The early days of hemostasis in neurosurgery

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Two key discoveries in the 19th century—infection control and the development of general anesthesia—provided an impetus for the rapid advancement of surgery, especially within the field of neurosurgery. Yet the field of neurosurgery would not have existed in the modern sense without the development and advancement of techniques in hemostasis. Improvement in intraoperative hemostasis came more gradually but was no less important to enhancing neurosurgical outcomes. The history of hemostasis in neurosurgery is often overlooked. Herein, the authors briefly review the historical progression of hemostatic techniques since the beginning of the early modern era of neurosurgery.

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The popularization of general anesthesia and the discovery of the concept of antisepsis in the 19th century paved the way for rapid advancement in neurosurgery.25 William Morton’s (1819–1868) now famous demonstration of ether anesthesia in 1846 at the Massachusetts General Hospital, and Joseph Lister’s (1827–1912) later identification of microorganisms as causative of postoperative infection contributed greatly to improvement in neurosurgical outcomes; prior to this time, operations resulted in severe morbidity, and not infrequently were fatal.22,34 Although improvement in intraoperative hemostasis came more gradually, this was no less important to enhancing neurosurgical outcomes. Recognition of a need to stem unwanted bleeding, both above and beneath the cranium, and the consequent measures that grew to address this need allowed cautious attention to detail, surgical precision, and a greater meticulousness hitherto prevented by excessive blood losses, thereby enabling progress in the field.39 The history of hemostasis in neurosurgery is often overlooked. Herein, the authors briefly review the historical progression of hemostatic techniques since the beginning of the early modern era of neurosurgery.

Above the Skull

The Scalp

Neurosurgery in the late 19th and early 20th centuries was often stymied by a lack of effective methods of scalp hemostasis. The utility of pressure in promoting hemostasis was known to the early neurosurgeons, but applicators were crude. Various forms of tourniquets had been used intermittently until this time; beginning in 1875, Robert Weir (1838–1927) employed a rubber band, which William Keen (1837–1932) adopted in modified form as an Esmarch bandage in 1888.11,24 In 1904, Harvey Cushing (1869–1939) suggested the use of an inflatable tourniquet, a pressure cuff for the head not unlike the Riva-Rocci arm cuff; incidentally the arm cuff had also been introduced by Cushing himself for the purpose of blood pressure measurement, arguably his greatest contribution to perioperative care, inspired by Dr. Scipione Riva-Rocci’s (1863–1937) use of the sphygmomanometer in his research work in Italy.10,12 In 1908, Cushing discarded the apparatus in favor of a simpler rubber ring; a buckle at its back helped adjust the tension along its circumference, and a tape that ran from glabella to inion along the midline prevented its rolling down over the orbits.10,12 Although several modifications of the principle of rubber banding came into existence over the next several years, most disappeared almost as quickly as they surfaced because the challenge of resolving the tenuousness of superficial banding was not fundamentally overcome.

Hemostatic sutures to stem scalp bleeding were first reported by Lothar Heidenhain (1860–1940) in 1904; this was a variation of Emory Lanphear’s (1859–1920) earlier procedure described in 1895.17,20 Whereas Lanphear put in a continuous suture on the outer side of the incision,
Heidenhain placed overlapping loop sutures on both sides of the proposed incision. In both cases, the sutures were removed 10 days after the procedure. It must be noted that despite the official reported use of sutures for scalp hemostasis by Heidenhain, variants of the suture technique were popular and in use by surgeons as far back as the early 18th century; Lorenz Heister (1683–1758), for instance, popularized the interweaving scalp suture for hemostasis. Among neurosurgeons who preferred suturing to tourniquets or banding, most placed sutures across the base of the scalp flap, or across the base and then upward along the limbs of the incision. Most also preferred continuous suturing to interrupted sutures; inherent in the continuous stitch was the potential to extend the incision without disruption of the hemostatic procedure. At least one neurosurgeon from the early 20th century used curved metal plates in addition to the hemostatic sutures; long, tight, silk sutures around the plate and through the scalp compressed the plate against the scalp and helped to stem bleeding. Another prominent trick among early neurosurgeons was to ligate major scalp or neck vessels prior to cranial operations: Charles Frazier (1870–1936) also advocated exposure of the common carotid artery to permit its emergency occlusion in the event of excessive bleeding.

The role for manual pressure in hemostasis appears to have been rediscovered by Frazier in the early 20th century; in a 1906 report, he extols the benefits of gauze pads held down manually at the base of the flap and around the margins of the wound, possibly in combination with hemostatic clamps. This was endorsed in separate accounts by Cushing and others: firm digital compression along the limbs of the incision. It became Cushing’s practice to place hemostats along the cut edge of the galea aponeurotica while simultaneously applying pressure. The forceps would then be reflected over the scalp edge; allowing the instruments to hang ensured that the galeal edge folded sharply backward. The combined weight of the instruments and the pressure of the reflected and outfolded galea ensured occlusion of scalp bleeding. Cushing remarked that this technique had afforded him the luxury of bloodless incisions on several occasions; this technique appears to have been far superior to others of the time. Whatever chance there was of tears forming in the galea from this weight-induced hemostasis was vastly reduced with Anatole Kolodny’s (1893–1948) introduction of angular hemostatic forceps in 1927.

Although bunched hemostats served well the purpose of quelling profuse bleeding, they were often bulky and in the way when placed on the scalp flap. Subsequent attempts to reduce the bulk of these hemostats paved the way for the development of steel clips. Henry Soutar (1875–1964) described small steel clips applied with forceps to the scalp edge; later, in 1933, Alfred Adson (1887–1951) and Edgar Fincher (1900–1969) squeezed nonflexible German silver clips onto the scalp margin. A year later, in 1934, Percival Bailey (1892–1973) brought with him to the US the automatic Michel clip applier, an applicator that he fashioned as a modification from the instrument in use already by Clovis Vincent (1879–1947) in Paris. Eventually, in 1936, the spring scalp clips of Raney made their way into surgery, and many would say these have revolutionized our current conception of scalp hemostasis. Nonetheless, in several parts of the world, disposable clips often continue to be prohibitively expensive, and hemostats remain the hemostatic contraption of choice.

A landmark achievement in hemostasis came with Emil Mayer’s (1871–1938) report in 1901 on the clinical applications of vasoconstrictive agents. This became of neurosurgical relevance in 1909 when Heinrich Braun (1862–1934) described the hemostatic significance of procaine-epinephrine mixtures infiltrated into the scalp. It was his practice routinely to inject this mixture locally along the margins of the incision; especially when combined with other techniques developing concurrently and described above, the reductions in blood loss were marked. Braun also staunchly recommended reinfiltiration of the mixture along the edges of the scalp prior to the final closure of the galea aponeurotica. Since these humble beginnings, numerous drugs have been discovered and added to the armamentarium of local anesthesia, but the powerful underlying principle transformed the concept of hemostasis definitively.

The Bone

Deep to the scalp, neurosurgeons were faced with another challenge in hemostasis—bleeding from the bone. Despite the various techniques that existed to combat scalp hemorrhage, few effective means existed in comparison for bone bleeding. Most revolved around wood splints, cotton wool, and ivory and decalcified bone plugs that were used to stem bleeding from the diploë or emissary vessels. Agnew, in 1891, even suggested crushing the diploë concentrically. The most lasting contribution to bone hemostasis, however, came in 1888 when Sir Victor Horsley (1857–1916) introduced bone wax. This was a complex formulation fashioned from a combination of beeswax, almond oil, and salicylic acid; inherent in its recipe was the ability to model the wax, giving the material tenacity and plasticity. It was possible to sterilize the material and apply it as deemed necessary to bleeding surfaces of the cut cranium. News of this easily applied material spread quickly across the globe, and by the late 19th century all types of surgeons had subscribed to its tremendous benefit. It is befitting at this juncture to acknowledge reports that despite the attribution of the bone wax concept to Horsley, many neurosurgeons from across the world, particularly Russia, argue that the formulation was developed and introduced into neurosurgery as early as the 1850s by surgeons in Moscow, Russia; certain centers in Russia continue to prepare “bees wax” according to the original 19th-century formula.

Beneath the Cranium

Even beneath the cranium, bleeding from the brain and its associated structures posed a significant challenge in the early days of neurosurgery. Bleeding from the vasculature was especially problematic: the brain was heavily vascularized, and clamping larger vessels to stem bleeding carried the risk of hemorrhage from rupture of the vessel. Ligature of the vessel was similarly not feasible;
it was William Fluhrer (1847–1932) in 1885 who suggested cautery of the vasculature—the use of heat to arrest bleeding.\textsuperscript{15} Alexander Bennett (1848–1901) and Rickman Godlee (1849–1925) in 1884 described the use of galvanocautery; even earlier, John Roberts (1852–1924) in 1881 had used a needle heated to the “point of redness” to stem bleeding, but several saw this as unethical or immoral (Horsley being one prominent critic, calling the technique “barbaric”).\textsuperscript{4,36} Horsley’s own habit was to apply gentle pressure on a soft sponge; alternately he would use hot irrigating solutions to arrest hemorrhage from capillaries and smaller arteries.\textsuperscript{16} To maintain a constant state of minimal bleeding, he devised a practical solution in the form of a spray bottle that constantly emitted saline solution warmed to approximately 115°F. In light of Lister’s aseptic principle gaining popularity, some neurosurgeons preferred dry operating environments instead; Fedor Krause (1856–1937), for instance, advised a hot air blast over hot saline to control hemorrhage.\textsuperscript{27}

Despite the recognition that ligated vessels may be more likely to rupture, it was a fairly routine practice to ligate major vessels. Silk carried on curved needles was sutured around lesions in some instances, and in others sutures were deeply placed to stem the bleeding within the parenchyma “en masse.”\textsuperscript{38} In Cushing’s practice, he routinely employed two rows of split silk ligatures to surround the lesion, and would incise between these two rows.\textsuperscript{12} Cushing often combined the use of suturing with that of cotton pledgets, either dry or wet (soaked in hot saline), and applied with gentle pressure to the bleeding parenchyma. These would typically be applied through strips of iodoform gauze. As an interesting aside, Cushing can also be credited with the first methodical approach to preventing the loss of cotton rolls inside surgical incisions; it became his practice, described first in 1911, to mark cotton patties with black ligatures.\textsuperscript{39} The pledgets and rolls served the additional purpose of cleansing and also dissecting tissues.

As with scalp hemostasis, the age-old principle of pressure application was not forgotten in stemming hemorrhage beneath the cranium. In the early 20th century, neurosurgeons often packed the tumor bed and cystic cavity with iodoform gauze.\textsuperscript{39} Hermann Oppenheim (1858–1919) described tampon pressure in his first few cases; Lanphear advocated the most scrupulous antiseptic when the underlying brain was thought to be infected by the presence of a foreign body. This was recognized later; Lanphear advocated the most scrupulous antiseptic precautions with the packing, advising its total removal at a maximum of 48 hours after insertion.\textsuperscript{29} In a landmark paper of 1911, Cushing wrote strongly against foreign body tamponade; these included oxygen inhalation and the avoidance of vomiting: their public acceptance among members of the neurosurgical community was scattered at best.

In the same manuscript mentioned above, Cushing in 1911 noted that living tissue products had also been frequently used in subcranial hemostasis, not only on the North American continent but also in Europe, especially in Britain and in Germany, by Horsley and Emil Theodor Kocher (1841–1917), respectively. He had himself used muscle stamps or partially organized blood clots.\textsuperscript{39} Around the same time, Horsley in 1914 expounded the uses of muscle products in hemostasis in a lengthy description of his experimental and clinical experiences with the agents; these were in frequent use at the time.\textsuperscript{5,21} When homologous or heterologous muscle was not immediately available, Cargile membrane was another popular material. Derived from ox peritoneum, this was adopted into neurosurgery from the general surgeons who used it predominantly to prevent adhesions from forming after abdominal surgery. Charles Downman (1849–1914) in 1914 published his experience with pieces of fascia for hemostasis, and noted that their benefit was often at least comparable to that of muscle products.\textsuperscript{14}

Cushing’s documentation of hemostatic agents and techniques also included a suggestion in the publication from 1911 that fibrin from whipped blood may also be prepared and used for hemostasis.\textsuperscript{7} Cushing established a professional relationship with a chemist and a physiologist while at Harvard Medical School, who had extracted fibrin from animal and/or human sources, which Cushing had used in clinical trials with good effect.\textsuperscript{39} The chemist and the physiologist worked in the lab during the following years to master the complexities of the mechanism of blood clotting; this relationship resulted in the identification of means to prepare thrombin and its several absorbable carriers on a wide scale, enabling its clinical application. In 1943, Tracy Putnam (1894–1975) used thrombin and oxidized cellulose; currently marketed as Surgicel (Johnson and Johnson Wound Management), this product looked clothlike and allowed for the denaturation of blood proteins initiating hemostasis.\textsuperscript{30,35} In 1944, Franc Ingraham (1898–1965) and Orville Bailey (1909–1998) reported on fibrin foams as a carrier for thrombin.\textsuperscript{23,39} In 1945, Richard Light (1902–1994) and Hazel Prentice (1922–1995) described the efficiency of gelatin sponge as a carrier; the gelatin consisted of a purified pork or bovine skin, the surface of which caused activation of the intrinsic coagulation pathway.\textsuperscript{7,50,51} Yet its main effect was its ability to absorb much weight, facilitating a concentration of coagulation factors at the site of bleeding. Familiar gelatin sponges today are Gelfoam (Pharmacia and Upjohn), Surgifoam (Johnson and Johnson Wound Management), and Floseal (Baxter). All these biochemical products aided strikingly in the control of ooze and bleeding in poorly accessible areas and in delicate tissues, and remain indispensable to surgical procedures today, particularly in neurosurgery.\textsuperscript{7,39}

Along with thermal coagulation, the use of high-frequency electrical currents in arresting bleeding became adapted to neurosurgical hemostasis in the period between the two World Wars. Cushing, in perhaps his greatest contribution to hemostasis, brought an electrical instrument fashioned in collaboration with William Bovie (1881–1958) to neurosurgery, through an apparatus first used in brain surgery in 1926 on a vascular myeloma.
of the skull. The first generation of this device was far removed from the sleek, slim instruments we are accustomed to seeing in today’s operating rooms; rather it required an assistant to operate a switchboard in the room and was almost the size of a handgun. Yet its use heralded great advances in hemostasis, and Cushing astutely remarked that it foreshadowed “untold possibilities for the future of neurosurgery.” This device greatly decreased intraoperative blood losses, and vascular tissues that had previously been inaccessible for surgical logistical purposes now became more readily operable, ushering in a new era and a new pace for neurosurgery.

In the years since, the techniques of hemostasis have been refined and new means and methods introduced. The importance of posture and of suctioning equipment was realized, for instance, and appropriate changes to neurosurgical patient care were introduced. The historical efforts at hemostasis at the turn of the last century dramatically impacted the field of neurosurgery as we know it today, allowing great advances to be made in the indications for operation and in the outcomes achieved. A look at the past to remind ourselves of the progress made and to stimulate our own endeavors in improving the field of neurosurgery is worth the effort to avoid its being ignored; the importance of hemostasis in surgery is fundamental—it is a crucial necessity for meticulousness.

Conclusions

The evolution of hemostasis and perioperative care from the early days of neurosurgery to the modern day offers a fantastic perspective on the advances of medicine and patient-centered improvements in comfort and delivery of medical care. Although neurosurgical procedures have been performed since prehistoric times, the greatest advances in neurosurgical understanding and operative outcomes were achieved relatively recently, coincident with improvements in anesthetic care, antiseptic techniques, and hemostasis. The contribution of advances in hemostasis to the development of neurosurgery has been of paramount importance, radically altering the field as we know it today.

Disclosure

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

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