Challenges in early operative approaches to intramedullary spinal cord tumors: Harvey Cushing's perspective

Courtney Pendleton, MD, Jordina Rincon-Torroella, MD, Ziya L. Gokaslan, MD, George I. Jallo, MD, and Alfredo Quinones-Hinojosa, MD

Department of Neurosurgery, The Johns Hopkins School of Medicine, Baltimore, Maryland

Although Harvey Cushing was mostly known for his contributions to brain tumor surgery, he was also a pioneer in the development of spinal cord surgery. This lesser known facet of Cushing's career can provide a fresh and unique perspective into how the founders of neurosurgery surmounted early challenges in the field. The authors bring to light and examine for the first time Cushing's unpublished writing "Technique of Laminectomy" along with his first 3 documented intramedullary spinal cord tumor (IMSCT) cases at the Johns Hopkins Hospital. The authors draw lessons from the challenges in pathological classification, preoperative diagnosis, tumor localization, and surgical technique of that time. Although Cushing's attempts at exploration and resection of IMSCT as described here were of limited success, his ability to adapt his clinical and surgical technique to the challenges of the time, as well as develop skills to successfully manipulate the spinal cord during these exploratory procedures without the patients incurring neurological damage, postoperative infection, or complications, is a testament to his determination to advance the field and his meticulous operative technique. In spite of the limitations imposed on the pioneer neurosurgeons, Harvey Cushing and his contemporaries persevered through many of the challenges and built an essential part of neurosurgery's common story.

<http://thejns.org/doi/abs/10.3171/2014.12.SPINE13427>

KEY WORDS Harvey Cushing; intramedullary spinal cord tumors; oncology

THE earliest documented attempt at resection of an intramedullary spinal cord tumor (IMSCT) was performed by Christian Fenger of Chicago in 1890, although the patient remained paralyzed postoperatively, as detailed in Church and Eisendrath.⁸ The earliest successful resection was performed in 1907 by Anton von Eiselsberg of Vienna (see Zervas).³⁶ Surgeons of the early 20th century continued to pursue methods for successful operative treatment of these lesions, with Charles Elsberg of New York developing a 2-stage operation to minimize manipulation of the spinal cord during resection.¹⁹

Although Harvey Cushing is known for his contributions to brain tumor surgery, his contributions to spine surgery,^{7,16–18,28} particularly for tumors of the spinal column, have only recently come to light.^{17,28} Cushing was fluent in German and French, and it is possible that he read published accounts of these cases during his early career. In

1888, Gowers and Horsley published in a European journal a very detailed description on the technique they used in the first recorded resection of a spinal meningioma.²¹ In 1900, Harvey Cushing spent 1 year in Europe. During that time he was introduced to new surgical techniques that could have encouraged him to start operating on spinal cord lesions once he returned to the US.

Cushing's papers at the Yale University Medical Historical Library contain his unpublished article "Technique of Laminectomy," in which he introduces a brief technical explanation of the laminectomy procedure (Fig. 1). This manuscript is evidence of Cushing's interest in furthering spine surgery. In addition to discussing that paper, we present 3 cases of IMSCTs that Cushing treated operatively during his career as a young attending at the Johns Hopkins Hospital.

To understand the context in which the first surgeries

ABBREVIATION IMSCT = intramedullary spinal cord tumor.

SUBMITTED May 12, 2013. **ACCEPTED** December 31, 2014.

INCLUDE WHEN CITING Published online June 26, 2015; DOI: 10.3171/2014.12.SPINE13427.

DISCLOSURE Dr. Gokaslan owns stock in US Spine and Spinal Kinetics. He also receives support of non-study-related clinical or research efforts that he oversees from NREF, AO, and DePuy. He is on the editorial boards of the *Journal of Neurosurgery*, *The Spine Journal*, *Journal of Spinal Disorders*, *European Spine Journal*, *Nature Review*, *World Neurosurgery*, and *Journal of Surgical Oncology*. Dr. Rincon-Torroella is a grant holder for "Fundació La Caixa" fellowship.

TECHNIQUE OF LAMINECTOMY

In the operation of laminectomy there are certain essential things to bear in mind. The first of these is the avoidance of bleeding from the tissues in exposing the spines and laminae; the second is the avoidance of trauma or jar during the process of opening the canal. There are many surgical tricks which enable one to accomplish these two ends.

It is not the purpose of this paper to discuss the localization of the lesion and it will be taken for granted not only that

FIG. 1. The first page of Cushing's unpublished manuscript "Technique of Laminectomy." Figure provided courtesy of the Yale University Harvey Cushing/John Hay Whitney Medical Library.

for IMSCTs took place, we present the historical diagnostic and technical challenges in the neurosurgical field at that period. It is the goal of this paper to highlight the challenges that were overcome by Harvey Cushing and other essential pioneers in neurosurgery, and in this way our paper contributes to the understanding of the historical roots of our current practice in spine surgery.

Methods

Following internal review board approval, and through the courtesy of the Alan Mason Chesney Archives, the surgical files for the Johns Hopkins Hospital from 1896 to 1912 were reviewed. Additional information regarding Cushing's approach to laminectomies was gathered from the collection at the Harvey Cushing/John Hay Whitney Medical Library at Yale University.

Case Presentation

Three patients on whom Cushing operated for IMSCTs were found in the surgical records. Their mean age was 26 years (range 14–40 years), and 2 patients were female (66%). Two patients underwent decompressive laminectomies with cyst evacuation and without tumor resection. One patient underwent a decompressive laminectomy with partial tumor resection. Two patients were discharged in "improved" condition, and one was discharged in "unimproved" condition (Table 1). A single, previously unreported case of an IMSCT resection is described below.

Case Report

On May 4, 1910, a 25-year-old woman with a history

of bilateral talipes equina and severe scoliosis presented with 3 months of bilateral lower-extremity weakness, bilateral lower-extremity hyperreflexia, and right lower-extremity sensory disturbance. She had a distant history of poliomyelitis at the age of 3 years, which left her with a slight left-sided foot drop. She had suffered a fall 1 year prior to admission, and complained of back pain, followed by intermittent weakness of her right leg, leading to occasional falls. The right-sided weakness and sensory loss progressed, and her left leg became involved on March 10, 1910.

Cushing suspected a tumor of the spinal cord, and brought the patient to the operating room on May 5, 1910, for a "Spinal decompression for intra-spinal tumor (glioma?) Partial removal of growth." Cushing's preoperative diagnosis of "glioma?" was borne out by the intraoperative findings. Cushing's observations of a distended, rubbery characteristic of the spine may refer to the presence of a tumor-associated syrinx. His operative note and illustration (Fig. 2) document the procedure:

The patient was placed in as comfortable a position as possible on the table in view of the extreme rotary curvature of the spine. Anaesthesia was beautifully taken during the course of the three and a half hours operation. Great difficulty was experienced at first in finding even the spines which were apparently flattened in such a way as to make their exposure difficult, particularly the spinal muscles on the right side were separated from the spines and laminae with difficulty owing to the tendency of the muscles to appear over on the left.

The actual work was however fairly easily done, each spine successively being removed with perforator and burr, then carrying the opening down to the posterior ligament. There

TABLE 1. Demographic data, operative details, and outcomes for 3 patients with IMSCTs treated by Harvey Cushing at the Johns Hopkins Hospital

Case No.	Age (yrs), Sex	Diagnosis	Op Date	Procedure Summary	Outcome
1	40, M	Tumor of spinal cord ... glioma	9/25/1908	Laminectomy. Attempted evacuation of cystic component, tumor not resected.	Improved
2	14, F	Glioma of cord ... syringomyelia	10/15/1908	Evacuation of cyst, tumor not resected.	Unimproved
3	25, F	Columnar glioma (spinal cord)	5/5/1910	Laminectomy. Partial resection of tumor.	Improved

was a matter of fact none of the abundant yellow elastic tissue which is usually seen.

The dura as exposed was extremely tense, a very broad channel of it having been brought fully into view. There should have been no unusual tension. Membrane was opened by a linear cut which was carried throughout the entire length of the exposure – viz. from the 6th thoracic to the first lumbar vertebrae inclusive. Cord was perfectly dry with no subarachnoid fluid whatsoever, and it bulged into the wound. It was of a rubbery consistency giving the sensation of a fairly tight hollow rubber tube. It was perfectly dry and of a straw yellow color. Blood vessels on the surface were much thinned. On splitting the dura the cord itself bulged into the wound so that it would have been absolutely impossible to have closed the dura again had this seemed advisable. At one area the nerve tissue looked somewhat grayish and translucent and here an incision was made throughout the posterior columns into the cord itself, disclosing a glioma. The tumor itself seemed to be merely a soft, grayish gelatinous mass, a few fragments of which were curetted out of the opening.

From the upper end of the incised dura the filiform bourie was then passed upward into the cord. At a distance of about 5 cm. cerebrospinal fluid was encountered for the first time.

Consequently two more spines and laminae were removed, making in all a laminectomy of 8 vertebrae. At about this level the cord seemed tight and some fluid was evacuated on tilting it from one side to the other. However, at this level it still had a distended rubbery characteristic.

The operation represents columnar glioma possibly on the way towards a condition of syringomyelia.

Wound was closed leaving the dura wide open, merely the superficial parts being brought together in the usual fashion, in layers.

In the immediate postoperative period, the patient was found to have motor and sensory defects. However, on postoperative Day 5 it was noted that she could “move toes on left foot, also flex at knee and hip feebly; no ankle motion. Apparently total anesthesia after the operation which seems to be clearing up somewhat. Definite crossed palsy. Rt. leg extremely hypersensitive.”

She was discharged on May 25, postoperative Day 20, in “improved” condition. Follow-up letters from her primary physician in Boston documented that in the month following her operation she was able to stand for short periods of time without assistance and was able to walk longer distances with crutches.

Discussion

In the mid-1700s, Heister first suggested surgery of the spine.²⁴ For more than a century, spine surgery was infre-

quently performed except for spinal trauma.³⁸ Surgery for spinal cord tumors emerged in 1887 when the surgeons Sir Victor Horsley and Sir William Gowers pioneered the successful operation for a spinal meningioma in England.²¹ The earliest successful resection of IMSCTs was performed in 1907 by Anton von Eiselsberg of Vienna.³⁶

Harvey Cushing’s first surgery for the removal of a spinal cord tumor was for a cervical meningioma in November 1903. The outstanding clinical results of this surgery led Cushing to state: “The case seems in many respects the most satisfactory of any heretofore recorded.”¹² Two years later, Cushing’s landmark publication “The special

FIG. 2. Cushing’s operative illustration documenting the severe scoliosis, tumor location, and laminectomy performed in Case 3. The text in the upper-right corner reads “Level of 2nd opening” and “Level of 1st opening.”

field of neurological surgery”¹³ reserved a special section for the spinal cord. Cushing summarized his early experience with spine lesions: “My personal experience with spinal tumors has been small”—mainly trauma cases, an enucleable tumor (aka meningioma), a fibroma, a dermoid cyst, and invasion of the spinal canal by malignant disease.^{13,14}

The cases reported in this paper, treated in 1908 and 1910, represent Harvey Cushing’s first documented attempts at IMSCT resection at Johns Hopkins.

Cohen-Gadol et al. reported 60 cases of spinal tumor resections performed by Cushing between 1912 and 1932. Seven of those were IMSCTs (4 astrocytomas, 3 ependymomas), demonstrating that Cushing refined his surgical techniques for spinal lesions throughout his lengthy career.⁹ Curiously, in his 1920 revision of the paper “The special field of neurological surgery,” Cushing did mention his thoughts about spinal tumors again, but without mention of his successful IMSCT resections.¹⁴

The Diagnostic Challenges

Not only tumors but also different degenerative, non-tumoral diseases can give rise to complex neurological symptoms. At the time of Harvey Cushing, it was not infrequent to incorrectly diagnose a spinal cord tumor and not find the tumor during the surgery.¹³ In 1922, another pioneer of spine surgery, W. J. Mixter, described the great variety of diagnoses associated with what he named “symptoms of chronic cord compressions of non-traumatic origin.”^{3,32,40} This, together with the classification of tumor histology published by Harvey Cushing in 1926,² eased the diagnostic challenges.

Clinical Spinal Localization

One of the principal challenges that spine surgeons faced was spinal-level localization. This issue is so important that the modern era of spinal tumor surgery is considered to begin with Horsley’s case in 1887. In 1892, Horsley provided important contributions to the knowledge of localization.^{26,33} In 1920, Cushing stated in reference to the surgery of spinal meningiomas:

No operation [...] in which the transformation from a suffering and bed-fast invalid to a normal life is more like a resurrection. One may imagine the elation which Horsley and Gowers must have felt in 1888 on the occasion of their epochal first case.¹⁴

In his unpublished paper “Technique of the Laminectomy” (available in the Harvey Williams Cushing Papers in the Yale University Library [MS 160], <http://hdl.handle.net/10079/fa/mssa.ms.0160>), Cushing introduces a brief statement on localization:

It is not the purpose of this paper to discuss the localization of the lesion and it will be taken for granted not only that the level of the lesion and extent of spinal involvement has been determined by preliminary neurological studies but that the nature of the lesion which is expected may also be more or less definitely determined.

Cushing emphasized the need for knowledge of neurological anatomy and the site of each spinal segment in

relation to the skeletal landmarks for localization in spine surgery: “The small and removable spinal cord tumors especially put one’s knowledge of localization to test.”¹³ Thus, Cushing always started the evaluation of his spinal cases with an in-depth history and physical examination: voluntary and involuntary movements, tactile sensation, pain, and temperature.¹⁶ Long annotations and drawings of dermatomes and spine levels filled his medical notes.

Diagnostic Tools

Although Roentgen discovered the use of x-rays in 1895,³⁵ there were very few publications about spine imaging until 1920.²⁵ Cushing used x-rays in neurosurgical patients as early as 1897, and his first published spine case described the use of x-rays to localize bullets from a gunshot.^{10,22,30}

Contrast studies of the spine were developed in the 1920s. Walter E. Dandy first postulated the injection of air in the spine,¹⁵ and later, radiopaque agents were developed. Lipiodol was the first iodinated contrast agent used for myelography.³⁷ Postulated in 1921 by Forestier and Sicard, Lipiodol myelography was one of the techniques used at that time for tumor localization.²⁵ Pain, inflammation, and arachnoiditis were common complications of the use of Lipiodol.²⁷ Harvey Cushing refused to use this technique because he was convinced that its complications outweighed its benefits, as was later demonstrated.

One of the diagnostic techniques that Harvey Cushing used for spinal tumors was the double puncture developed by J.B. Ayer in 1707. This technique was based on the comparison of the xanthochromia (yellow discoloration) of the cerebrospinal fluid above and below the compression point, with one puncture of the cisterna magna and a second one of the lumbar space.^{1,32} Later in his career, Harvey Cushing combined lumbar puncture and x-rays in his practice.⁴ He would continue using these techniques in his future at Brigham and Women’s Hospital and Yale.⁹

In many cases these techniques were not accurate enough, and after an exploratory laminectomy and dural opening, Cushing would extend the skin incision to locate the tumor.

The Technical Challenges and “Technique of Laminectomy”

Harvey Cushing used laminectomy to approach different lesions: metastatic lesions to the spine,²⁸ Potts disease,⁷ migraine,²⁹ deformities after poliomyelitis, and extraaxial spinal cord tumors.^{9,17}

Cushing’s papers at the Yale University Medical Historical Library contain his unpublished article “Technique of Laminectomy,” in which he introduces a brief technical explanation of the laminectomy procedure. The first technical challenge for spine surgery was the complications of patient positioning. As a contribution to spine surgery, Harvey Cushing devised a table to position the patient lying prone.^{5,6}

Hemostasis and healing were major concerns at that time, and electrocautery wouldn’t be available until 1926.^{11,31,39}

I prefer in these cases, as in all operations, to make a preliminary dermal scratch with the knife after cleaning the regions and before draping. [...] It is rarely necessary to put any clamps anywhere on the wound after bleeding is controlled in other ways.

This unfinished paper further illustrates the importance Cushing placed on the Halstedian principle of careful handling of tissues:

If, before the incision is carried down to the spines, the two assistants place their eight fingers on each side of the spinous processes and press the tissues down, the skin is rendered taught and drawn away as it separates when the preliminary cut is carried down to the spine.

Cushing's concern regarding damage to local tissues during retraction in those cases is a product of his early training under Halsted;²³ the risk of damaging the surrounding tissues is further emphasized by Cushing's description of the preferred methods of retraction in the same paper:

We usually employ and prefer hand retraction if sufficient helpers are available, the retractors for this purpose being flat and of such character that they hold the muscle properly apart without tearing or damaging it. The usual spreader which is on the market has such deep forks that they dig out into the muscular tissues unnecessarily and sometimes cause bleeding and damage to the muscles.

In the preantibiotic era, the importance of maintaining tissue integrity to ensure proper wound closure and postoperative healing could hardly be overstated. Despite some success treating central nervous system abscesses with early bacteriostatic agents,³⁴ options available for Cushing to treat infections of neurosurgical (or other) incision sites were significantly limited.

However, spine surgery required long incisions. The 3 cases described here illustrate Cushing's use of long incisions to achieve adequate exposure for exploration of the lesion. In Case 1, Cushing reports using an incision "about 20 cm. in length" to expose a tumor from C-7 to T-5; in Case 2, Cushing reports a "possibly 5-inch exposure" through an incision from C-4 or C-5 to T-2; and in Case 3, Cushing reports an incision from T-6 to L-1. In the absence of modern neuroimaging techniques, these extensive incisions were necessary to enable exploration and localization of the tumor, in addition to minimizing the need for retraction. As we can read, in the same paper Cushing emphasizes the need for wide exposure:

If [the] tumour is to be exposed and its situation is evident, the laminae of three, or better four, vertebrae at least should be removed and this makes it advisable to remove the spine at least of the vertebrae above and below. As six vertebrae are thus involved, the incision has to be long, and it is unusual to see a laminectomy performed without the surgeon's having to lengthen his incision. It is just as well therefore to have it sufficiently long at the outset. A long wound of this kind heals just as rapidly as a short one and probably better, for there is less likelihood of trauma of the tissues in the process of retraction.

Over the course of the 20th century, the advent of operative microscopes, improved hemostatic devices, and the use of lasers and ultrasonic aspirators to aid in IMSCT resection have allowed neurosurgeons to limit both the inci-

sion length and the number of levels involved in laminectomies.³⁶

One of the main technical concerns of Cushing's time was damaging the cord during the laminectomy.⁶ Harvey Cushing incorporated the use of burs, rongeurs, and laminectomy forceps. Mallets and saws were not used, to avoid injury to the underlying nervous tissue during the procedure:

The spines and laminae thus being exposed, freed from periosteum and soft parts, are then removed as follows: with a heavy pair of long-handled bone forceps, the spines are cut off with a single cut [...]. In order to avoid any jar in the succeeding delicate procedure in getting the laminae off, a broad, arrow-pointed perforator attached to the usual brace and bit is then used to make a conical-shaped defect through the remaining stump of the spine until the point opens into the extradural portion of the canal. [...] The arrow-pointed perforator is then followed by a burr of 2 cm. in diameter, which opens the canal widely down to the fatty tissue surrounding the dura. [...] There then remains merely a thin bridge of laminae of the two adjacent vertebrae which usually can be removed with a single bite of the ordinary small rongeurs of the Horsley pattern.

Following the dural opening, there was extrusion of the nervous tissue, especially if an anterior tumor was pushing the spinal cord to the back of the spinal column.³² In the case presented above, Harvey Cushing mentioned this disadvantage and the inability to close the dura mater afterward:

On splitting the dura the cord itself bulged into the wound so that it would have been absolutely impossible to have closed the dura again had this seemed advisable.

After the dural opening, the challenge was localizing the tumor. We discovered that Cushing adapted his surgical technique to the limited preoperative diagnostic exploration: he would make an extensive skin incision, laminectomy, and dural opening to explore the region. If the localization of the tumor was correctly approximated, he would see a region of distended spinal cord. If the localization was not precise, he would pass a catheter to feel for any obstruction or resistance. He would then extend the skin incision, the levels of the laminectomy, and the dural opening toward the bulging region or obstruction.

It is unusual to see a laminectomy performed without the surgeon's having to lengthen his incision.

Once approaching the tumor itself, the challenge was distinguishing the bulging from tumor versus the bulging from syrinx, especially in the IMSCTs that had a cystic nature. Harvey Cushing would look for a change of texture and consistency in the tissue by either visual or tactile evaluation. When tumor was suspected, the cord was incised and the cyst evacuated, with spooning out of the tumor in some cases. When Cushing assumed that the bulging region was syringomyelia, he would use a needle to drain the fluid.

From publications by Mixer in 1922, we learn more about the management of intramedullary lesions at that time.³² "Removal at once of an intramedullary tumor is not to be attempted on account of damage to the cord. Cyst evacuation is indicated and result may be extremely satisfactory." Tumor resection was technically challenging and

cyst evacuation for decompression was accepted as a good surgical outcome.

To overcome the challenge of tumor resection, in 1911 Charles Elsberg proposed one of the revolutionary techniques in treatment of IMSCTs: a 2-stage operation to minimize manipulation of the spinal cord during tumor resection.^{19,20} He advised the surgeon to split the cord over the tumor mass without tumor resection in the initial surgery. During a second sitting, and in the hope that the tumor would have extruded during the time between the first and the second surgery, a resection of the lesion would be performed.³²

The challenge of spinal cord injury during surgery was the main reason why some surgeons considered the laminectomy a dangerous and aggressive procedure. As stated in 1912 by Bottomley, Cushing and others promoted and supported its use, although with some reservations: "Kocher and Harvey Cushing, both masters in neurological surgery, consider laminectomy anything but a harmless operation and are most conservative advising its use."⁶

Conclusions

One might ask why Harvey Cushing never finished or published his paper "Technique of Laminectomy." Although this question can only be answered with assumptions, it might be worthwhile to cite his own words in his paper "The special field of neurological surgery after another interval" in 1920: "I have read over the general statement in my papers of ten and fifteen years ago regarding the surgery of the spinal cord, and though I might give many additional illustrations I do not know that there is very much to add to the general principles of these operations then described. There are more things, possibly, to retract than to add."¹⁴

Although Cushing's attempts at exploration and resection as described here demonstrated only limited success in treating IMSCTs, his ability to manipulate the spinal cord during these exploratory procedures without the patients incurring permanent neurological damage, as well as the absence of postoperative infection or complications, is a testament to his meticulous operative technique and his surgical skills.

Without regard to the limitations imposed on them, Harvey Cushing and his contemporaries faced all those challenges, and built an essential part of our common story.

Acknowledgments

We thank Alexandra Larsen and Elisabet Pujadas for their help and assistance in editing and for their accurate review of the cohesion of this article.

References

1. Ayer JB, Viets HR: Spinal fluid findings characteristic of cord compression. *JAMA* **67**:1707, 1916
2. Bailey C, Cushing H: **Classification of Tumors of the Glioma Group on a Histogenic Basis with a Correlated Study of Prognosis**. Philadelphia: Lippincott, 1926
3. Barker FG II: The Massachusetts General Hospital. Early history and neurosurgery to 1939. *J Neurosurg* **79**:948–959, 1993
4. Bau-Prussak S: Über den diagnostischen wert der lipiodol-myelographie. *Z Gesamte Neurol Psychiatr* **99**:453–474, 1925
5. Blake JB: Comment on the surgical treatment of injuries of the spinal column affecting the cord by Bottomley. *Medical Communications Massachusetts Med Soc* **23**:252–256, 1912
6. Bottomley JT: The surgical treatment of injuries of the spinal column affecting the cord. *Boston Med Surg J* **167**:691–696, 1912
7. Bydon A, Dasenbrock HH, Pendleton C, McGirt MJ, Gokaslan ZL, Quinones-Hinojosa A: Harvey Cushing, the spine surgeon: the surgical treatment of Pott disease. *Spine (Phila Pa 1976)* **36**:1420–1425, 2011
8. Church A, Eisendrath D: A contribution to spinal cord surgery. *Am J Med Sci* **103**:403–405, 1892
9. Cohen-Gadol AA, Spencer DD, Krauss WE: The development of techniques for resection of spinal cord tumors by Harvey W. Cushing. *J Neurosurg Spine* **2**:92–97, 2005
10. Cushing H: Haematomyelia from gunshot wounds of the spine. A report of two cases, with recovery following symptoms of hemileision of the cord. *Am J Med Sci* **115**:654–683, 1898
11. Cushing H: I. The control of bleeding in operations for brain tumors: with the description of silver "clips" for the occlusion of vessels inaccessible to the ligature. *Ann Surg* **54**:1–19, 1911
12. Cushing H: Intradural tumor of the cervical meninges. *Ann Surg* **39**:934–955, 1904
13. Cushing H: The special field of neurological surgery. *Bull Johns Hopkins Hosp* **16**:77–87, 1905
14. Cushing H: The special field of neurological surgery after another interval. *Arch Neurol Psychiatry* **4**:603–637, 1920
15. Dandy WE: Ventriculography following the injection of air into the cerebral ventricles. *Ann Surg* **68**:5–11, 1918
16. Dasenbrock HH, Pendleton C, Cohen-Gadol AA, Witham TF, Gokaslan ZL, Quinones-Hinojosa A, et al: "No clinical puzzles more interesting": Harvey Cushing and spinal trauma, the Johns Hopkins Hospital 1896–1912. *Neurosurgery* **68**:420–430, 2011
17. Dasenbrock HH, Pendleton C, Cohen-Gadol AA, Wolinsky JP, Gokaslan ZL, Quinones-Hinojosa A, et al: "No performance in surgery more interesting and satisfactory": Harvey Cushing and his experience with spinal cord tumors at the Johns Hopkins Hospital. *J Neurosurg Spine* **14**:412–420, 2011
18. Dasenbrock HH, Pendleton C, McGirt MJ, Sciubba DM, Gokaslan ZL, Quinones-Hinojosa A, et al: "Fulfilling the chief of his duties as a physician": Harvey Cushing, selective dorsal rhizotomy and elective spine surgery for quality of life. *J Neurosurg Spine* **14**:421–427, 2011
19. Elsberg C, Beer E: The operability of intramedullary tumors of the spinal cord. A report of two operations with remarks upon the extrusion of the spinal cord. *Am J Med Sci* **142**:636–647, 1911
20. Elsberg CA: **Diagnosis and Treatment of Surgical Diseases of the Spinal Cord and its Membranes**. Philadelphia: W.B. Saunders Co, 1916
21. Gowers WR, Horsley V: A Case of tumour of the spinal cord. Removal; Recovery. *Med Chir Trans* **71**:377–428, 11, 1888
22. Gunderman RB, Seymour ZA: Harvey W. Cushing. *AJR Am J Roentgenol* **194**:296–298, 2010
23. Halsted WS: The training of the surgeon. *Bull Johns Hopkins Hosp* **15**:267–275, 1904
24. Heister L: **General System of Surgery**, ed 6. London: W. Innys, et al., 1757
25. Hoeffner EG, Mukherji SK, Srinivasan A, Quint DJ: Neuro-radiology back to the future: head and neck imaging. *AJNR Am J Neuroradiol* **33**:2026–2032, 2012

26. Horsley V: **The Structure and Functions of the Brain and Spinal Cord**. London: Charles Griffin, 1892
27. Krause F: [Comments on the myelography by means of lipiodol and jodipin.] **Z Gesamte Neurol Psychiatr** **99**:514–517, 1925 (Ger)
28. Latimer K, Pendleton C, Cohen-Gadol AA, Gokaslan ZL, Quinones-Hinojosa A: Harvey Cushing's operative treatment of metastatic breast cancer to the central nervous system in the early 1900s. **Arch Surg** **146**:975–979, 2011
29. Latimer K, Pendleton C, Rosenberg J, Cohen-Gadol AA, Quinones-Hinojosa A: Dr. Harvey Cushing's attempts to cure migraine based on theories of pathophysiology. **J Neurosurg** **115**:924–928, 2011
30. Light RU: The contributions of Harvey Cushing to the techniques of neurosurgery. **Surg Neurol** **35**:69–73, 1991
31. Malis LI: Electrosurgery and bipolar technology. **Neurosurgery** **56**:ONS1–ONS12, 2006
32. Mixer WJ: Experiences with tumors of the spinal cord. **Boston Med Surg J** **186**:276–279, 1922
33. Naderi S, Türe U, Pait TG: History of the spinal cord localization. **Neurosurg Focus** **16**(1):E15, 2004
34. Pendleton C, Jallo GI, Quinones-Hinojosa A: Early multimodality treatment of intracranial abscesses. **World Neurosurg** **78**:712–714, 2011
35. Roentgen WC: Über eine neue Art Von Strahlen. **Sitzsber Physik Med Ges Wuerzburg** **137**:132–141, 1895
36. Sciubba DM, Liang D, Kothbauer KF, Noggle JC, Jallo GI: The evolution of intramedullary spinal cord tumor surgery. **Neurosurgery** **65** (6 Suppl):84–92, 2009
37. Sicard JA, Forestier J: Méthode générale d'exploration radiologique par l'huile iodée (lipiodol). **Bull Mém Soc Méd Hop Paris** **46**:463, 1922
38. Stewart J: Lorenz Heister: surgeon (1683-1758). **Can Med Assoc J** **20**:418–419, 1929
39. Voorhees JR, Cohen-Gadol AA, Laws ER, Spencer DD: Battling blood loss in neurosurgery: Harvey Cushing's embrace of electrosurgery. **J Neurosurg** **102**:745–752, 2005
40. Zervas NT (ed): **Neurosurgery at the Massachusetts General Hospital, 1909-1983: a Short History and Alumni Record**. Boston: Massachusetts General Hospital, 1984

Author Contributions

Conception and design: Quinones-Hinojosa, Pendleton, Rincon-Torroella. Acquisition of data: Quinones-Hinojosa, Pendleton, Rincon-Torroella. Analysis and interpretation of data: all authors. Drafting the article: all authors. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Quinones-Hinojosa. Study supervision: Quinones-Hinojosa, Pendleton, Rincon-Torroella.

Correspondence

Alfredo Quinones-Hinojosa, Department of Neurosurgery, The Johns Hopkins School of Medicine, 1550 Orleans St., CRBII, Rm. 247, Baltimore, MD 21231. email: aquinon2@jhmi.edu.