Evolution of techniques for the resection of vestibular schwannomas: from saving life to saving function

Historical vignette

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The current state of surgery for vestibular schwannomas (VSs) is the result of a century of step-by-step technical progress by groundbreaking surgeons who transformed the procedure from its hazardous infancy and high mortality rate to its current state of safety and low morbidity rate. Harvey Cushing advocated bilateral suboccipital decompression and developed the method of intracapsular tumor enucleation. Walter Dandy supported the unilateral suboccipital approach and developed the technique of gross-total tumor resection. Microsurgical techniques revolutionized VS surgery to its current status. In this article, the authors review the early history of surgery for VSs with an emphasis on contributions from pioneering surgeons. The authors examined the Cushing Brain Tumor Registry for clues regarding the bona fide intention of Cushing for the resection of these tumors. (DOI: 10.3171/2008.3.17473)

Key Words • enucleation • history • total resection • vestibular schwannoma

Since the auditory nerve is early destroyed in most cases, its origin from the acoustic nerve has been assumed, hence its other name, acoustic neuroma. But occasionally the function of the acoustic nerve, at least the cochlear division of hearing, is intact. Realization of this fact has then forced another assumption, i.e., that it arises from the vestibular branch of the auditory nerve. But the origin of the tumor from the auditory nerve is by no means established.

Walter Dandy, Surgery of the Brain, 1945

Vestibular schwannoma surgery as practiced by today’s experienced neurosurgeon is a relatively safe, fulfilling, and challenging operation. However, the procedure has not always been as efficacious as it is at the present time. Current success has become a reality following a century of step-by-step technical progress by groundbreaking surgeons who brought VS surgery from its hazardous infancy and high mortality rate to its current state of safety and low morbidity rate. These surgeons were eventually able to shift their focus from merely preserving patient lives to preserving patient neurological function.

Historically, surgery in the region of the CPA has presented some of the most extreme challenges in our discipline. Given the lack of microsurgical techniques, the limited space in the posterior fossa, the vicinity of critical neurovascular structures such as the brainstem and cranial nerves, and the minimal number of available facilities to deal with temporary postoperative deficits, safe GTR of a VS was considered a daunting and controversial task. In fact, one of the greatest controversies in the early conception of neurological surgery was related to VS surgery and originated between Harvey Cushing and Walter Dandy. They disagreed regarding the feasibility of total resection of a VS. In this paper, we review the history of VS surgery with a special emphasis on its early pioneers. Note that Koerbel and colleagues have also explored the history of VS surgery.

Early Technical Developments in VS Surgery

The first description of a VS was most likely made in 1777 by Sandifort who discovered a small unilateral tumor “adherent to the right auditory nerve” during an autopsy, and hence the initial misnomer “acoustic neuroma.” In 1822, Wishart described a patient with bilateral VS, who

Abbreviations used in this paper: CPA = cerebellopontine angle; GTR = gross-total resection; VS = vestibular schwannoma.
had presented with blindness, bilateral deafness, facial twitching, and unrelenting vomiting and headaches. On an autopsy procedure in this patient, Wishart found several tumors, including 2 attached to the “seventh cranial nerve pair,” each “the size of a small nut, and very hard.” The first definitively accurate postmortem description of this tumor was not made until Sir Charles Bell carefully presented his autopsy findings in 1830, however. Three years later Bell would also be the first to show the relationship of Meckel cave neuromas to the CPA, based on his experience with such a case.

Jean Cruveilhier, known for his atlas Anatomie pathologique du corps humain, which included the first ever color illustrations of brain pathology, published an unprecedentedly detailed account of the progression of symptoms and autopsy findings in a 26-year-old woman with a VS. She became deaf at the age of 19 years and presented 7 years later with headaches, progressive blindness, and facial weakness. Although Cruveilhier was unable to correctly localize the tumor until autopsy, he initially believed that the tumor was at the skull base. No one would correctly diagnose and localize a VS prior to autopsy until almost 50 years later, when Oppenheim in Germany became the first to accomplish this feat.

During the late 1800s, numerous advances allowed consistent and accurate diagnoses at autopsy. In 1900, Sternberg was the first to describe the histopathology of a VS, whereas leading physicians such as Oppenheim, von Monakow, Jackson, Gowers, Babinski, and Starr were refining their knowledge of functional brain anatomy, especially in the cerebellar region. These pioneering developments in diagnosis and localization facilitated an earlier diagnosis of VS—while the patient was still alive—and set the stage for surgical intervention. The concurrent evolution of anesthetic and aseptic techniques during this period fueled the era of surgical exploration in the posterior fossa. Nonetheless, further refinement of the surgical methods available for the supratentorial space and intraoperative control of intracranial tension was necessary to approach the infratentorial space relatively safely.

In 1890, von Bergmann attempted the surgical removal of a tumor, which at autopsy was discovered to be a VS; he was unable to intraoperatively localize the tumor before the patient died. Annandale is credited with the first successful VS surgery in 1895, although a year earlier Ballance resected a tumor that may have been either a meningioma or VS. At that time most physicians frowned on intracranial surgery, considering it unwise and irresponsible. In the early 1900s earlier tumor diagnosis and localization was possible and surgical intervention for intracranial pathology gained some popularity. Prominent surgeons such as von Monakow published optimistic papers encouraging doctors to be less reluctant in attempting intracranial surgery.

As more surgeons independently attempted surgical intervention for VS, a variety of techniques and approaches developed, some of which were early versions of the procedures used today. Woolsey, Fraenkel, and Krause used a unilateral suboccipital approach with some success. Borchardt performed the first “transsigmoid” VS surgery in 1905, the same year Horsley first resected a VS.

The patient in Horsley’s case survived the operation but became severely disabled, most likely due to a brainstem infarct. In 1903, Garré was the first to attempt surgery for bilateral VS and had dismal results, as did Biggs a few years later in 1909:

On November 19th Mr. McGavin reopened the wound. . . The hemorrhage was only stopped after the application of forceps. The cerebellum bulged extensively into the wound, but no tumor could be felt or seen. The patient lost a considerable amount of blood and saline had to be administered per rectum. The wound was sutured and dressed, the forceps being left in situ, and the patient was sent back to the bed. On the 22nd Mr. McGavin, under chloroform, removed the forceps and plug-ging, but the hemorrhage was so severe that they had to be replaced. . . The patient died at 2:30 AM on the 24th.

In 1913 at the International Congress of Medicine in London, the 3 so-called great European surgeons—Horsley of London, Eiselsberg of Vienna, and Krause of Berlin—reported mortality rates for the VS surgeries they performed: 67% in 15 cases, 77% in 17 cases, and 84% in 31 cases, respectively. Krause described VS as the most problematic of all brain tumors. All of the above surgeons used a unilateral suboccipital approach and an index finger or spatula to quickly dislodge the tumor, which usually caused injury to the cerebellum and brainstem. Eiselsberg and Horsley further attempted the operation in 2 stages without better success.

The “success patients” were often severely crippled. Surgeons operated on giant tumors most likely associated with hydrocephalus. Given the limited ability to control intracranial pressure, the surgeon often struggled to achieve sufficient tumor exposure using rudimentary methods of illumination and hemostasis.

The significant mortality rates for VS surgery were the impetus for developing new ideas and surgical approaches. Thierry de Martel preferred operating with the patient in the sitting position and reported some success. In 1904, Panse described a new translabyrinthine approach similar to the one used today. However, this approach was abandoned because of its high risk of cerebrospinal fluid leakage, destruction of the middle ear, and limited exposure of large tumors. Still hoping to overcome the high mortality rates, some surgeons combined petrosal and suboccipital approaches with little success. The stage was set for Harvey Cushing, who in 1910 tackled VS surgery. The emergence of his meticulous surgical techniques combined with adequate control of intracranial hypertension and intracapsular tumor decompression set the stage for a new era in VS surgery.

Further Developments in VS Surgery

In 1904, Cushing began working with Amory Codman to record a patient’s pulse, temperature, respiration, and ether dosage during surgery in an attempt to discover the changes indicative of imminent death. This novel idea led to further progress in neuroanesthesia and more specifically in posterior fossa surgery. Cushing also introduced the silver clip in 1911 and electrocautery in 1925 for controlling intraoperative hemorrhage. Armed with
these tools as well as his initial experience with intracranial supratentorial surgery, Cushing surgically treated VSs with remarkably lower mortality rates than those of his predecessors. In 1917 he published the results of 30 VS cases in his famous monograph *Tumors of the Nervus Acusticus and the Syndrome of the Cerebellopontine Angle*, in which he reported a vastly superior mortality rate of 10–15%.

One of his most important contributions in this monograph was a demonstration of the chronology of symptom development among patients harboring VSs, from the earliest unilateral hearing loss to death.

In contrast to earlier strategies, Cushing proposed a bilateral suboccipital craniectomy for subtotal intracapsular tumor decompression. He believed that this method was safer than complete resection, allowed decompression of the brainstem (a principle similar to that of subtemporal decompression for inoperable supratentorial tumors), and avoided medullary compression during surgical manipulation of the tumor. Although this was not the first time a bilateral suboccipital approach had been proposed, Cushing was one of the first surgeons to emphasize the importance of controlling intracranial pressure by using a ventricular tap and therefore avoiding medullary compression and cerebellar herniation. The bilateral approach allowed surgeons to explore both CPAs, as findings on radiographic images were not always reliable. Cushing's gentle and meticulous methods, combined with his conservative philosophy of performing only intracapsular decompression, proved the safety but not necessarily the efficacy of VS surgery using the now-obsolete technologies of his day.

In response to critics who questioned the safety of intracranial surgery and the establishment of neurosurgical specialty during the discipline's infancy, Cushing likely was more concerned with establishing the procedure's safety rather than its long-term outcome. Unfortunately, despite his significantly lower mortality, Cushing's method of partial resection for VS was associated with a higher tumor recurrence rate; the 5-year mortality rate was 54%.

Cushing accepted that another approach for total resection would be far superior if neuroanesthesia, operative, and diagnostic technologies could be improved. Dandy's introduction of air ventriculography in 1918 allowed neurosurgeons to localize and operate on smaller tumors partly through the early detection of hydrocephalus. Dandy was very technically skilled, and he believed in his ability to improve on Cushing's results. By this time the syndrome of the CPA was more widely recognized, and surgical intervention was no longer reserved only for patients at the terminal stage of the disease. The above factors assisted Dandy in achieving GTR of VSs of relatively smaller sizes.

Despite the benefits of ventriculography, however, Cushing was extremely reluctant to embrace its clinical use, claiming that it would undermine the importance of a detailed neurological examination. He did not consider Dandy's innovation a next step in the advancement of intracranial surgery. Cushing may have adopted and strongly advocated the use of this new diagnostic tool had it been invented by anyone but Dandy; however, their long-standing dispute may have caused Cushing to grow resentful of rather than thankful for his student's accomplishment.

Dandy believed that the 54% 5-year mortality rate Cushing had reported was unacceptable, and he searched for a safe way to perform a GTR of VS despite Cushing's doubts about its feasibility. In his early experience with intracapsular decompression, Dandy was convinced that the residual "shell of tumor" was responsible for delayed neurological deterioration after surgery. He thought he found the answer when in 1922 he published a preliminary report on a successful total VS resection performed 5 years earlier. In this report, he described how he had made a bilateral suboccipital flap, first removing the interior portion of the growth as described by Cushing, then meticulously clipping the veins and arteries surrounding the capsule, and finally pulling the capsule carefully away from the brainstem. Dandy wrote, "As the capsule is cautiously retracted, several small blood vessels crossing from the brainstem or cerebellum are brought into view and doubly 'clipped' and the vessel divided."

Previously, Horsley had advocated blunt finger removal of an intact large tumor, and Cushing had favored subtotal enucleation of a VS as an adjunct to osseous suboccipital decompression. Dandy took the next step in the history of VS surgery by performing extensive intracapsular decompression followed by meticulous tumor capsule excision and careful management of surrounding vasculature to respect important vessels and avoid postoperative hemorrhage.

In this 1922 report, however, Dandy failed to mention any of Cushing's 1917 monograph, and so Cushing promptly wrote a letter attacking his manners and professional ethics and dismissed Dandy's success. Rather than considering Dandy's new approach, Cushing rigidly maintained his belief that the high mortality rates of total VS resection would make it irresponsible even to attempt such an approach. He considered Dandy's method to be inconsistent with the standard of care. Some neurosurgeons who had been trained by Cushing followed his recommendations.

A review of Cushing's original patient records available at the Yale University Brain Tumor Registry may shed light on this controversy. Ironically, we located a hospital record in which Cushing described GTR of a VS in 1921, a year before Dandy published his preliminary report on the subject. It is possible that Cushing was not so averse to aggressive VS resection after all. If only the resection method had been first described by anyone other than Dandy and Dandy had included Cushing's contributions in his preliminary report.

Cushing's above-described patient was admitted to Peter Bent Brigham Hospital in August 1921 with a right facial palsy and hearing loss, staggering gait, and swallowing difficulty. An examination was positive for right-sided cerebellar signs. A bilateral suboccipital decompression and inspection of the right CPA revealed a "cystic acoustic tumor." Following decompression and drainage of the cystic tumor, Cushing wrote:

The wall of the cyst was sufficiently tough so that it could be easily handled and by grasping the walls it was finally possible by slow dissection to draw out the entire cyst. The bundle of the nerves to the lower foramen were exposed during this whole procedure and also the two points of attachment of the...
cyst, one at the side of the pons, where a few nerves were divided, evidently the pontine attachment of the acoustic nerve. . . . The facial nerve was not identified.

He adds, “This is the first time I have ever been able to safely remove an acoustic tumor in its entirety.”

This patient was left on the operating room table in the prone position until 6:00 p.m. (6 hours after surgery was complete) when he had stopped vomiting and was doing well. This delayed mobilization of the patient from the operating room table was customary for Cushing. With the patient in this position, the wound could be opened in a timely manner if neurological deterioration occurred immediately after surgery. Moreover, patients had a decreased risk of aspiration in the prone position (especially considering posterior fossa procedures in patients who had preoperative swallowing difficulty and the use of ether anesthesia and its nauseating consequences).

The patient was ambulating in the hospital 2 weeks after surgery but had complete right-sided facial paralysis. Other preoperative symptoms and signs demonstrated significant improvement. Our review revealed 2 other patient records (both from 1931; Figs. 1 and 2) describing GTR of VS without any significant morbidity. Records of other patients with VS surgically treated between 1920 and 1932 reveal that Cushing consistently attempted to “draw upon” the tumor capsule after its intracapsular decompression (Fig. 3.) These attempts testify to Cushing’s interest in exploring the possibility of removing VSs in their entirety.

In 1925, Dandy15 published a full follow-up to his preliminary report, in which he included a lengthy discussion about the benefits of total resection and acknowledged the high mortality rates reported by earlier surgeons. In that paper he also questioned the appropriateness of the title “acoustic neuroma,” saying that it was inaccurate because the origin of these tumors was still in dispute. In 1934, he described a further refined technique using a less invasive unilateral suboccipital approach similar to the one formerly used by Krause. In 1941, Dandy17 reported the results in 46 patients with VSs who had undergone this new approach.

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surgery within the cranial space, including VS surgery. The next era involved the development of collaborations between neurosurgeons and otorhinolaryngologists in the treatment of skull base tumors. These collaborations inspired the evolution of various approaches to different regions of the skull base. The transmission of knowledge was more readily possible, especially given the availability of courses devoted to teaching the surgical technique. Using his extensive experience with VS surgery, Madjid Samii has established landmark outcomes with respect to the preservation of facial and hearing functions.\(^{26,27}\)

The invention of other diagnostic modalities such as CT and MR imaging have further increased a surgeon's ability to reliably identify VS earlier. Moreover, the application of facial nerve electromyography has decreased the intraoperative risk of facial nerve injury. These advances translated into the current VS surgery mortality rates of 0.8–5%.

Preservation of hearing has been the ultimate challenge in VS surgery, especially among patients with bilateral tumors and suffering from neurofibromatosis Type 2. Since 1979, House and Hitselberger have introduced auditory brainstem implants, which provide a partial return of hearing function by direct recording and stimulation of central auditory systems. Auditory brainstem implantation has become popularized and currently is being refined. In 1951, Leksell\(^ {29}\) introduced stereotactic radiosurgery as a method of treating intracranial lesions by a single high dose of ionizing radiation. Subsequently, in 1961, Leksell and Noren performed the first radiosurgical procedure on a VS. Lunsford and Kondziolka have used such a technique in a large group of patients, establishing the procedure's efficacy in long-term tumor control and high preservation rates of facial and cochlear function.\(^ {27}\)

**Conclusions**

Harvey Cushing and Walter Dandy's contributions to the field of neurosurgery can hardly be overstated. Were it not for Cushing, VS surgery might have been postponed given its significant mortality rate. Were it not for surgeons with the technical confidence of Dandy, further progress in total resection of skull base tumors and deep-seated lesions would have awaited another generation. Both Cushing with his clinical observation and surgical diligence and Dandy with his surgical observation and technical innovation shaped the early history of VS surgery. The introduction and refinement of microsurgical techniques and surgical corridors by House, Hitselberger, Kurze, Yaşargil, Samii, and our otology colleagues shaped the status of VS surgery as we know it today.

**Disclaimer**

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

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