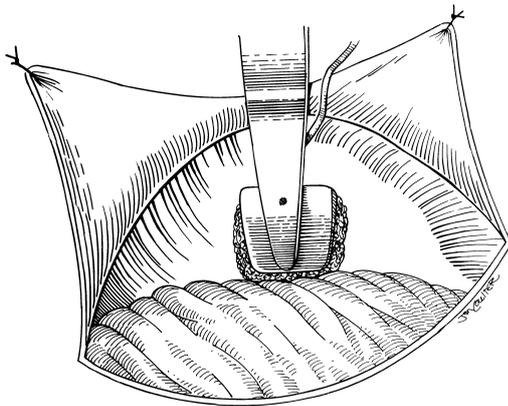


FIG. 4. Drawing showing how, in the event of inadvertent petrosal vein avulsion, bleeding can be controlled by gentle pressure and packing of the tentorial side using Surgicel covered with a cottonoid. The retractor can be used for placing gentle pressure on the cottonoid and Surgicel while the surgeon looks for the free end of the avulsed vein.

ond time and cut completely.

On entering the cerebellopontine angle, the first structure visualized will be the seventh–eighth nerve complex, located superficially and caudal to the trigeminal nerve. The trigeminal nerve is located in the most superior and deepest position. The petrosal vein complex usually consists of a confluence of two or three veins draining into the tentorial edge. If bleeding is encountered from this complex, it may be torrential. Occasionally, this can even occur from gentle cerebellar retraction before division of the vein. Bleeding can be controlled by gentle pressure and packing of the tentorial side by using Surgicel and a cottonoid. The retractor can be used to exert gentle pressure while the surgeon looks for the free end of the avulsed vein (Fig. 4). Once the avulsed vein is identified and coagulated, the procedure can continue. If bleeding is severe, a large bore suction tip can be used to allow visualization of the field. Additionally, placing the patient in the reverse Trendelenburg position will decrease venous pressure and bleeding. In the senior author's experience, bleeding can always be controlled, but it may require tamponade for as long as 10 to 30 minutes.

For seventh nerve or lower cranial nerve decompressions, an inferior approach is required. The retractor blade is placed over the rubber dam and cottonoid on the inferolateral aspect of the cerebellum and the cerebellar tonsils are gently elevated. The cisterna magna is identified and opened with a bent 25-gauge needle or microscissors. After adequate CSF drainage, the ninth, 10th, and 11th cranial nerves are identified as they enter the jugular foramen. Slightly more superiorly, the seventh–eighth nerve complex can be seen.

#### Step 5. Nerve Decompression

“The pathology lies at the brainstem side of the nerve, but may be more lateral” (P.J.J.).

Decompression is relatively straightforward if the surgeon keeps two principles in mind at all times: 1) “there must be a vessel, and it is my job to find it”; and 2) the

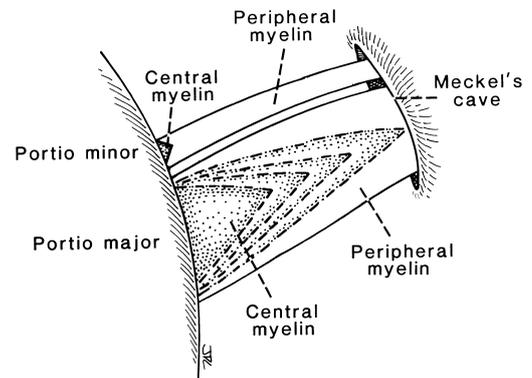


FIG. 5. Diagram showing that the dorsal root entry zone of the trigeminal nerve can be variable in length and may extend to a more distal portion of the nerve.

dorsal root entry or exit zone can be variable in length, particularly in the case of the trigeminal nerve, and may extend to a more distal portion of the nerve. Therefore, the nerve should be inspected from its origin at the brainstem laterally to its exit from the cerebellopontine angle and all vessels should be treated (Fig. 5).

Microvascular decompression of the trigeminal nerve requires sharp dissection of all arachnoid around the trigeminal nerve and superior cerebellar artery. The most common vessel found is a rostroventral superior cerebellar artery loop, which compresses the trigeminal nerve either at the brainstem or distally (Fig. 6). After the arachnoid is dissected and the vessel is freed, the loop can be mobilized to the lateral aspect of the nerve, and a piece of shredded Teflon felt can be placed between the vessel and the nerve (Fig. 7).

The most frequent vessel found compressing the cochlear or vestibular nerve is an anterior inferior cerebellar artery loop. Arachnoid dissection in this area requires sharp dissection of the flocculus from the vestibular nerve. This dissection is necessary to visualize the dorsal root entry zone. Changes in the brainstem evoked response (BSER) observed during this part of the procedure are frequently due to traction on the eighth cranial nerve. If BSER changes occur, the retractor should be relaxed somewhat and the surgeon should pause and await return of the BSERs. Frequent visualization of the retractor is paramount because it has a tendency to slip. Unnoticed slips in the retractor may cause rapid and possibly, irreversible damage to the cochlear nerve. Less frequently, decompression of a vessel loop causes impingement on the cochlear nerve and requires manipulation to prevent hearing loss.

The facial nerve commonly receives inadequate decompression because of poor exposure of the nerve. This is usually related to improper positioning of the vertex of the head before opening and inadequate inferolateral bone exposure. If the vertex is positioned 15° downward and a wide inferolateral exposure is obtained, the dorsal root exit zone and intrapontine portions of the facial nerve are easily visualized and may be adequately decompressed.

The most common vessel causing compression of the facial nerve is the posterior inferior cerebellar artery. This

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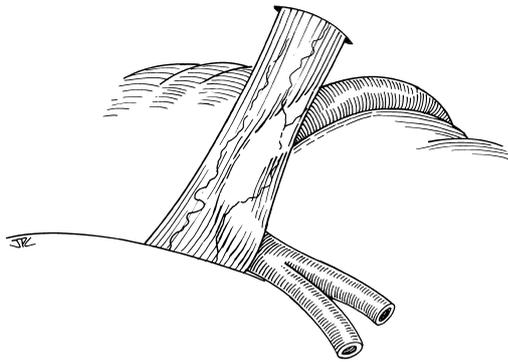


FIG. 6. Drawing of the most common vessel found causing typical trigeminal neuralgia, a rostroventral superior cerebellar artery loop, which compresses the trigeminal nerve either at the brainstem or distally.

vessel must be sharply dissected free from the arachnoid and mobilized laterally away from the nerve so that a Teflon implant can be placed. In cases of atypical hemifacial spasm, the pathological vascular entity is almost always located rostral to the nerve or between the seventh and eighth nerves. An anterior inferior cerebellar artery running between the seventh and eighth nerve may have a perforating branch to the pons that must be preserved.

Exposure of the lower cranial nerves and lateral medulla oblongata is excellent with inferolateral placement of the retractor. The arachnoid is dissected sharply and the pathological vascular entity can be identified and treated appropriately.

### Step 6. Surgical Closure

“Wax the bone edges on the way in and on the way out” (P.J.J.).

At the conclusion of the decompression procedure, several Valsalva maneuvers are performed to ensure hemostasis. The retractor is then removed and the cerebellar surface is carefully inspected. Valsalva maneuvers are repeated to verify hemostasis. The area is gently irrigated with warm saline bulb irrigation and the durotomy is closed. Syringe irrigation is to be avoided because it may injure the cochlear nerve with a jet of fluid. We are aggressive in performing dural closure in which fascia/muscle grafts from the inferior portion of the incision are used as necessary to ensure watertight closure. The bone edges of the mastoid air cells are thoroughly waxed for a second time. A small pad of cellulose and Gelfoam are then placed over the durotomy, and cranioplasty is performed using methylmethacrylate or wire mesh. The deep and superficial muscles are approximated with interrupted No. 2.0 absorbable sutures, and the fascia is closed with the same type of sutures. The fascial closure must be watertight to prevent any CSF leakage. Interrupted sutures lend strength to the fascial closure. A second Valsalva maneuver may reveal further egress of CSF through the fascia, necessitating reinforcement of the closure. The subcutaneous tissues are approximated with No. 3.0 interrupted absorbable sutures. A well-approximated subcutaneous layer can also afford protection from CSF leakage. The

skin is closed with No. 4.0 nylon sutures in a running locked fashion with care taken not to impair the vascular supply to the incision by excessive tension on the skin suture.

Postoperative care includes routine overnight observation in the neurosurgical continuous care unit. It is important to monitor blood pressure carefully and to treat hypertension (systolic blood pressure > 160 mm Hg) aggressively. We routinely use invasive arterial pressure monitoring in the perioperative period. Intravenous antiemetic medications are administered liberally to minimize postoperative nausea and emesis. Early mobilization of our patients is encouraged, beginning on postoperative Day 1. Provided the postoperative course is uneventful, patients are discharged at 72 hours and frequently at 48 hours. Most patients have some degree of frontal headache or incision pain; however, the presence of severe headache unresponsive to low-dosage narcotic medications necessitates obtaining a computerized tomography scan to rule out hemorrhage. If the scan is negative for hemorrhage we routinely perform a lumbar puncture and drain CSF until the closing pressure is equal to one-half of the opening pressure. We have found that many postoperative headaches are due to temporarily high opening pressures and are definitively treated with one or, rarely, two lumbar punctures performed during the postoperative period.

### Complication Avoidance

We chose to examine trends over time with respect to the three complications thought to be directly related to operative technique during microvascular decompression. The complications evaluated were cerebellar injury, hearing loss, and CSF leakage. These three complications are by no means comprehensive, but are easily defined and determined objectively through routine postoperative clinical, radiographic, and neurophysiological evaluations. Other rare complications of the procedures, such as facial weakness or anesthesia, lower cranial nerve dysfunction, or recurrent symptoms, were not evaluated because of their relative infrequency and because they have been reported in detail in previous communications.<sup>1,2,11</sup> By evaluating cerebellar injury, hearing loss, and CSF leakage, decreases in their occurrence could be detected in operations performed since 1990. Of the 4415 operations performed for trigeminal neuralgia, hemifacial spasm, or glossopharyngeal neuralgia performed since 1972, there have been 30 cerebellar injuries (0.68%), 64 hearing deficits (1.45%), and 96 CSF leaks (2.17%) (Table 1). When operations performed before 1990 were compared with those performed since 1990, we found that these rates have decreased. The largest decline was in hearing loss (1.98% compared with 0.8%,  $p < 0.01$ ; test for equality of distributions, Table 1). Although BSERs were used before 1990, the rate of hearing loss includes many operations performed early in our series when use of BSERs was experimental. Thus, use of intraoperative BSERs appears to have contributed significantly to the observed decline in postoperative hearing deficits.

Other factors have also contributed to this decline. Hearing loss did not occur following decompression of

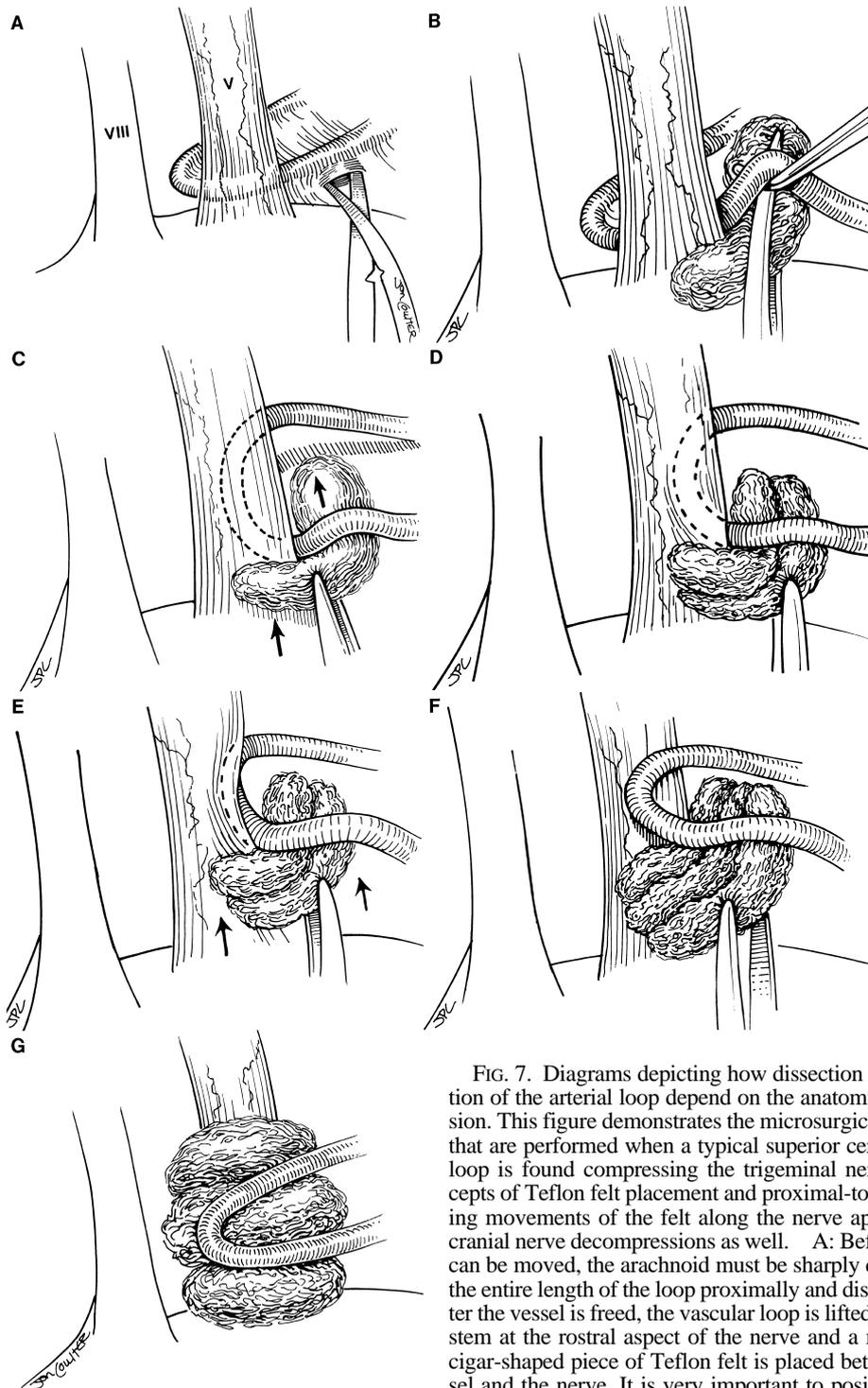


FIG. 7. Diagrams depicting how dissection and mobilization of the arterial loop depend on the anatomy of compression. This figure demonstrates the microsurgical movements that are performed when a typical superior cerebellar artery loop is found compressing the trigeminal nerve. The concepts of Teflon felt placement and proximal-to-distal sweeping movements of the felt along the nerve apply for lower cranial nerve decompressions as well. A: Before the vessel can be moved, the arachnoid must be sharply dissected over the entire length of the loop proximally and distally. B: After the vessel is freed, the vascular loop is lifted off the brainstem at the rostral aspect of the nerve and a medium-sized cigar-shaped piece of Teflon felt is placed between the vessel and the nerve. It is very important to position the distal

portion of the felt with the tips of the forceps. The Teflon felt should not be pushed into position by holding its proximal portion. C: After the Teflon felt is placed under the loop, the pledget is gently pushed in a proximal-to-distal fashion along the nerve toward Meckel's cave. This movement elevates the arterial loop and causes it to begin to rotate outward from the ventral surface of the nerve. D: A second Teflon felt, approximately the same size, is placed where the first felt was originally positioned. Using the same proximal-to-distal sweeping motion, the felt should be advanced over the length of the nerve toward Meckel's cave. E: As the Teflon pledgets are advanced, the vascular loop progressively rotates from the ventral aspect of the nerve to the dorsal side. F: A third Teflon pledget is placed where the first felt was originally positioned and, again, a proximal-to-distal sweeping movement along the trigeminal nerve flips the vascular loop to the dorsal aspect of the nerve. G: After the vascular loop is flipped to the dorsal surface of the nerve, pledgets are placed between the vessel and the nerve.

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TABLE 1

*Incidence of complications during microvascular decompression of cranial nerves*

Complications	Before 1990 (2420 ops)	Since 1990 (1995 ops)	Total (4415 ops)
cerebellar injury	21 (0.87%)	9 (0.45%)	30 (0.68%)
eighth nerve injury	48 (1.98%)	16 (0.80%)	64 (1.45%)
CSF leak	59 (2.44%)	37 (1.85%)	96 (2.17%)

the ninth and 10th cranial nerve, and the rate after decompression of the fifth cranial nerve was much less than that observed after treatment of hemifacial spasm (Table 2). The approach "turning the corner" to the ninth and 10th nerves, discussed previously, involves elevation of the cerebellar tonsils and a corridor along the floor of the occiput. This places no retraction on the seventh–eighth nerve complex. A common error is to approach the ninth and 10th nerves too superiorly, exposing the seventh and eighth nerves prematurely before moving inferior to the ninth and 10th nerves. This route requires retraction of the cerebellum at the level of the seventh and eighth cranial nerves, often before visualization of these structures. The same is true for decompression of the fifth cranial nerve. The seventh–eighth nerve complex should not be approached directly with subsequent dissection moving superiorly to the fifth cranial nerve. The petrotentorial junction is the proper corridor to approach the fifth nerve and the seventh–eighth nerve complex should have little tension from retraction. However, decompression of the fifth cranial nerve does require some retraction, which places tension on the seventh and eighth nerves and, hence, may lead to hearing loss. If during a fifth nerve decompression the BSERs begin to decline, it is often related to the tethering of the arachnoid to the seventh–eighth nerve complex. When delays are encountered, the surgeon should continue sharp arachnoidal dissection down to, and slightly below, the seventh–eighth nerve complex. This maneuver frequently will relieve the tension on the cochlear nerve and cause improvement in the BSERs.

Decompression of the lower cranial nerves, however, places relatively little tension on the seventh–eighth nerve complex and is, therefore, associated with a minimal risk of hearing loss (none in our series) (Table 2). Decompression of the seventh or eighth nerve should also be approached from above or below as described previously. This allows good visualization of the seventh and eighth nerves before retracting near their proximal origins.

When BSERs change during the procedure, it is usually due to retraction. The first response of the surgeon should be to reduce or remove retraction, or at least change the position of the retractor. We have found this usually improves the BSERs. Constant surveillance of the retractor is imperative because it often shifts and is frequently only millimeters from the eighth cranial nerve. Occasionally the BSERs will change after decompression and is not corrected with alterations in retraction. In these cases, inspection of the entire length of the eighth nerve will often disclose impingement from a Teflon implant or displaced vessel. Appropriate alterations should then be made. Finally, a change in BSERs may occur on closure

TABLE 2

*Incidence of hearing loss following microvascular decompression of cranial nerves\**

Decom	Before 1990	Since 1990	Total
CN V	22 of 1659 (1.33%)	9 of 1537 (0.59%)	31 of 3196 (0.97%)
CN VII	26 of 692 (3.76%)	6 of 377 (1.59%)	32 of 1069 (2.99%)
CN IX/X	0 of 69 (0.0%)	0 of 81 (0.0%)	0 of 150 (0.0%)
total	48 of 2420 (1.98%)	15 of 1995 (0.75%)	63 of 4415 (1.43%)

\* CN = cranial nerve; decom = decompression procedure.

of the dura. Although this happens very rarely, the dura should always be reopened. Opening the dura usually causes the BSERs to return to baseline. In this situation, reexploration of the decompression and the eighth cranial nerve will often disclose tension on the nerve from a Teflon pad or displaced vessels, which somehow worsens after the CSF is replaced and the dura is closed. Manipulation of any impingements on the eighth nerve and closure of the dura can then be safely completed. We have also observed that small amounts of blood or cold saline irrigation on the cochlear nerve may adversely affect BSERs.

Cerebellar injuries, including hemorrhage and contusion, have also occurred with less frequency since 1990 (0.87% compared with 0.45%,  $p < 0.01$ ; Table 1). Limitation of the degree and duration of retraction remains essential in avoiding cerebellar injury. The entire decompression procedure (from skin incision to skin closure) generally takes less than 2 hours and requires only a small corridor of exposure between the cerebellum and petrous temporal bone. This corridor is kept to a minimum by adequate exposure of the sigmoid sinus by mastoid bone removal prior to durotomy. This allows a dural incision very close to the sigmoid sinus rather than a more posterior durotomy that requires more cerebellar retraction to permit visualization along the petrous temporal bone. We place rubber dams made from latex gloves on the cerebellar side of all cottonoids so that smooth gentle advancement can be performed. Also, the approach superiorly and inferiorly allows CSF drainage from cisterns prior to significant retraction. An approach that leads straight in requires more cerebellar tissue to be retracted and exposes the seventh–eighth nerve complex, rather than a CSF cistern, which can allow further relaxation of the cerebellum.

Avoidance of CSF leaks remains problematic after transgression of mastoid air cells and exposure of multiple overlapping tissue planes. Our incidence of CSF leaks has declined since 1990 from 2.44% to 1.85% ( $p < 0.01$ ). Mastoid air cells are frequently opened to obtain adequate visualization of the margin of the sigmoid sinus. Copious amounts of bone wax should be applied before durotomy and after dural closure. The nuchal musculature does not extend above the digastric groove. Therefore, good surgical technique should be applied and the muscular layers approximated before fascial closure. Care should be taken not to include the galea in the deep muscle closure at the inferior aspect of the wound, so that a single layer of fascia is left to close along the entire length of the incision. This should be closed with interrupted sutures. An inverted, interrupted No. 3.0 absorbable closure of the subcuta-

neous tissues should also be watertight and should not be placed until a Valsalva maneuver reveals a watertight galeal closure. Postoperative CSF leaks usually resolve with lumbar drainage, although a minority of cases require operative intervention including reexploration of the dural closure and careful inspection of the mastoid air cells.

### Conclusions

Since the inception of microvascular decompression, the procedure has undergone changes designed to improve safety and efficacy. Implementation of neurophysiological monitoring and meticulous attention to the microsurgical anatomy of the posterior fossa have improved complication rates for cerebellar injury and hearing loss to less than 1%. We believe this six-step approach, combined with the surgical wisdom gained from more than 4400 procedures, remains the key to successful outcomes.

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Manuscript received April 14, 1998.

Accepted in final form September 8, 1998.

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