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The history of external ventricular drainage

Historical vignette

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External ventricular drainage (EVD) is one of the most commonly performed neurosurgical procedures. It was first performed as early as 1744 by Claude-Nicholas Le Cat. Since then, there have been numerous changes in technique, materials used, indications for the procedure, and safety. The history of EVD is best appreciated in 4 eras of progress: development of the technique (1850–1908), technological advancements (1927–1950), expansion of indications (1960–1995), and accuracy, training, and infection control (1995–present). While EVD was first attempted in the 18th century, it was not until 1890 that the first thorough report of EVD technique and outcomes was published by William Williams Keen. He was followed by H. Tillmanns, who described the technique that would be used for many years. Following this, many improvements were made to the EVD apparatus itself, including the addition of manometry by Adson and Lillie in 1927, and continued experimentation in cannulation/drainage materials. Technological advancements allowed a great expansion of indications for EVD, sparked by Nils Lundberg, who published a thorough analysis of the use of intracranial pressure (ICP) monitoring in patients with brain tumors in 1960. This led to the application of EVD and ICP monitoring in subarachnoid hemorrhage, Reye syndrome, and traumatic brain injury. Recent research in EVD has focused on improving the overall safety of the procedure, which has included the development of guidance-based systems, virtual reality simulators for trainees, and antibiotic-impregnated catheters. *(http://thejns.org/doi/abs/10.3171/2013.6.JNS121577)*

Key Words • **external ventricular drainage** • **intracranial pressure monitoring** • **ventriculostomy** • **history**

The ventricles of the brain and their relationship to the pathology of increased ICP has been intermittently studied for several centuries.[43] The earliest recorded mention of CSF appears in the Edwin Smith Papyrus, an ancient Egyptian text from approximately 1500 BCE, which described the "spillage of clear fluid from the interior of the brain."[61] In 1664, Thomas Willis first postulated that the production of CSF came from the choroid plexuses and that the fluid was contained within the ventricles.[43] Antonio Pacchioni produced one of the next major advances, describing his "Pacchioni granulations" in 1705.[8] Key and Retzius put these previous studies together, proving that CSF is secreted by the choroid plexus, flows through the ventricular system, and is reabsorbed via subarachnoid villi and Pacchonian granulations.[2,44] In 1765, Alexander Monro secundus (Fig. 1) described the connection between the lateral and third ventricles that now bears his name. However, it was not until the hypotheses by George Burrows and Harvey Cushing that the role of CSF in ICP was understood.

The histories of hydrocephalus[29] and third ventriculostomy[58] have been recently reviewed. External ventricular drainage, one of the most common neurosurgical procedures, has a long and rich history that has not been previously examined. External ventricular drainage was first documented by Claude-Nicolas Le Cat (1700–1768) in October 1744.[25] He performed a ventricular puncture and left a wick in place for some time.[14] Robert Whytt (1714–1766) expressed grave trepidation when commenting on ventricular drainage in his *Observations on Dropsy in the Brain*,[60] published in 1768. Whytt considered "dropsy" to be analogous to ascites of the abdominal cavity. He warned of high morbidity and death if hydrocephalus was not treated, but also wrote that "any such attempt to draw off the water [CSF], could have no other effect than to hasten death." In fact, he was so sure of this that he said that anyone who believed to have successfully treated the condition

Abbreviations used in this paper: EVD = external ventricular drainage; ICP = intracranial pressure.

Fig. 1. Illustration of Alexander Monro secundus. Monro's understanding of CSF dynamics and flow paved the way for the explorations of CSF drainage in the following century. Image courtesy of the NIH/National Library of Medicine.

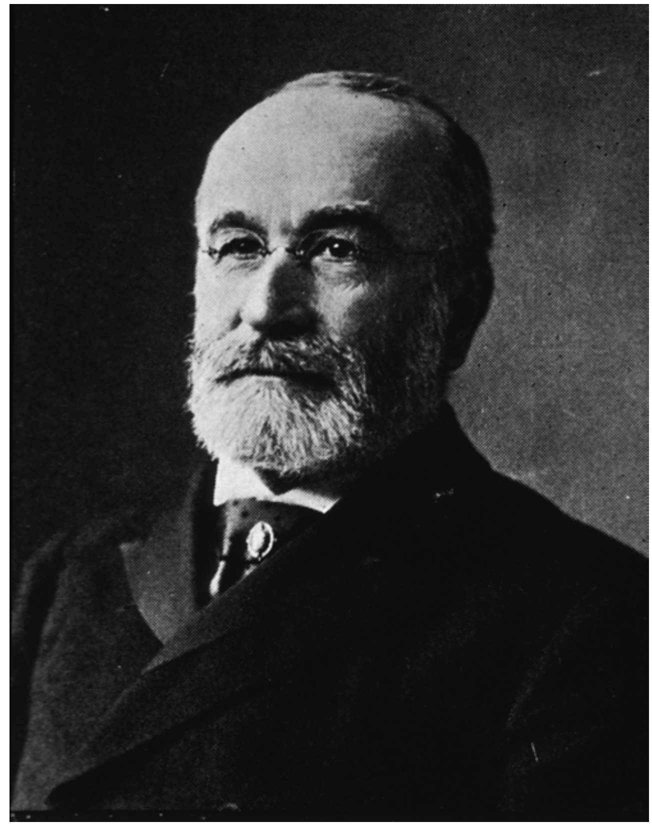

Fig. 2. Photograph of William Williams Keen. Keen's paper in 1890 was the first comprehensive review of EVD techniques. Image courtesy of the NIH/National Library of Medicine.

must have had the incorrect diagnosis.[60] However, from his publication, it is unclear whether Whytt ever attempted ventricular drainage himself; he comments on his medical management, which was to no avail.

Development of EVD Technique (1850–1908)

Benjamin Hill, a professor of surgery and anatomy at the Cincinnati Eclectic Institute, was among the first to comment at some length on the procedure of ventricular puncture, although apparently not the first to attempt it. His procedure consisted of puncturing the lateral ventricles of hydrocephalic infants through the fontanelle. In his *Lectures on the American Eclectic System of Surgery*, published in 1850, Hill notes the dismal results of this procedure to date.[17] "This is one of the questionable operations, which though resorted to from the earliest records of surgery, has been followed with so little success that it is not generally recommended - even as a last resort." Hill does close his comments on ventricular puncture with faint optimism for the procedure: "…there is reason to believe that better results would follow. Other operations and wounds on the parts show that the opening of the brain is not necessarily fatal."

Carl Wernicke performed the inaugural sterile ventricular puncture and EVD in 1881.[23] William Williams Keen (W. W. Keen, 1837–1932; Fig. 2) relayed credit for this accomplishment in his 1890 lecture; Wernicke wrote: "When performed with aseptic precautions, this operation is intrinsically perfectly safe." Others of this era also attempted prolonged ventricular drainage, including Pollock (1884), Zenner (1886), von Bergmann (1887), and Broca.[16] In these early days, various catheter-like devices were used, including catgut wicks, silk, and horsehair.[2]

W. W. Keen published the next report on ventricular drainage in "Surgery of the lateral ventricles of the brain."[23] Keen was one of the pioneers in American neurosurgery. Cushing commented on Keen, "When that most unpromising of all specialties, surgery of the nervous system, needed an optimistic pioneer, [Keen] was called upon…"[6] Keen graduated from Jefferson Medical College in Philadelphia and practiced there for most of his illustrious career. He collaborated with and studied under many well-known surgeons and physicians, including Joseph Pancoast, Rudolf Virchow, and Joseph Lister. Lister delivered a lecture in Philadelphia in September 1876 on antiseptic techniques, which Keen attended. Having followed the development of bacteriology and Pasteur's work during some years he spent in France, Keen was immediately impressed by the value of Lister's techniques.[56] Keen was thus one of the first Americans to fully adopt antisepsis, initiating its use in his St. Mary's Hospital in October 1876. His attention to this procedure is evident in his technical description of ventricular drainage in 1888; however, his execution of aseptic technique falls far short of modern standards. After trephination, "three stout double horse hairs were then passed into the ventricle" and left there so that CSF could flow out into the bedding.

Keen's paper published the details of trephination with prolonged ventricular drainage in 7 cases performed by 4 separate surgeons.[23] Some serious consequences of excessive drainage were reported, namely seizure, syncope, and death. One of the more promising cases included in Keen's report was from Mr. Mayo Robson. A 10-year-old girl with a history suggesting meningitis following otitis media underwent ventricular drainage: "Even half an ounce of fluid seemed to have imperiled life by pressure, and the operation undoubtedly saved her life – a most important and encouraging lesson for the future." The full case series of 7 patients, including those of others, showed a mortality rate of 71%. Keen concluded that hydrocephalus, whether acute or chronic, is usually a fatal disease: "Surgical procedures for tapping the ventricles for their relief are easy and certainly do not involve great danger per se. Whether these procedures will cure the disease is as yet not determined."

Keen advocated external drainage of the ventricles for hemorrhage and abscess. The site of puncture he advocated bears his name and continues to be used today: 3 cm superior to the pinna and 3 cm posterior, "Keen's point."[15,57] He later listed 12 conclusions on the procedure, 2 of which remain very applicable:[23]

> 5) Surgical procedures for tapping the ventricles for its relief are easy, and certainly do not per se involve great danger
>
> 6) In acute effusions, tapping, with or without drainage, as may be thought best, will certainly save some lives otherwise doomed to be lost, and in the chronic form long-continued slow drainage at an early period is at least worthy of a trial, with a reasonable hope of success in a few cases

Despite being best known as a thyroid surgeon, Kocher is known to have collaborated with several neurosurgeons, including Harvey Cushing. He advocated ventricular puncture through a point in the midpupillary line 10-cm posterior to the nasion. Kocher's description of his eponymous point appears in his 1894 *Textbook of Operative Surgery*.[50]

The next significant advancement in the EVD technique was by H. Tillmanns, as detailed in 1908. He reported a technique that closely resembled that of modern practice.[57] There was no consensus on the optimal point of trephination. Tillmanns advocated using Kocher's point but discussed several other approaches, including Keen's lateral approach and von Bergmann's frontal approach, in which the catheter was passed through a forehead incision (later described by Kaufmann and Clark,[22] without reference to Tillmans or von Bergmann, for emergency, no-shave use). The less commonly used Dandy's point, 2 cm from midline and 3 cm above the inion, was described a few years later.[11] Tillmanns also referenced a German book titled *Mitteilungen aus den Grenzgebieten der Medizin und Chirugie* (*Releases from the Frontier of Medicine and Surgery*), by Neisser and Pollack. In the book, Neisser and Pollack cite 36 patients in whom ventricular puncture was performed 136 times. Based on his reading of their treatise, he states, "we certainly gather from their observations that in suitable cases excellent results may be obtained from puncture of the brain, both from the diagnostic and therapeutic point of view."

Other aspects of modern technique described by Tillmanns included the use of local anesthetic and both anterior and posterior approaches. His description was quite close to that of modern neurosurgical practices. In fact, the only major difference between modern practice and Tillmanns' method is the use of subcutaneous tunneling, introduced in 1979 by Saunders and Lyons.[13,49] The introduction of the flexible Silastic catheter in 1969 facilitated tunneling. Saunders and Lyons reported on 174 ventriculostomy procedures using Silastic catheters and tunneling. They found that despite prolonged usage, infection rates could be as low as 2%.[49] This technique was reported on in greater detail by Friedman and Vries in 1980[13] and then became standardized (Fig. 3).

Fedor Krause (1857–1937) was one of the pioneering German neurosurgeons. He performed EVD in patients with hydrocephalus for as long as 8 weeks without infection.[2] He developed this technique for perioperative use in posterior fossa surgery, a field in which he made major contributions.[46]

For some years following Keen's and Tillmanns' studies in EVD technique, there was a relative lull in technical progress as techniques such as third ventriculostomy were under active development.[11] Ventricular puncture for indications other than CSF drainage such as air ventriculography (described by Walter Dandy in 1918) brought the technique of ventricular puncture (though not necessarily external drainage) into wider use.[12]

Up to this period, EVD had been used for congenital pediatric hydrocephalus.[16] Le Cat's first case report was that of a 5-year-old boy, and Keen cited some pediatric cases as well. However, from the next section onward, the focus of this paper will shift away from this indication, as shunting was found to be a more viable therapeutic option for these patients.

Technological Advancements (1927–1950)

Following the initial studies of the viability of ventricular drainage and establishment of the technique, the next significant step was the development and use of new materials for drainage. Over the first half of the twentieth century, a wide variety of materials were used, from metal cannulas to the eventual development of the modern Silastic catheter (Table 1). Developments also included the addition of various elements to the standard drainage setup, including manometers and flow control.

An early, significant addition to the drainage setup used by Tillmanns was ICP monitoring. In 1927, Adson and Lillie, a neurosurgeon and ophthalmologist, respectively, published a landmark paper relating ICP and intraocular tension, focusing on manometry and the related signs and symptoms.[1] These investigators sought to better understand what pressures caused various presentations. They used an elbowed system involving a silver cannula, rubber tubing, stopcock, and manometer attached to the head of the bed. Most interesting was their locking device, a "beef bone washer threaded into the trephine hole" that allowed good control of the rigid catheter at the point of drainage, the posterior horn of the lateral ventricle. Even without the benefit of a historical perspective, their work was described in commentary by Walter R. Parker

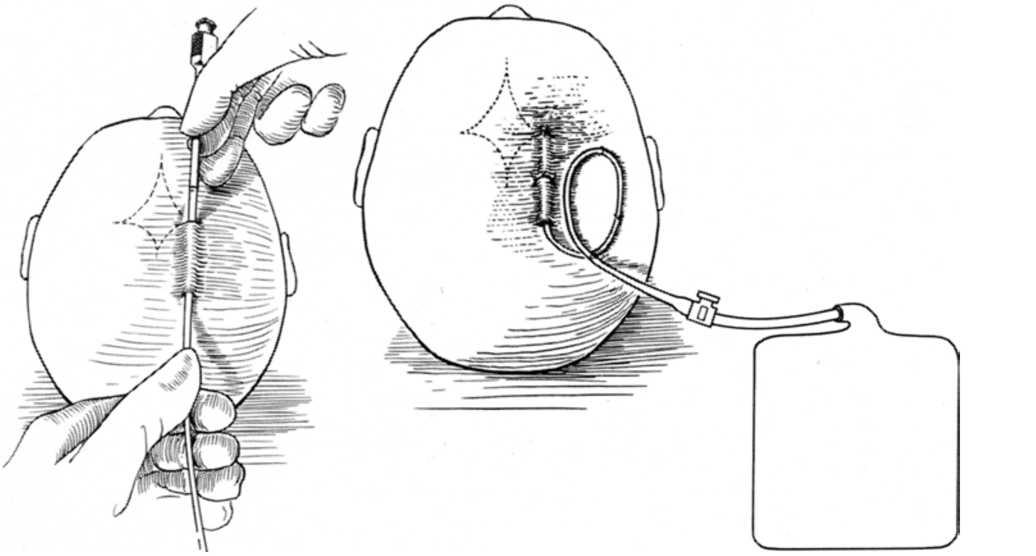

Fig. 3. Illustration of the technique of Friedman and Vries. This tunneling technique, described in a seminal 1980 paper, is one of the most frequently cited and used in modern-day EVD placement. Reproduced with permission from Friedman and Vries: *J Neurosurg 53:*662–665, 1980.

as "colossal… they are going to the bottom of some very perplexing problems."[1]

The 1940s brought on an era of small changes in materials and drainage systems to increase ease of use, stability, and control of EVD. Common in the publications of this period was the inclusion of sketches of various instruments and tubing circuitry. Beginning with a widely cited paper by Ingraham (Fig. 4) and Campbell in 1941,[20] a standardization of the apparatus followed. Their paper in the *Annals of Surgery* described the first closed drainage system. Their system enhanced sterility compared with CSF egress into the patient's bed, and their device included a stopcock system to offer slow, controlled drainage, avoiding rapid pressure fluctuations and overdrainage. Ingraham's system overcame 2 of the major causes of death in previous case series,[23,57] but they still advised against long-term drainage applied for more than 72 hours.[20,33]

James Poppen indicated in his 1943 paper that although ventriculostomy was most frequently used perioperatively, it should and could be applied more broadly. He noted its use in "well over 500 patients, without known untoward effects."[41] This was achieved without any novel techniques, but he carefully controlled drainage duration and sterility. Most importantly, he focused on using a closed drainage system to avoid infection.[54]

TABLE 1: Summary of the many materials used over the years in EVD, prior to the modern Silastic catheter

Material Used	First Published Description
horsehairs	Keen, 1890
catgut wick	1899
metal cannula	1911
silver cannula secured by beef bone washer	Adson & Lillie, 1927
flanged silver cannula	Ingraham & Campbell, 1941
rubber tubing	Crawford & Munslow, 1943
silk urethral catheter	Robinson, 1948
Silastic catheter	White et al., 1969

Albert Crawford and Ralph Munslow also showed some interest in "prolonged" ventricular drainage in 1943.[10] They were the first to employ a rubber catheter that allowed placement to variable depths, an impossibility with Ingraham's flanged silver catheter. They identified risk of infection as the greatest barrier to extensive use of the technique, a problem that they helped overcome by use of a drip chamber to prevent backflow of stagnant, potentially contaminated CSF to the brain.

The plastics revolution also brought advances to EVD, as polyethylene was found to be "of pure composition, well tolerated by tissues, which can be made into flexible tubes and thin, pliable sheets." In an article in *JAMA* about widespread applications for surgery, Frank Ingraham commented that "the use of the tubing for constant drainage of ventricular or subarachnoid fluid immediately suggests itself."[19] Bering first reported his use of polyethylene tubing in a case series of 26 patients in 1951.[5] Polyethylene tubing remained in vogue until Silastic catheters were developed in 1969.[59]

The change in materials has shown great stepwise evolution, from Keen's horse hairs, Adson's metal cannula,[1] Robinson's woven silk urethral catheter,[45] Ingraham's silver cannula,[19] Crawford and Munslow's rubber catheter,[10] to the modern Silastic catheter[13] (Table 1). In addition to the development of catheter materials, changes to the drainage system improved the safety and functionality of EVD. In 1948, Franklin Robinson published a paper in which he described a manometer-based system for measuring ventricular pressure in conjunction with the drainage.[45] His method allowed constant drainage and manometry to be performed at any time, via a double-stopcock system (Fig. 5).

Robert White and colleagues presented an external-

FIG. 4. Photograph of Franc D. Ingraham, AANS President 1944–1946. Ingraham and Campbell published the first use of a closed-drainage system. Reproduced with permission from Matson: *J Neurosurg 24:*945–948, 1966.

ized system that included a Spitz-Holter valve and Silastic tubing in their 1969 case series of 33 patients.[59] Following the standardization of Silastic catheters and manometry as part of the ventriculostomy apparatus, various disposable, prefabricated drainage systems became available. With a greater perceived safety, experience, and ease of use, drainage times could be increased and the indications for ventricular drainage progressively expanded (Table 2).

Expansion of EVD Indications (1960–1995)

By the 1950s, virtually all of the modern EVD placement techniques had been described and the drainage systems were nearly equivalent to current technology in materials and monitoring capability; despite this, EVD was rarely employed. Over the ensuing decades, careful study of the value of ventricular drainage and ICP measurement in various conditions expanded the indications for EVD.

In 1960, Nils Lundberg (Fig. 6) published an exhaustive study of his use of EVD in patients with brain tumors. He introduced the work with a summation of the state of EVD usage in 1960: "Single measurements of the ventricular fluid pressure or continuous recording of this pressure via an indwelling ventricular cannula have been used by a few authors for special research purposes, but, judging from the available literature, these measures have not been applied routinely in clinical practice." In his landmark study that totaled more than 200 pages, Lundberg meticulously recorded observations of prolonged ventricular drainage in 143 patients, the vast majority with brain tumors. The work provided minute-by-minute analysis of ICP and waveforms that firmly established the feasibility of prolonged drainage and the link between elevated ICP and neurological decline.[31] Intracranial pressure waveforms are eponymously named for Lundberg's contribution to the correlation between heartbeat, respirations, and ICP.

Following Lundberg's study, the indications for EVD slowly but steadily expanded. Despite the magnitude and implications of his paper, usage of therapeutic EVD and ventricular-based ICP monitoring changed little in the following decade. In attempting to develop a disposable and easily established system, Shapiro et al. praised Lundberg's work but provided some critique: "Despite Lundberg's work more than a decade ago, ICP measurement has not been widely used on neurosurgical wards, although his methods for measuring and recording ICP proved safe and reliable. … Lundberg's system is complicated and costly."[53]

Reye Syndrome

In 1978, Richard Saunders from Dartmouth sent a survey regarding ventricular monitoring to all 100 neurosurgical training programs in the US: "The responding neurosurgeons were usually quite selective in who was monitored, and even those few neurosurgeons with a great deal of experience with monitoring declared that it was not a routine. Some program directors clearly felt that this was just another cause of iatrogenic disease. Present techniques were viewed as crude."[48] Despite the resistance against monitoring in general, Reye syndrome was frequently cited in this survey as an ideal situation for monitoring.[7] Because the most common cause of death in Reye syndrome is diffuse cerebral edema, ICP monitoring via ventriculostomy proved essential in advancing treatment.[39]

Subarachnoid Hemorrhage

In a case-control series of 20 patients with Hunt and Hess Grade IV and V subarachnoid hemorrhage, 8 of 11 patients receiving ventriculostomy improved, compared with 1 of 9 controls.[27] These observations by Kusske et al. made a strong case for the use of ventriculostomy in the treatment of subarachnoid hemorrhage. Acute hydrocephalus is a common complication of subarachnoid hemorrhage, with an incidence nearing 20%.[42] As the pathophysiology of acute hydrocephalus after subarachnoid hemorrhage was understood in the 1980s, ventriculostomy came to be routinely used for this indication.[42] Modern reports show that subarachnoid hemorrhage is the most common indication for EVD.[21,38]

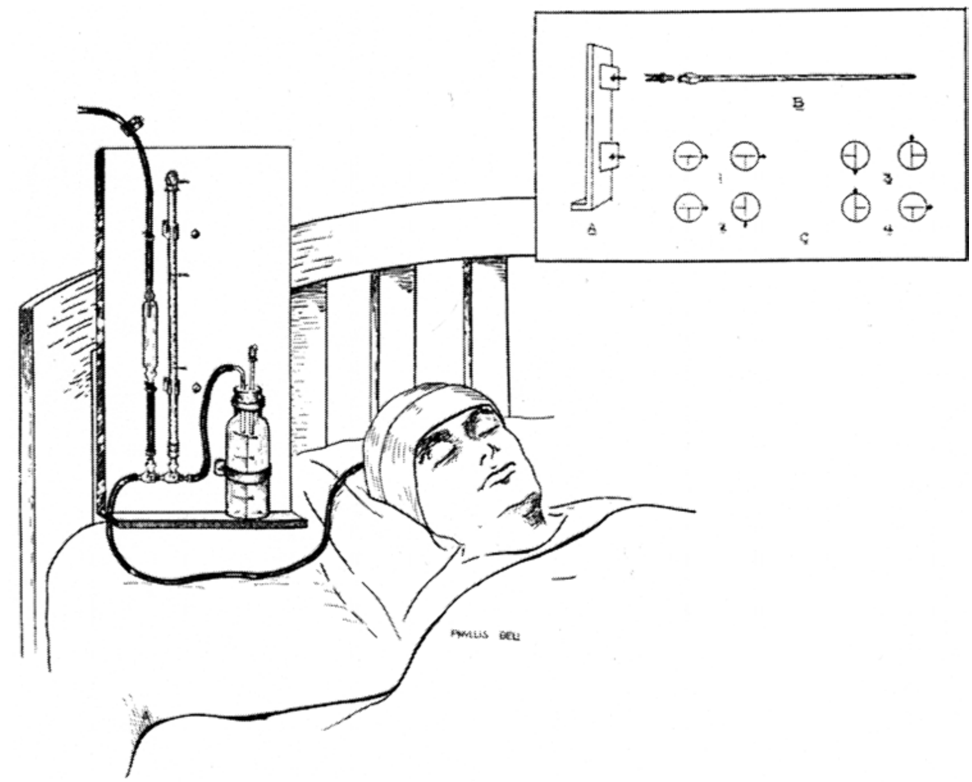

Fig. 5. Illustration of Robinson's EVD apparatus. This sketch includes a fixation to the wall and manometry, all in a closed system. **Inset** shows various combinations of stopcock positions. Reproduced with permission from Robinson: *J Neurosurg 5*:320–323, 1948.

Traumatic Brain Injury

The use of EVD was further expanded to traumatic brain injury in the 1980s.[4,35] This expansion began with Lawrence Marshall's 2-part paper, with Part 1 focusing on the significance of ICP monitoring via a ventricular catheter.[32] Thomas Saul and Thomas Ducker followed in 1982 with an analysis of mortality rate stratified by ICP. They concluded that early aggressive treatment based on ICP reduced the mortality rate of severe head injury.[47] A more definitive and lengthy study was published later in 1982 by Narayan et al.[36] With the correlation between outcome and ICP established, this study showed that, with some guidelines for judicious use, continuous ICP monitoring and control significantly improved outcomes.[36] In 1995, the Brain Trauma Foundation guidelines provided some consensus, with recommendations for ICP monitoring in any trauma patient with Glasgow Coma Scale scores of 3–8.[7]

TABLE 2: A selection of studies summarizing variable EVD times*

Authors & Year	Mean Drainage Time (days)	Maximum Drain Time
Smith & Alksne, 1976	4	9 days
Saunders & Lyons, 1979	6	3 wks
Bering, 1951	6	18 days
White et al., 1969	21.5	176 days
Chan & Mann, 1988	16	44 days

* While not all authors reported this information, several mentioned how long patients remained with drainage and the longest in their series. When not explicitly provided, mean drainage was calculated from available data.

Training, Accuracy, and Infection Control

Today, external ventricular drain placement is among the most common neurosurgical procedures, often performed in the intensive care unit. Nearly 25,000 ventriculostomies are performed annually.[51] The ease of the practice and ability to confirm accurate placement with CT has helped to propagate EVD use. In academic centers, EVD is frequently the first independent procedure performed by junior neurosurgical residents.[21]

A few novel techniques have been developed in the recent past to improve accuracy and limit morbidity of external ventricular drain placement.[38] In 1985, Jamshid Ghajar put forth a novel instrument, the "Ghajar guide," to improve accuracy. The guide consisted of a plastic-molded tripod applied to the patient's scalp, which would direct the ventricular catheter perpendicularly. When most recently studied in a prospective trial, placement with a Ghajar guide was found to be closer to the target; however, successful cannulation was often achieved without it as well.[37] Despite its efficacy, it is infrequently used, with only 5% of practicing neurosurgeons and 0% of residents reporting usage.[38] The same study by O'Neill et al. found marked resistance to methodological change, with most respondents reporting they would not accept a 10-minute increase in procedural time for 100% accuracy.[38]

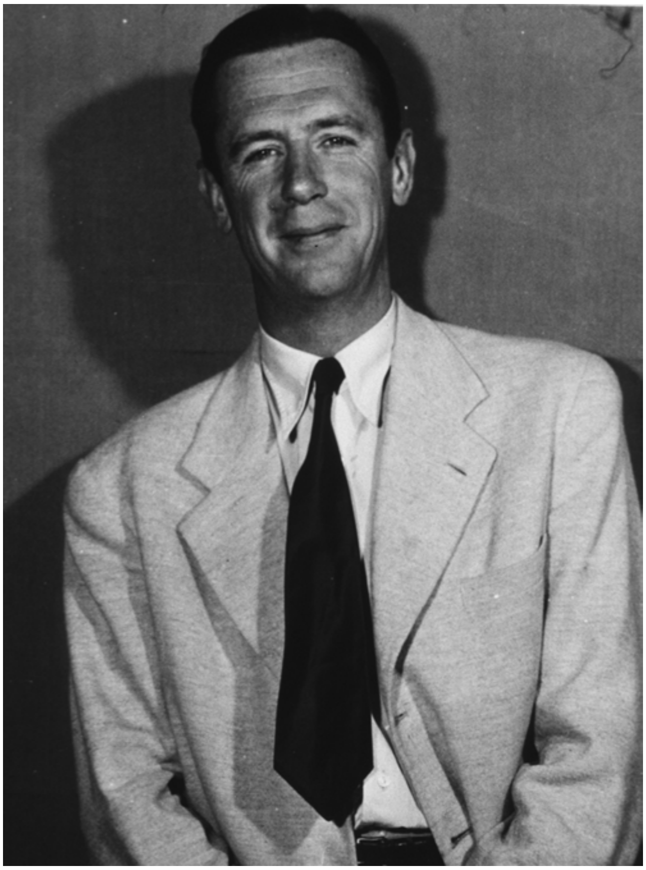

Fig. 6. Photograph of Nils Lundberg. Lundberg's 1960 paper describing ICP changes in patients with tumors was essential in the expansion of indications for EVDs. Image courtesy of the NIH/National Library of Medicine, unknown copyright.

Many neurosurgical procedures have been enhanced by the application of computer-assisted navigation, using a combination of imaging and patient anatomy. This technology has been applied to the placement of external ventricular drains, especially for those with variant anatomy or ventricular shift. However, due to the time and resources required to use these imaging systems, they are rarely applied. Due to the relative resistance to guidance-based systems,[38] combined with the fact that external ventricular drains are often placed by postgraduate Year 1 and Year 2 residents,[21] many authors have focused on better methods of teaching the procedure. This instruction has been conducted through multiple means, including the Society of Neurological Surgeons Boot Camp courses[52] and virtual reality simulators.[3,18,26,28]

Since the advent of the procedure, infection control has been a major concern. The use of prophylactic antibiotics has been debated and well reviewed.[30] In 1972, Wyler and Kelly presented a retrospective study of 70 patients with and without prophylaxis.[62] Infection rate in the prophylaxis group was 9%, compared with 27% without. Currently, there is no consensus on the use of prophylactic antibiotics.[34,55] For the last decade, research has involved the use and efficacy of antibiotic-impregnated catheters[40,63] and even silver.[24]

Conclusions

The history of EVD is a great example of technical innovation and evolution in the field of neurosurgery. It can be considered in 4 eras of progress: development of the technique (1850–1908), technological advancements (1927–1950), expansion of indications (1960–1995), and accuracy, training, and infection control (1995–present). The contributions of W. W. Keen, Nils Lundberg, and many more have been vital to the development, refinement, and application of this very common procedure (Fig. 7).

Disclosure

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

Author contributions to the study and manuscript preparation include the following. Conception and design: Srinivasan, O'Neill. Acquisition of data: Srinivasan, O'Neill. Analysis and interpretation of data: Srinivasan, O'Neill, Jho, Oh. 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: Srinivasan. Study supervision: Whiting, Oh.

References

1. Adson AW, Lillie WL: The relationship of intracranial pressure, choked disc, and intraocular tension. **Trans Amer Acad Opht Otolaryng 30:**138–154, 1927
2. Aschoff A, Kremer P, Hashemi B, Kunze S: The scientific history of hydrocephalus and its treatment. **Neurosurg Rev 22:**67–95, 1999
3. Banerjee PP, Luciano CJ, Lemole GM Jr, Charbel FT, Oh MY: Accuracy of ventriculostomy catheter placement using a head- and hand-tracked high-resolution virtual reality simulator with haptic feedback. **J Neurosurg 107:**515–521, 2007
4. Becker DP, Miller JD, Ward JD, Greenberg RP, Young HF, Sakalas R: The outcome from severe head injury with early diagnosis and intensive management. **J Neurosurg 47:**491–502, 1977
5. Bering EA Jr: A simplified apparatus for constant ventricular drainage. **J Neurosurg 8:**450–452, 1951

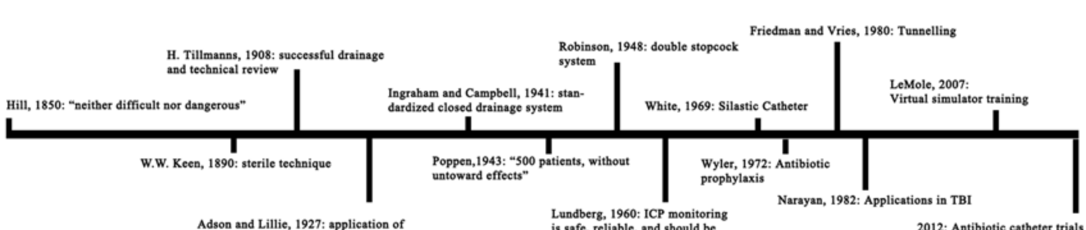

Fig. 7. A brief summary timeline of important milestones in the development and use of EVD. TBI = traumatic brain injury.

6. Bingham WF: W. W. Keen and the dawn of American neurosurgery. **J Neurosurg 64:**705–712, 1986
7. Brain Trauma Foundation: Recommendations for intracranial pressure monitoring technology. **J Neurotrauma 13:**685–692, 1996
8. Brunori A, Vagnozzi R, Giuffrè R: Antonio Pacchioni (1665-1726): early studies of the dura mater. **J Neurosurg 78:**515–518, 1993
9. Chan KH, Mann KS: Prolonged therapeutic external ventricular drainage: a prospective study. **Neurosurgery 23:**436–438, 1988
10. Crawford AS, Munslow RA: A method of prolonged ventricular drainage. **Ann Surg 117:**798, 1943
11. Dandy WE: An operative procedure for hydrocephalus. **Bull Johns Hopkins Hosp 33:**189–190, 1922
12. Dandy WE: Ventriculography following the injection of air into the cerebral ventricles. **Ann Surg 68:**5–11, 1918
13. Friedman WA, Vries JK: Percutaneous tunnel ventriculostomy. Summary of 100 procedures. **J Neurosurg 53:**662–665, 1980
14. Greenberg BM: Historical perspective, in Irani DN (ed): **Cerebrospinal Fluid in Clinical Practice.** Philadelphia: Saunders/Elsevier, 2009, pp 3–4
15. Greenberg MS: **Handbook of Neurosurgery, ed 7.** Tampa, FL: Greenberg Graphics, 2010
16. Haynes IS: I. Congenital internal hydrocephalus: its treatment by drainage of the cisterna magna into the cranial sinuses. **Ann Surg 57:**449–484, 1913
17. Hill BL: **Lectures on the American Eclectic System of Surgery, ed 2.** Cincinnati: Scudder and McCarthy, 1866
18. Huyette DR, Turnbow BJ, Kaufman C, Vaslow DF, Whiting BB, Oh MY: Accuracy of the freehand pass technique for ventriculostomy catheter placement: retrospective assessment using computed tomography scans. **J Neurosurg 108:**88–91, 2008
19. Ingraham FD, Alexander E Jr, Matson DD: Polyethylene, a new synthetic plastic for use in surgery; experimental applications in neurosurgery. **J Am Med Assoc 135:**82–87, 1947
20. Ingraham FD, Campbell JB: An apparatus for closed drainage of the ventricular system. **Ann Surg 114:**1096–1098, 1941
21. Kakarla UK, Kim LJ, Chang SW, Theodore N, Spetzler RF: Safety and accuracy of bedside external ventricular drain placement. **Neurosurgery 63 (1 Suppl 1):**ONS162–ONS167, 2008
22. Kaufmann GE, Clark K: Emergency frontal twist drill ventriculostomy. Technical note. **J Neurosurg 33:**226–227, 1970
23. Keen WW: Surgery of the lateral ventricles of the brain. **Lancet 136:**553–555, 1890
24. Keong N, Bulters D, Richards H, Farrington M, Sparrow O, Pickard J, et al: The SILVER (Silver-Impregnated Line Vs EVD Randomized) trial: a double-blind, prospective, randomized controlled trial of an intervention to reduce the rate of external ventricular drain infection. **Neurosurgery 71:**394–404, 2012
25. Kompanje EJ, Delwel EJ: The first description of a device for repeated external ventricular drainage in the treatment of congenital hydrocephalus, invented in 1744 by Claude-Nicolas Le Cat. **Pediatr Neurosurg 39:**10–13, 2003
26. Krombach G, Ganser A, Fricke C, Rohde V, Reinges M, Gilsbach J, et al: Virtual placement of frontal ventricular catheters using frameless neuronavigation: an "unbloody training" for young neurosurgeons. **Minim Invasive Neurosurg 43:**171–175, 2000
27. Kusske JA, Turner PT, Ojemann GA, Harris AB: Ventriculostomy for the treatment of acute hydrocephalus following subarachnoid hemorrhage. **J Neurosurg 38:**591–595, 1973
28. Lemole GM Jr, Banerjee PP, Luciano C, Neckrysh S, Charbel FT: Virtual reality in neurosurgical education: part-task ventriculostomy simulation with dynamic visual and haptic feedback. **Neurosurgery 61:**142–149, 2007
29. Lifshutz JI, Johnson WD: History of hydrocephalus and its treatments. **Neurosurg Focus 11(2):**E1, 2001
30. Lozier AP, Sciacca RR, Romagnoli MF, Connolly ES Jr: Ventriculostomy-related infections: a critical review of the literature. **Neurosurgery 51:**170–182, 2002
31. Lundberg N: Continuous recording and control of ventricular fluid pressure in neurosurgical practice. **Acta Psychiatr Scand Suppl 36:**1–193, 1960
32. Marshall LF, Smith RW, Shapiro HM: The outcome with aggressive treatment in severe head injuries. Part I: the significance of intracranial pressure monitoring. **J Neurosurg 50:**20–25, 1979
33. Matson DD: Franc Douglas Ingraham. **J Neurosurg 24:**945–948, 1966
34. McCarthy PJ, Patil S, Conrad SA, Scott LK: International and specialty trends in the use of prophylactic antibiotics to prevent infectious complications after insertion of external ventricular drainage devices. **Neurocrit Care 12:**220–224, 2010
35. Miller JD, Becker DP, Ward JD, Sullivan HG, Adams WE, Rosner MJ: Significance of intracranial hypertension in severe head injury. **J Neurosurg 47:**503–516, 1977
36. Narayan RK, Kishore PR, Becker DP, Ward JD, Enas GG, Greenberg RP, et al: Intracranial pressure: to monitor or not to monitor? A review of our experience with severe head injury. **J Neurosurg 56:**650–659, 1982
37. O'Leary ST, Kole MK, Hoover DA, Hysell SE, Thomas A, Shaffrey CI: Efficacy of the Ghajar Guide revisited: a prospective study. **J Neurosurg 92:**801–803, 2000
38. O'Neill BR, Velez DA, Braxton EE, Whiting D, Oh MY: A survey of ventriculostomy and intracranial pressure monitor placement practices. **Surg Neurol 70:**268–273, 2008
39. Pizzi FJ, Schut L, Berman W, Holzhapple W: Intracranial pressure monitoring in Reye's syndrome. **Childs Brain 2:**59–66, 1976
40. Pople I, Poon W, Assaker R, Mathieu D, Iantosca M, Wang E, et al: Comparison of infection rate with the use of antibiotic-impregnated vs standard extraventricular drainage devices: a prospective, randomized controlled trial. **Neurosurgery 71:** 6–13, 2012
41. Poppen JL: Ventricular drainage as a valuable procedure in neurosurgery: report of a satisfactory method. **Arch Neurol Psychiatry 50:**587–589, 1943
42. Rajshekhar V, Harbaugh RE: Results of routine ventriculostomy with external ventricular drainage for acute hydrocephalus following subarachnoid haemorrhage. **Acta Neurochir (Wien) 115:**8–14, 1992
43. Rengachary SS, Ellenbogen RG: **Principles of Neurosurgery, ed 2.** Edinburgh: Elsevier Mosby, 2005
44. Retzius MG, Key A: **Studien in der Anatomie des Nervensystems und des Bindegewebes.** Stockholm: Samson and Wallin, 1875
45. Robinson F: An apparatus for continuous ventricular drainage and intraventricular therapy. **J Neurosurg 5:**320–323, 1948
46. Rosegay H: The Krause operations. **J Neurosurg 76:**1032–1036, 1992
47. Saul TG, Ducker TB: Effect of intracranial pressure monitoring and aggressive treatment on mortality in severe head injury. **J Neurosurg 56:**498–503, 1982
48. Saunders RL: Intracranial pressure monitoring survey. **Neurosurgery 3:**130, 1978
49. Saunders RL, Lyons TA: External ventricular drainage. A technical note. **Crit Care Med 7:**556–558, 1979
50. Schültke E: Theodor Kocher's craniometer. **Neurosurgery 64:**1001–1005, 2009
51. Sekula RF, Cohen DB, Patek PM, Jannetta PJ, Oh MY: Epidemiology of ventriculostomy in the United States from 1997 to 2001. **Br J Neurosurg 22:**213–218, 2008
52. Selden NR, Origitano TC, Burchiel KJ, Getch CC, Anderson VC, McCartney S, et al: A national fundamentals curriculum for neurosurgery PGY1 residents: the 2010 Society of Neurological Surgeons boot camp courses. **Neurosurgery 70:**971–981, 2012

53. Shapiro HM, Wyte SR, Harris AB, Galindo A: Disposable system for intraventricular pressure measurement and CSF drainage. Technical note. **J Neurosurg 36:**798–801, 1972
54. Smith RW, Alksne JF: Infections complicating the use of external ventriculostomy. **J Neurosurg 44:**567–570, 1976
55. Sonabend AM, Korenfeld Y, Crisman C, Badjatia N, Mayer SA, Connolly ES Jr: Prevention of ventriculostomy-related infections with prophylactic antibiotics and antibiotic-coated external ventricular drains: a systematic review. **Neurosurgery 68:**996–1005, 2011
56. Stone JL: W. W. Keen: America's pioneer neurological surgeon. **Neurosurgery 17:**997–1010, 1985
57. Tillmanns H: Something about puncture of the brain. **BMJ 2:**983–984, 1908
58. Walker ML: History of ventriculostomy. **Neurosurg Clin N Am 12:**101–110, viii, 2001
59. White RJ, Dakters JG, Yashon D, Albin MS: Temporary control of cerebrospinal fluid volume and pressure by means of an externalized valve-drainage system. **J Neurosurg 30:**264–269, 1969
60. Whytt R: **Observations on Dropsy in the Brain.** Edinburgh: J. Balfour, 1768
61. Wilkins RH: Neurosurgical Classic—xvii. **J Neurosurg 21:** 240–244, 1964
62. Wyler AR, Kelly WA: Use of antibiotics with external ventriculostomies. **J Neurosurg 37:**185–187, 1972
63. Zabramski JM, Whiting D, Darouiche RO, Horner TG, Olson J, Robertson C, et al: Efficacy of antimicrobial-impregnated external ventricular drain catheters: a prospective, randomized, controlled trial. **J Neurosurg 98:**725–730, 2003

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