Historical vignette

Harvey W. Cushing and cerebrovascular surgery: Part I, aneurysms

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The development of surgical techniques for the treatment of intracranial aneurysms has paralleled the evolution of the specialty of neurological surgery. During the Cushing era, intracranial aneurysms were considered inoperable and only ligation of the carotid artery was performed. Cushing understood the limitations of this approach and advised the need for a more thorough understanding of aneurysm pathology before further consideration could be given to the surgical treatment of cerebral aneurysms. Despite his focus on brain tumors, Cushing’s contributions to the discipline of neurovascular surgery are of great importance. With the assistance of Sir Charles Symonds, Cushing described the syndrome of subarachnoid hemorrhage. He considered inserting muscle strips into cerebral aneurysms to promote aneurysm sac thrombosis and designed the “silver clip,” which was modified by McKenzie and later used by Dandy to clip the first intracranial aneurysm. Cushing was the first surgeon to wrap aneurysms in muscle fragments to prevent recurrent hemorrhage. He established the foundation on which pioneers such as Norman Dott and Walter Dandy launched the modern era of neurovascular surgery.

KEY WORDS • aneurysm • cerebrovascular surgery • Harvey Cushing • neurosurgical history

Abbreviations used in this paper: CA = carotid artery; CCA = common CA; ICA = internal CA.

Intracranial aneurysms, even those which arise from the internal carotid or Willian circle, are apt to be comparatively silent lesions until they happen to rupture. Most of them are small, pea-sized lesions, and they may occur in the young or old. Rupture usually causes a characteristic syndrome of sudden extreme cephalgia often followed by unconsciousness, bloody cerebrospinal fluid being disclosed by a lumbar puncture. Should the patient recover, a unilateral palsy of the oculomotorius with numbness in the upper trigeminal skin field is a common sequel of the accident.9

In this article, Cushing expressed his lack of enthusiasm for the surgical management of these lesions: “How it is that a surgeon comes to write a note upon a lesion having such remote surgical bearings may be told.”4 Like other surgeons of his time, Cushing was pessimistic about the surgical treatment of intracranial aneurysms because of the high rate of hemiplegia that was associated with CA ligation. He wrote:

Ligation of internal carotid in the neck for an aneurysm in the region of circle of Willis is futile, inasmuch as the lesion is equally well fed from both sides. Should such a ligation chance to affect the aneurysm favorably, it would be at the same time and for the same reasons in an elderly person be almost certain to cut off the circulation from the hemisphere and cause a contralateral hemiplegia.3

Cushing accidentally exposed intracranial aneurysms during his exploratory craniotomies in the search for tumors. Even though he detailed his extensive familiarity with the resection of brain tumors in his various publications, he did not report his experience with the surgical management of cerebral aneurysms. We reviewed his approach to intracranial aneurysms by directly exploring his original patients’ records. This review may provide us with insight into...
Materials and Methods

We reviewed Cushing’s “Little Black Book,” which lists all his surgical cases by patient name and corresponding pathological diagnoses. These patients were treated at the Peter Bent Brigham Hospital between 1922 and 1933. Louise Eisenhardt managed the “Little Black Book” meticulously, keeping records of all patients who underwent surgery for a “verified” or “suspect” tumor. A review of the “suspect” tumor category revealed nine patients with the diagnosis of an intracranial aneurysm who underwent surgery performed by Cushing.

Previously we reviewed the medical records of 1870 consecutive patients who underwent surgery at the Peter Bent Brigham Hospital performed by Dr. Cushing between 1912 and 1932, and indexed the records by demographic data at the Cushing’s Tumor Registry housed in the Yale University Department of Neurosurgery. We found the records of seven of nine patients with the diagnosis of an intracranial aneurysm in this database. The chart of each of these seven patients was reviewed for symptoms and signs at presentation as recorded by Cushing’s resident, Cushing’s own evaluation notes, surgical details that included hand-drawn illustrations, and outcome. The operative reports contained rich detail and often Cushing’s personal reflections about the surgical procedure. The records included detailed hand-drawn illustrations by Cushing designed to describe the operative findings. He retained careful follow-up records by asking each patient to record his or her status in a letter on the anniversary of that patient’s surgery. Introductory and concluding notes in each operative report included observations on lessons learned from the operation and how these observations modified previous surgical experience. These detailed notes allowed us to investigate Cushing’s decision-making process and his surgical techniques. In this paper all unreferenced quotations attributed to Cushing were extracted from patient records.

Illustrative Cases

Details on the seven patients are summarized in Table 1. We present three cases in further detail to illustrate Cushing’s approach to intracranial aneurysms. Cushing cautiously approached an intracranial aneurysm in Case 1. Based on our review, this was his first attempt at such an operation.

Case 1

This 58-year-old woman presented in 1925 with complaints of a 1-year-duration change in facial sensation and pain, double vision, and decreased visual acuity. One of Cushing’s residents, William P. Van Wagenen, wrote the admission notes. The physical evaluation revealed a bilateral reduction in visual acuity, right-eye proptosis, decreased sensation in the distribution of the right trigeminal nerve, and paralysis of the right temporalis and masseter muscles. The right corneal reflex was decreased. An examination of the eye muscles revealed paresis of the right lateral rectus muscle. Skull x-ray films revealed a marked calcification over the frontal region. The sella turcica was slightly expanded and the posterior clinoids were eroded. A tumor in the region of the gasserian ganglion was suspected. Cushing’s evaluation note contains the following:

In view of the long duration of the symptoms I assumed that she had a benign tumor, probably a meningioma arising from the trigeminal sheath. I had no very definite inspiration as to just how I should go about this operation. There were two possible things to do. One, to satisfy myself with the avulsion of the sensory root so as to spare her any further pain in case the tumor was one beyond removal. The other was to make a large exploration and to expose a larger part of the hemisphere so as to prepare the field for tumor extirpation.

Cushing performed a large frontotemporal osteoplastic craniotomy. He then noted:

With the flap turned forward it was then possible to go under the temporal lobe and elevate the dura . . . The margin of the flap adherent to the dura was divided and there came into view a rounded, smooth tumor about the size of a pigeon’s egg which I thought to be almost certainly a meningioma. In further preparing the field and elevating the dura away from it I found the tumor was actually extradural, and that what we were peeling away was the dura itself, so that I was aware that we must be confronted with some unusual situation. On further study of this tense tumor it was obvious from the first that it was pulsating and we evidently have exposed the large part of an unusual big aneurysm of the internal carotid, which, as is unusual, did not show in the x-ray plates for there were no lime salts in its capsule.

Cushing included a note in this file regarding his experience with poor outcomes in patients with aneurysms who were left untreated. Incidentally, this patient’s brother, a physician, was present at the operation and encouraged Cushing to proceed further. Cushing therefore asked Percival Bailey, his assistant during the operation, to expose the ipsilateral CA in the neck and ligate the artery. Cushing apprehensively continued:

While Dr. Bailey held these ligatures it was evident that pulsation in the tumor was greatly lessened, tho not entirely checked by a ligation of the internal carotid. I felt at last that this was sufficiently diminished pulsation to justify making the step I had proposed to make.

Cushing opened the aneurysm sac and removed its thrombus as illustrated in his sketch (Fig. 1).

However, after the sac was completely emptied there was a sudden and uncontrollable gush of blood from the lower portion and consequently I inserted the mass of muscle in through the incision and by some pressure wet pledges implanted on the collapsed sac, and to my great relief the bleeding was thus secured. At this junction internal carotid was tied and I closed the capsule of the sac over the muscle implantation. I think it was perhaps a foolish step for in all possibilities. It would have been possible to remove the muscle and then to have enfolded the sac as one would do in a [sic]aneurysmmorrhaphy [italics added by author].

Cushing also wrapped the aneurysm in muscle fragments. After the operation had been completed, the patient awoke from the ether-induced anesthesia with a left hemiplegia. Her weakness improved greatly by the time of discharge. She was found dead at home 9 months later.

Case 3

This 10-year-old girl was admitted to Dr. Cushing’s service in 1927, 2 years after she had experienced a sudden left...
### TABLE 1

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Date of Surgery (mo/day/yr)</th>
<th>Presenting Symptom</th>
<th>Physical Exam Findings</th>
<th>Imaging Findings</th>
<th>Surgical Approach</th>
<th>Intraop Finding</th>
<th>Intervention</th>
<th>Immediate Outcome</th>
<th>Long-Term Outcome</th>
<th>Last FU</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>12/04/1925</td>
<td>facial sensory changes, diplopia, decreased visual acuity</td>
<td>decreased bilateral visual acuity, right eye proptosis, trigeminal nerve sensory changes, right temporalis &amp; masseter muscle weakness, right lateral rectus muscle weakness</td>
<td>skull x-ray films: sellar enlargement</td>
<td>rt frontotemporal craniotomy</td>
<td>rtICA ligated &amp; aneurysm opened, clot evacuated, muscle strip inserted, aneurysm closed</td>
<td>lt hemiplegia, improving</td>
<td>sudden death</td>
<td>09/03/1926</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>07/17/1926</td>
<td>loss of vision in the right eye, vision deteriorating on left side, bilateral UE tingling</td>
<td>bilateral optic nerve atrophy; bilateral temporal hemianopia</td>
<td>skull x-ray films: unremarkable</td>
<td>rt frontal craniotomy</td>
<td>rtICA aneurysm</td>
<td>verification of aneurysm by puncture, muscle strip placed over aneurysm</td>
<td>lt eye vision improved</td>
<td>sudden death</td>
<td>03/29/1927</td>
</tr>
<tr>
<td>3</td>
<td>03/05/1927 03/14/1927</td>
<td>lt-sided weakness (suddenly occurred 2 yrs previously), vomiting for 5 days</td>
<td>left homonymous hemianopia, left hemiparesis, left hemianesthesia</td>
<td>ventriculogram: midline shift to left side, compression of right lateral ventricle</td>
<td>rt temporal craniotomy</td>
<td>rt &quot;temporal&quot; aneurysm from &quot;willisian branches&quot;</td>
<td>insertion of muscle strips in aneurysm after puncture of dome w/ brain needle</td>
<td>stable</td>
<td>02/02/1931</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>07/09/1929</td>
<td>bilateral failing vision</td>
<td>left eye with light perception; right vision 10/20, left homonymous hemianopia; bilateral optic atrophy</td>
<td>skull x-ray films: unremarkable</td>
<td>rt frontal craniotomy</td>
<td>aneurysm in sella turcica elevating the chiasm aneurysm</td>
<td>rt optic nerve (extremely thin) sectioned to release left optic nerve</td>
<td>vision improving</td>
<td>sudden death</td>
<td>12/06/1929</td>
</tr>
<tr>
<td>5</td>
<td>09/18/1929</td>
<td>progressive bilateral visual loss, HA</td>
<td>bilateral optic atrophy, right eye almost blind</td>
<td>skull x-ray films: unremarkable</td>
<td>rt frontal craniotomy</td>
<td>rtICA aneurysm under chiasm</td>
<td>verification of aneurysm by puncture, rt optic nerve sectioned to release rt optic nerve aneurysm opened w/ needle &amp; packed w/ muscle</td>
<td>found dead in bed on the 1st postop night</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>6</td>
<td>04/16/1930</td>
<td>bilateral optic nerve atrophy, right lower facial weakness</td>
<td>ventriculogram: ventricle megaly &amp; filling defect in frontal horn of left ventricle</td>
<td>rt frontal craniotomy</td>
<td>most likely ACoA aneurysm</td>
<td>rt optic nerve opened w/ needle &amp; packs w/ muscle</td>
<td>no improvement</td>
<td>sudden death</td>
<td>08/10/1939</td>
<td></td>
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<tr>
<td>7</td>
<td>07/07/1930</td>
<td>epilepsy</td>
<td>bilateral papilledema</td>
<td>skull x-ray films: calcified right temporal lesion, ventriculogram: filling defect in right temporal horn</td>
<td>rt temporal craniotomy</td>
<td>large rt &quot;temporal&quot; aneurysm</td>
<td>verification of aneurysm by puncture, lesion wrapped in muscle</td>
<td>no change</td>
<td>sudden death</td>
<td>08/10/1932</td>
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*ACoA = anterior communicating artery; HA = headache; UE = upper extremity.*
hemiparesis. In the interim she had noted progressive left-sided visual deficits. Five days before admission she had vomited in association with a severe headache. Hugh W. B. Cairns, one of Cushing’s residents, performed the initial evaluation. The physical examination was consistent with data from the patient’s history and also revealed bilateral nystagmus. Skull x-ray films were nondiagnostic and a ventriculogram indicated a right temporal lobe mass lesion. Cushing expected that the patient harbored a deep-seated temporal lesion; therefore, a temporal craniotomy was completed. After opening the dura mater, Cushing used a needle to puncture the temporal lobe in his search for a mass lesion and wrote:

“I then punctured in two directions and posteriorly came upon a resistant mass at about a depth of 4 cm. I thought that possibly we were going to find a solid tumor, perhaps a congenital tumor.

He then performed a cortical incision as illustrated in his sketch in Fig. 2. He inserted a needle into the growth and
I was in the center of aneurysm. Blood spurted from the end of the needle. The needle was then withdrawn and holding the sucker in the neighborhood of the opening which was bleeding profusely I made use of a but of muscle which fortunately was at hand to plant it over the opening. I was then at a loss to know what further to do. I of course did not know where the aneurysm originated but presumed it must be from one of the Willissian branches. Having used the ordinary drain needle for the puncture I thought I might possibly take some strips of the muscle which I had at hand and insert them through the opening with the aid of Mayo plunger of the needle. This I found an extremely simple procedure, and I put in several strands of muscle into the cavity amounting all told I should think to as [sic] strip 4 to 5 cm in length and possibly 3 to 4 mm in diameter.

The patient did well postoperatively; however, Cairns recorded a loud systolic murmur over the patient’s head, especially over the parietooccipital region. The obvious pulsations over the area of subtemporal decompression were described “as though the aneurysm was almost under the surface.” The child told Dr. Cairns that this is the sound she has used for a long time to “count herself to sleep at night.” These intense surface pulsations prompted Cushing to ligate her right CCA 8 days later. On ligating the CCA, Cushing noted:

To my dismay, Dr. Cairns who was listening during this procedure to the subtemporal decompression stated that the bruit which had been for the last day or two somewhat indistinct was increased in its intensity. This I could not account for nor can I now account for, and perhaps it was foolish to have persisted with the operation and have completed the occlusion of the vessel.

This patient insisted that she could use her left hand better after the second surgery; however, an examination by Dr. Cairns failed to document any objective motor improvement. The last note to Dr. Cushing in 1931 reported that the patient remained stable. No further follow up was available.

Case 6

This 32-year-old man presented to Dr. Cushing in 1930 with complaints of severe episodic left-sided headaches and confusion that had continued for 3 months. He had a history of generalized epilepsy. Dr. Eric Oldberg obtained the history and performed the physical examination. He reported the patient’s poor memory, bilateral “choked” optic discs, and right facial weakness. Skull x-ray films were unremarkable and Cushing advised Oldberg to perform a ventriculogram. The ventriculogram disclosed a marked ventricular dilation. Dr. M. C. Sosman (radiologist) also noted “a large irregular collection of air in the right frontal region communicating with the anterior horn of the ventricle.”

Dr. Cushing’s sketches in Fig. 3A and B show the outline of the filling defect that raised suspicion that it was a mass lesion located near the right foramen of Monro. Cushing suspected a third ventricular tumor. After completing a frontotemporal craniotomy and entering the frontal horn of the lateral ventricle though a cortical incision, he found a “plumb-colored, purplish tumor,” projecting into the cavity (Fig. 3C).

The appearance was a most extraordinary one. The tumor was visibly pulsating but still the whole brain was slightly pulsating . . . There was little question but that from its situation and from its appearance the tumor was an aneurysm. . . . Being certain of this I prepared to pack around the tumor [aneurysm], to put a lumbar puncture needle into it, and as I was sure of

Fig. 1. Sketch by Cushing showing an ICA aneurysm sac from which he removed thrombus.

Fig. 2. Sketch by Cushing showing a cortical incision made to expose a “temporal” aneurysm.
meeting with a sharp gush of blood I was ready with muscle to cover the opening or to insert into the opening. Thru the opening made I then inserted a strip of muscle to plug up the hole from the inside.

Cushing continued his dissection, inspected the vascular anatomy, and confirmed that the aneurysm originated from the “anterior cerebral branch.”

It was quite possible that this growth might have been excised and that I might have caught the anterior cerebral artery but the chances are that it came off so near the growth that I almost certainly would have gotten into difficulty. I suppose that I might have ligated the carotid itself but this did not seem to me to be really a justifiable procedure as I might very possibly have gotten a hemiplegia.

This patient did well postoperatively and was discharged. Nevertheless, “sudden death” occurred 9 years later and no autopsy was performed.

Discussion

Early descriptions of the circle of Willis provided an understanding of the normal cerebral vascular anatomy. The definition of the syndrome of subarachnoid hemorrhage facilitated an early recognition of aneurysms in patients before death. The last step was elucidation of the anatomical details of cerebral aneurysms to permit the development of direct techniques to deal with these lesions. Cushing’s career preceded to the last stage: the only reliable diagnostic tool available to Cushing to confirm the presence of an aneurysm may have been tapping the aneurysm after its exposure. There was no means of providing an awareness of aneurysm anatomy relative to the parent artery. To Cushing’s precise ideology, the treatment of intracranial aneurysms through a hunterian carotid ligation was risky and nonselective. Pilz reported a 43% average rate of surgical mortality from CA ligation in 1868.

Cushing faced many challenges as he strove to establish the specialty of neurological surgery. Even though he focused his attention on intracranial tumors, he performed operations for other neurological disorders including hydrocephalus, spinal tumors, peripheral nerve lesions, spinal dysraphism, and torticollis. Unlike tumors, the surgical treatment of cerebral vasculature highly depends on detailed knowledge of vascular anatomy and would require the introduction and application of cerebral angiography.

For this reason, Cushing was unable to design a safe surgical approach to cerebral aneurysms and believed “whether there are surgical indications such as ligation of the internal carotid, further experience alone can tell.”

Case 1 epitomizes Cushing’s reluctance to deal with vascular lesions. He elaborated on this unwillingness by including the following statements on exposure of the aneurysm:

It possibly would have been best to have withdrawn at this stage, but, having in mind the last of these patients who had come into the hospital with the diagnosis of tumor in this situation which could be seen upon the x-ray plates and after debating the advisability of ligating the internal carotid in the hope that she might escape from any further successive episodes connected with periodical rupture of the aneurysm—I say that in view of this case which we did not treat and which ended in sudden fatality in two to three weeks after leaving the hospital, I thought that I ought to go ahead with this woman and was encouraged to do this by her brother, a doctor who was present at the operation.

In this case, he persisted and removed the intrasaccular thrombus, packed the aneurysm with muscle pledges, and closed the aneurysm sac. He called ligation of the CA a “foolish step” and speculated about aneurysmorrhaphy, a technique already practiced at that time on experimental aneurysms. This technique became possible for intracranial aneurysms many years later after the introduction of micro-
surgical techniques. When this patient died 9 months later, her brain was sent to Dr. Cushing for evaluation. A coronal section of the specimen revealed the size of the aneurysm (Fig. 4).

Because the topography of cerebral aneurysms was not appreciated at the time, Cushing may have incorrectly considered the origin of the aneurysm in the second patient to be in the anterior circulation, justifying a CA ligation. The resultant increased aneurysm pulsations that occurred following CA ligation, however, may highlight the posterior circulation as the origin of this patient’s aneurysm. Cushing’s curiosity about the origin of aneurysms guided him in Case 6 to explore the vascular anatomy of an anterior communicating artery aneurysm so that he could consider more selective obliterative strategies. His conclusion was that such an approach was uncertain and potentially risky. Cushing consistently used fragments of muscle to control bleeding. Although he first reported this technique, he admitted in a footnote to his paper, “The control of bleeding in operations for brain tumors,” that Horsley previously had demonstrated the “hemostatic action of a fragment of muscle on the exposed brain during the progress of a laboratory experiment.” Nevertheless, Cushing was most likely the first surgeon to pack and wrap an intracranial aneurysm by using muscle pledges. He passed on this technique to his residents including Norman McComish Dott, who performed his residency under the tutelage of Cushing in 1923 and 1924. Dott has been recognized as an innovator in cerebrovascular surgery. He performed the first planned direct intracranial operation for an aneurysm in 1931. In that instance, he wrapped an ICA bifurcation aneurysm in pieces of muscle. Dott was also the first surgeon to operate on a cerebral aneurysm, which had been identified through CA angiography in 1933.

Cushing’s most important contribution to aneurysm surgery may remain the development of the silver clip in 1911. Dott designed this clip for “placement on inaccessible vessels, which, though within reach of a clamp, are either too delicate or in a position too awkward for safe ligation.” The silver clip revolutionized Cushing’s ability to maintain homeostasis in tumor operations, but he did not utilize the clip for obliteration of intracranial aneurysms. Six years after the intracranial operation was performed by Dott, Dandy performed the first aneurysm clipping by using a Cushing silver clip that had been modified by McKenzie. The clip allowed definitive selective exclusion of the aneurysm from the cerebral vasculature, thereby pioneering the modern era of aneurysm surgery. Even though the original silver clip has undergone significant modifications, its conception and development by Cushing remains a landmark contribution to all subspecialties of neurological surgery. Cushing summarized his surgical approach to aneurysms:

When a supposed intracerebral cyst was tapped with a large-sized needle and found to be an aneurysm, fine strips of fresh muscle, fortunately at hand for purposes of hemostasis, were fed in through the puncture opening until it became occluded from the inside. It is quite possible that the sac might have been safely filled in this way and have subsequently become solidified with clot.”

Dott and Dandy marked the beginning of the modern era of aneurysm surgery and facilitated subsequent successes in the treatment of aneurysms. Intracranial aneurysms were first detected on imaging in 1933 following the introduction of cerebral angiography by Antonio Caetano de Egas Moniz in 1927. With the application of cerebral angiography, the diagnosis and treatment of intracranial aneurysms entered a new stage. We have learned from our predecessors who improved the diagnosis and surgical treatment of aneurysms while facing uncertainty and disappointing outcomes. Their persistence, wisdom, and lessons have led to the development of effective techniques to treat neurosurgical disorders.

Conclusions
Cushing’s contributions to neurological surgery are numerous. Despite his interest in brain tumors, he considered occlusion of intracranial aneurysms and prevention of their recurrent hemorrhage by placement of muscle fragments in and around the aneurysms. His silver clips proved to be a critical tool used by the pioneers in the discipline of neurovascular surgery.

References

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