W. W. Keen and the dawn of American neurosurgery

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Before the turn of the century, W. W. Keen was the most celebrated neurosurgeon in the United States. During the Civil War he served as a surgeon in the Union Army. He collaborated with Mitchell and Morehouse in clinical studies that culminated in their publishing *Gunshot Wounds and Other Injuries of Nerves*. In 1887, he was the first surgeon in the Americas to remove a benign brain tumor. He perfected a technique for ventricular puncture, devised operations for spasmodic torticollis, microcephalus, and tic douloureux, and introduced many European neurosurgical techniques to the United States. An astute clinician and excellent teacher, Keen had no research interests other than anatomical and pathological dissections. He published over 50 papers on neurosurgical topics, in addition to articles on numerous other subjects. Although recognized as a pioneer in neurosurgery, he is not usually considered a founder of neurosurgery in the United States because of his failure to develop the specialty further than his contemporaries in the remainder of the neurosurgical world. This failure related not to his abilities, but probably to the fact that he was elderly before it became technically possible to perform safe and effective intracranial procedures.

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When that most unpromising of all specialties, the surgery of the nervous system, needed an optimistic pioneer, [Keen] was called upon. . . .

—Harvey W. Cushing

Born in Philadelphia on January 19, 1837, William Williams Keen received his early education at Saunders' Academy and Central High School before matriculating to Brown University. His initial intent had been to enter the clergy, but he became fascinated by the physical sciences. In 1859, Keen graduated first in his class but remained an extra year to prepare for medical school. He entered Jefferson Medical College in Philadelphia in 1860.11

The Civil War erupted during the second half of Keen's 1st year. That summer he was recommended by one of his tutors, John H. Brinton, for the temporary post of surgeon to the Fifth Massachusetts Regiment.21,32 Taking oath “in the shadow of the Capitol” on July 4, 1861, he was appointed Assistant Surgeon and assigned to Camp Alexandria. On July 21, he served in the thick of the first Battle of Bull Run. On August 1, he was honorably discharged. He reentered Jefferson that fall and graduated in March, 1862.21,31

Two months later, Keen was sworn in as Acting Assistant Surgeon in the Union Army. He was put in charge of Eckington Hospital near Washington, D.C. and later Hospital No. 1 in Frederick, Maryland. He thus participated in the second Battle of Bull Run and at Antietam. That winter he was transferred back to Philadelphia, where, because of its medical resources and strategic location, a total of 14,508 Union casualties were cared for throughout the war.21,31

At the outbreak of the War Between the States, S. Weir Mitchell was a well established Philadelphia physician with many publications to his credit, including two papers with William A. Hammond.2 Because of his father's death, Mitchell was responsible for the support of his family, and he did not enter military service at the earliest opportunity. He did enlist as a “contract surgeon” in October, 1862. In that capacity, Mitchell could continue a private practice while being assigned part time to one of the local military hospitals. He became interested in injuries and afflictions of the nervous system while serving as an Acting Assistant
Surgeon at the Filbert Street Hospital. He soon arranged for patients with neurological problems to be transferred to his wards since other physicians eschewed such cases; “they were so little understood and so unsatisfactory in their results.” 29 He suggested to the Surgeon General of the United States Army, his old friend Hammond, that a special hospital for such problems be created.

On May 5, 1863, Hammond ordered the establishment of the United States Army Hospital for Diseases of the Nervous System on Christian Street in Philadelphia. Mitchell was placed in charge along with George R. Morehouse, a Jefferson classmate and fellow Philadelphia physician with whom he had worked at both the Filbert and Christian Street Hospitals. Mitchell also requested that Keen, whom he had first met as a medical student, be assigned to the hospital because, as Keen later boasted, “He never could kill me with hard work.” The youngest of the three, Keen was the only one who had served in combat. Following “the awful harvest of Gettysburg” that July, the 275-bed Christian Street Hospital overflowed, and a new facility was required. In August, 1864, Turner’s Lane Hospital, with a 400-bed capacity, was established on the grounds of an old estate in what was then suburban Philadelphia. As full-time resident surgeon, Keen lived on the grounds.30

Mitchell and Morehouse continued their private practices while working at Turner’s Lane. They typically began the working day with a brief visit at 7 a.m., pursued their private practices during the remainder of the morning and early afternoon, and then returned to Turner’s Lane in the late afternoon to stay until midnight or the early morning hours. The workload was enormous. “Here at one time were eighty epileptics, every kind of nerve-wound, palsies, singular choreas, and stump disorders. I sometimes wonder how we stood it,” reflected Mitchell shortly before his death in 1914.32 Mercifully freed from administrative chores by special order, Mitchell, Morehouse, and Keen devoted themselves exclusively to clinical work. Unfortunately, there was no stenographic or clerical help, and all records, literally thousands of pages of notes, were handwritten.31

After 15 months of careful observation and experience, Mitchell, Morehouse, and Keen published Gunshot Wounds and Other Injuries of Nerves in 1864.11 Its plethora of detail is perhaps best exemplified by the case of Edward Mooney, who sustained a gunshot wound to the right superior sympathetic ganglion at Chancellorstown in May, 1863.33 When Keen first met Mooney, he mused silently, “You are Dalton’s cat.” Years later he explained, “Those of you who are familiar with Dalton’s good old text-book of physiology will remember a picture of a cat whose right cervical sympathetic nerve had been severed.”21 When Keen visited Claude Bernard in Paris after the war, he described Mooney’s case. Bernard, who had trained Dalton many years before, was thrilled to have clinical confirmation of the same lesion he had created in rabbits.31 However, because Mooney’s case was buried in an avalanche of data, including the first clinical description of causalgia, it was overlooked, and when Horner described the syndrome that bears his name in 1869, it was heralded as the first account.12

When the armistice was declared, Turner’s Lane Hospital was disbanded. By then, Hammond had been court-martialed because of repeated conflicts with Secretary of War Stanton, and a new Surgeon General ordered all notes to be handed over to the Army.32 Although they were hurriedly copied for further research, only Mitchell, the instigator and organizer, continued the project. Morehouse resumed his full-time private practice, and Keen, the only one of the three destined for a professorship, pursued a variety of interests over the next two decades.31 First, he worked with and studied under the leading researchers and clinicians of Europe: Bernard and Pouchet in Paris, Billroth and Conneheim in Vienna, and Virchow in Berlin.10 Upon his return, Keen began the first lecture course in pathological anatomy at his alma mater. Later, he established Jefferson Medical College’s first surgical research laboratory as well as its first course in surgical pathology.1 In 1866, Keen acquired ownership of the Philadelphia School of Anatomy, the nation’s only remaining independent anatomical school until its closure 9 years later.8 In 1867, he married Emma Corinne Borden of Fall River, Massachusetts. They had four daughters, but Mrs. Keen died when the eldest was barely 18 years old.1 He did not remarry.

One of Keen’s most fascinating activities, probably an outgrowth of his work with the School of Anatomy, was his role in the teaching of artistic anatomy. From 1876 to 1881, he provided a lengthy series of lectures for students at the Pennsylvania Academy of Fine Arts. Visual aids included actual dissections, plaster casts, galvanic muscle stimulation, and live models. Later, he urged the use of live models for medical teaching. One of his most significant contributions to the Academy was the appointment of Thomas Eakins as Chief Demonstrator. Keen intended to write a book entitled Artistic Anatomy, but it never progressed beyond a handwritten outline.9 His involvement with the Academy dwindled in the early 1880’s with the growth of his surgical practice.

Concomitantly, Keen’s academic career was beginning to flourish. An excellent teacher, he was appointed Professor of Surgery at Women’s Medical College of Philadelphia in 1884, and 5 years later he succeeded the younger Gross as Professor of the Principles of Surgery and Clinical Surgery at Jefferson Medical College. He remained there until his retirement in 1907 (Fig. 1). His publications, mostly written without assistance and covering a vast array of surgical subjects, also increased dramatically, and few physicians then or now could match his output. Even so, it was common for
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articles to be duplicated, abstracted, translated, rewritten, and generally recycled for different medical audiences, and, aside from isolated case reports, Keen rarely wrote a single paper on a single topic. In 1890, for example, he authored 15 discrete articles, but four reappeared in abstracted or even unexpurgated form in six other journals. All of the articles but one, an account of sciatic nerve stretching for treatment of symmetrical lateral sclerosis penned with C. K. Mills, were written alone. Keen also read the medical literature voraciously, and whenever something intriguing and foreign caught his eye, he was quick to introduce it to the United States. The use of the Gigli saw for craniotomy was first described in Europe by Obalinski in 1897 and in America by Keen in 1898.

Keen’s interests, however, remained too widespread, and serial articles on the same subject served mainly to keep his series current or to bring the reader up to date. His writings did not reflect a sustained, well organized program of clinical or laboratory investigation, only the observations, experiences, and speculations of an astute clinician. Although Keen did not engage in animal experimentation, he strongly supported it during his entire professional life, and he campaigned vigorously against the anti-vivisectionists. Nonetheless, his only laboratory was the dissection room.

Keen’s relative silence on neurological surgery in the first few decades after the Civil War must be viewed in the context of the times. General anesthesia was well established by 1865, but antiseptic surgery did not exist. Lister’s discovery, first enunciated in 1867, was not fully accepted by the medical profession until almost 1880. Also lacking was sufficient knowledge of cerebral localization to allow accurate anatomical diagnosis. Matas recalled that during this period “the head, chest and abdomen were still regarded as ‘sanctuaries’ not to be opened, unless by accident.” That the first operations on the brain were delayed until these necessary preconditions were met is not surprising, and Keen, while not the first to attempt brain surgery, certainly showed appropriate restraint when, at 50 years of age (Horsley was then 30 years old, Cushing 18), he was the first in the western hemisphere to resect a benign brain tumor.

The patient was a 26-year-old carriage maker who had developed headache, seizures, partial blindness, variable aphasia, and progressive right hemiparesis over the preceding 3 years. He failed to respond to the nostrums of the day, and he repeatedly requested surgery. He was admitted to St. Mary’s Hospital, “formerly □9 a dwelling house that was still quite primitive,” and the operation was carried out on December 15, 1887. Elaborate antiseptic precautions were taken by Keen, who in 1876 had been the first Philadelphia surgeon to adopt Lister’s method. The carpet was removed. The room “contained only necessary furniture. The walls and ceilings were carefully wiped the day before, and all the wood-work and furniture, as well as the floor, were thoroughly scrubbed with carbolic solution . . . the instruments were all boiled for two hours . . . the spray of carbolic acid was used in the room all the morning of the operation, but not during the operation or at any of the redressings . . . The day of the operation the patient’s head was shaved, then scrubbed with soap and water, then with ether and covered with a wet sublimate dressing of 1:1000, which was retained in its place by bandages until the operation began, when the ether and sublimate washings were repeated. The hands and nails of myself and all my assistants were, of course, carefully cleaned and disinfected by soap and water, alcohol and sublimate solution.” Surgical gloves had not yet been introduced.

The operation took place at 1 p.m. The late starting time may have been an attempt to take advantage of the best natural light available during the winter solstice. Several assistants and a host of observers were present, including Mitchell and Mills. Drop-ether anesthesia was employed. Keen used a “large semi-elliptical flap” based...
FIG. 2. Appearance of the scalp of Keen’s meningioma patient. Left: Between 2 and 10 weeks after surgery. Right: Sixteen years postoperatively. When the patient was at rest the wound was 5.5 cm deep, but it would bulge nearly an inch (2.5 cm) above the skull concavity with straining. (Reproduced from Keen WW, White JW: An American Textbook of Surgery for Practitioners and Students, ed 4. Philadelphia: WB Saunders, 1903, p 586, with permission of the publisher.)

in the left frontotemporal region. (This site corresponded to a scar on the scalp that resulted from a head injury the patient had sustained when he was 3 years old; Keen remained convinced of a causal relationship between the head injury and the tumor that was found many years later.23) Both the scalp and the underlying bone bled profusely. A 1 1/8-in. (3.8-cm) trephine opening was made just in front of the coronal suture and above the frontotemporal junction. Through the opening was disclosed a hard mass extending beyond its limits in all other directions,” and Keen made a second burr hole posterior to the first. More tumor and bone erosion were evident. He enlarged the opening so that it extended “two and a half inches (6.4 cm) transversely by three inches (7.6 cm) anteroposteriorly.” The tumor was fully exposed medially where it came to within 3 in. (1.9 cm) of the midline. Laterally, it was still buried 1/4 in. (1.3 cm) below the edge of the craniectomy.22

Keen incised the dura peripherally. He found it increasingly adherent to the tumor centrally. “I therefore severed its connections all round, and was able now to enucleate the growth by the finger with but very little force.” Profuse bleeding, mostly from “several large veins,” followed and was eventually controlled with several catgut ligatures, sponge pressure, and hot-water irrigation. The bottom of the cavity contained “softened, and in part shreddy, white brain tissue.” During the time required for hemostasis, the cavity was filled up nearly one-half by resilient brain tissue.22

The night of surgery, Keen wrote: “perfectly conscious; called me by name. Aphasia somewhat marked.” There was no paralysis. The dressing was soaked for the first 2 days and needed changing. The aphasia then worsened, and the flap became more rounded. Roughly 4 ounces (120 ml) of blood and brain debris was expressed from the wound the following day, with clearing of the aphasia. The drains and skin sutures were gradually removed. He seemed neurologically stable.22

“The second week was full of peril.” The patient’s temperature, which had hovered about 100°F (37.8°C) for the 1st week, reached a maximum of 104.2°F (40.1°C) on the 10th day when “the face and arm were distinctly paralyzed; speech very thick, and later unintelligible; aphasia marked. . . . Fearing an accumulation of pus as the cause of all the danger, I reopened the wound with my finger to over half its extent disclosing a mass . . . resembling brain tissue. The microscope showed no pus.” By the end of the 2nd week the brain began to herniate through the crescentic opening (Fig. 2 left) and to adhere to the flap.22

The following week the brain fungus increased in size, with granulations and pus forming on its surface. Copious quantities of “limpid fluid” began to drain from the surface of the hernia. The patient ran a low-grade fever much of the time, his temperature occasionally rising as high as 102.4°F (39.1°C). His condition slowly improved. All drainage ceased on the 37th day. Skin grafts from his arm were used to hasten the healing of the granulations on the hernial surface. By the 71st day, cicatrization was complete, and the hernia was level with the skull surface. Four days later the area contained a “deep hollow.” He was discharged on the 84th day.22

The patient was followed faithfully for the next 30 years. The concavity in his skull eventually sank 5.5
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cm (Fig. 2 right), but more alarming was the effect of posture and straining. The area bulged when he lay down; it was depressed on sitting or standing. "Any muscular effort — for example, using the dynamometer, and the Valsalva maneuver — caused the unusually deep hollow . . . to bulge nearly an inch (2.5 cm) beyond the level of the skull. To protect his brain against injury I bent a piece of tin to fit the surface of his head, covered it with black silk, and sewed this to the inside of a skull-cap which he always wore."[23]

Grossly, the tumor measured $2\frac{1}{8} \times 2\frac{1}{2} \times 1\frac{1}{8}$ in. (7.3 x 6.4 x 4.5 cm) and weighed 3 ounces 49 grains (96.5 gm). It was not adherent to the brain but "intimately united with the dura." Microscopically, it contained "an arrangement in bundles of fibrous elements." It was called a fibroma and would probably be classified as a fibroblastic meningioma today. When the patient died in 1918, A. G. Ellis, a pathologist who worked with Keen, traveled to the patient's home in Lancaster, Pennsylvania to procure the brain which the patient had promised Keen years before. Upon reflecting the scalp, he found a "newly formed fibrous membrane" covering the brain but not adherent to it. When it was reflected, a huge "crater-like cavity" was exposed which included the floor of the left lateral ventricle. Both ventricles were enlarged and the optic nerves and chiasm were atrophic. There was no recurrent tumor.[23]

More than any of his previous experiences, this case spurred Keen on to further neurosurgical ventures. He was fascinated by the erosion of the tumor into the roof of the lateral ventricle and by its negligible effect on the patient's level of neurological function. He concluded "that such involvement of the ventricles was in no wise so dangerous as had been supposed," and later, in 1888, he proposed tapping the ventricles to relieve increased intracranial pressure.[23] After considering possible sites for ventricular puncture, he advised making a small burr hole 1 1/4 in. (3.2 cm) above and 1 1/4 in. (3.2 cm) behind the external auditory meatus. The trocar and cannula were to be aimed at a point 2 1/4 in. (6.4 cm) above the opposite external auditory meatus.[19] Keen later performed many ventricular punctures, and the burr-hole site became known as Keen's point.[14] In addition to draining the ventricle, Keen advised irrigating both ventricles with warm boric acid solution by means of bilateral ventriculostomies: "It felt good," said one patient. Most patients who needed ventricular taps, especially for chronic or repeated drainage, eventually died of infection.[19]

Virchow differentiated between microcephaly and craniosynostosis in his 1877 monograph, but their clinical distinction, especially before the discovery of x-ray imaging, took much longer.[5] Since the concept of neurological impairment secondary to premature suture closure was well accepted, surgeons attempted to prevent disability by various forms of craniectomy or craniotomy. In 1890, Keen performed the first craniectomy for microcephalus in America.[13] The procedure consisted of a large unilateral flap. Believing that "this child . . . certainly improved steadily and considerably,"

Keen performed a similar operation on the other side using rongeurs of his own design which reduced the operative time from 75 to 35 minutes. The patient's progress was not affected by the second procedure. Keen performed two more craniectomies, one of the children dying of "heart failure" in the immediate postoperative period.[15] The procedure came under harsh criticism, and it was generally abandoned. Roentgen's discovery of x-ray imaging in 1895 enabled more accurate diagnosis, and the operation was revived when more appropriate selection of patients could be made.[5]

In 1887, Mitchell asked Keen whether it would be possible to divide or excise the nerves supplying the posterior rotatory neck muscles for patients with spasmodic torticollis. Keen "made a number of careful dissections to determine the feasibility of the operation," and, in 1890, F. X. Dercum referred to him a patient with "spasmodic wry neck" on whom Keen performed the procedure for the first time. Visualization of the depth of the wound proved his greatest problem, one which was later solved with electric lighting. The patient made a speedy recovery. The following year Keen reported his operation in detail,[16] it consisted of sectioning the posterior divisions of the first three cervical nerves. (He probably also divided the spinal accessory nerve: his article is ambiguous on this point.) Many years later Finney and Hughson[4] described Keen's operation as "the first really carefully studied and scientific attempt to treat the disease on a rational basis." Other surgeons followed his lead, and over the next several decades all surgical approaches for this condition were "more or less closely patterned after the method suggested by Keen.[24]

Keen's most celebrated non-neurosurgical patient was President Grover Cleveland. The only President to serve two nonconsecutive terms, Cleveland had just been reelected when he discovered an ulcer in the roof of his mouth in 1893. The lesion was biopsied and found to be a sarcoma. Dr. Joseph D. Bryant, a noted New York surgeon and intimate friend of the President, was asked to consult, and he advised excision. Cleveland wished to keep the matter secret since the nation was in the throes of a financial depression. Arrangements were made to undergo surgery aboard the presidential yacht as it cruised in Long Island Sound between New York City and his summer home on Cape Cod. Keen was asked to assist, and it was probably a special cheek retractor which he had brought back from Paris in 1866 that allowed the entire operation to be performed within the mouth without any facial incision. Most of the left upper jaw was removed, along with a small portion of the soft palate and tumor extension into the maxillary sinus.[20]

Two weeks later Bryant and Keen performed a brief second procedure in which they "removed all the suspicious tissue and cauterized the entire surface with
the galvanocautery.” Bryant declared the wound “all healed” 2 months from the date of surgery, and the President was fitted with a permanent prosthesis the following month. Meanwhile the nation was also slowly recovering. Keen traveled to Washington several times thereafter to examine the President’s mouth and never found any recurrence. Cleveland died in 1908, 15 years after surgery without evidence of local recurrence or metastasis. The operation remained secret until 1917. Bryant had since died, and Keen’s definitive account first appeared in the Saturday Evening Post and later in book form.20

One of Keen’s most enduring neurosurgical interests was trigeminal neuralgia, a condition that thwarted virtually all of the early attempts at treatment because of poor results and distressing morbidity and mortality. Meirowsky and Pipito30 divided the history of the surgical treatment of tic douloureux into four phases: operations on the peripheral branches of the trigeminal nerve, on the gasserian ganglion, on the sensory root, and on the central connections in the brain stem. Keen’s earliest attempts consisted of various procedures upon the peripheral nerves with “the usual poor results.”11 In view of his experience with therapeutic stretching of the facial nerve for hemifacial spasm — a disorder that he termed “tic non douloureux”18 — and sciatic nerve stretching for lateral sclerosis,24 it is surprising that he did not apply this concept to trigeminal neuralgia.

In 1894, with John K. Mitchell (who continued much of the work of his illustrious father S. Weir Mitchell), Keen reported his first attempt at removing the gasserian ganglion via the Hartley-Krause technique.25 The patient was a previously healthy 30-year-old dentist who had already undergone multiple procedures for intractable tic douloureux, including ligation of the facial artery and excision of the entire upper jaw on that side. Necessity forced Keen to stage the procedure. When he first opened the skull, he encountered “a considerable hemorrhage” and thought that he had torn a branch of the middle meningeal artery or perhaps even entered the cavernous sinus. Neither suspicion proved true, but because Keen could not control the bleeding he packed the wound with a piece of iodoform-saturated gauze measuring 37 × 6 in. (94.0 × 15.2 cm). He reopened the wound on the 3rd postoperative day. “I drew out the gauze very carefully,” he wrote, “keeping a stream of hot water playing on it all the time so as to loosen it very thoroughly.” Although hemorrhage was again “moderately profuse,” he was able to overcome the bleeding with small hot sponges and pressure. Despite continued bleeding, he succeeded in exposing the ganglion and “with the Allis dissector and a small sharp spoon . . . thoroughly destroyed the ganglion.” Although Keen claimed the patient made a “complete and rapid operative recovery and was out of bed on the 4th day,” Mitchell remarked that the patient’s mental condition was such that a reliable sensory examination could be performed only just before discharge 2 months later.
simplicity, efficacy, and safety, the newer operation was quickly adopted. In 1883 and 1887, Keen updated the American editions of *Gray's Anatomy*. With J. William White, Professor of Surgery at the University of Pennsylvania, he then edited a new textbook of surgery emphasizing bacteriological principles. First published in 1892, *An American Textbook of Surgery for Practitioners and Students* achieved a worldwide reputation and passed through four large editions. In 1906, he edited *Surgery, Its Principles and Practice* which appeared in eight serial volumes. He asked Cushing to contribute the section on "Surgery of the head," and Keen limited him to 80 printed pages. Keen was "not a little disturbed when H. C. coolly submitted a highly illustrated manuscript running to some 800 typed pages which was eventually compressed into a monograph of 276 pages and 154 illustrations." Anticipating his retirement, Keen began to look around for a successor as Professor of Surgery at Jefferson Medical College as early as 1904. He discussed the matter informally with Cushing, who mulled over the proposal for 2 years. Unfortunately, there is no preserved correspondence except for Cushing's handwritten letter of regret dated March 13, 1906. Keen retired at the compulsory age of 70 years in 1907. He was succeeded by John Chalmers DaCosta, another Jefferson alumnus who had advanced through the ranks of its Department of Surgery.

Retirement did not curtail Keen's many interests. Although they were less technical, he continued to write papers on medical topics into his nineties. Altogether he published over 50 papers on neurosurgical subjects, the last being his report of the 30-year follow-up and autopsy of his famed meningioma patient. Keen also maintained an active and lively correspondence; the following letter to Walter Dandy was written in his 91st year:

My dear Dandy:

As I have told you before, you are rightly named. Here you are removing half of a fellow's brains and letting him go around just as usual. Whenever you get to the point when you can take out all the brains,* I may consult you.

Sincerely yours,

W. W. Keen

*for all those who have any.

Throughout his professional life and well into retirement, Keen was showered with honors and awards. Kudos received during his lifetime included 10 honorary degrees from universities in North America and Europe and Fellowships in the Royal College of Surgeons of England, Ireland, and Edinburgh. He died in Philadelphia on June 7, 1932, at the age of 95, "mourned as a noble exemplar of the highest ideals of the medical profession."
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