When asked about his greatest contribution to the development of neurosurgery as a viable subspecialty, Dr. Harvey Cushing would often joke, “Tell them that I closed the galea.” And for the decades hence, closure of the galea has remained a central dogma of postoperative craniotomy wound care. Not many would question the origin of the term galea aponeurotica beyond its definition as the “intermediate tendon connecting the frontalis and occipitalis muscles” prior to the time of Cushing, few recognized it as a separate layer. Proper identification of anatomical structures was key to the advancement of medicine, and more so in the practice of surgery. We propose to trace the etymology and historical significance of galea aponeurotica, graphically represented in Fig. 1.

**History**

*Galea in the Ancient World*

In ancient Greece, the term galea referred to a helmet worn by soldiers, typically made of animal hide or leather. The word simultaneously referred to a weasel or ferret, the animal from which the helmets were typically made. Throughout antiquity, physicians referred to all soft tissue between the skin and the skull as panniculus, a standard established by Galen of Pergamon. A manual of surgery in the Middle Ages referred to the entire scalp as a “great panicle that is called pericranium.” During the early Renaissance, Leonardo da Vinci famously and stylistically analogized the dissection of the cranium with the peeling of an onion. Not until 1724 would the tendinous sheath connecting the frontalis and occipitalis muscles be defined as “Galea tendinosa crani.” By 1741, the convention of referring to the galea as an aponeurosis was well established.

Harvey Cushing’s wartime experiences at Army Base Hospital No. 5 reinforced the surgical significance of the galea. Operative mortality was significantly diminished due to “closure of the wounds with buried sutures in the galea.” This operative nuance was then passed from teacher to pupil and has now become one of the tenets of modern neurosurgical practice.

**KEY WORDS**

- galea aponeurotica
- galea
- Galen
- Harvey Cushing
- history of neurosurgery
the calvaria, removing bone fragments with trephine and chisel, and packing the wound open with linen, silk, or marine sponge soaked in egg white, rosewater, or wormwood. The Hippocratic/Galenic theories of humorism relied on suppuration and pus formation for adequate healing and represented the standard of care for almost 1500 years.

**The Middle Ages**

Not until the late 12th century in Bologna would the premise of primary closure of the scalp be entertained. For a time, this method was explored and adopted by Hugo of Lucca and several of his students, including Theodoric and Henri de Mondeville, although the practice failed to extend beyond Henri. In 1363, Guy de Chauliac, the revered Master of Medicine and Surgery at Montpelier, published his seminal treatise on surgery, *Chirurgia Magna*, a text that was destined to be released in more than 100 editions over hundreds of years. In this work, he refers to the entire scalp as a “great panicle that is called pericranium,” making no distinction among its layers, and reverts to the recommendation of open packing of cranial wounds and the encouragement of “laudable pus.” This remained the practice well into the late 18th century.

The decree of Frederick II in 1224, ordering the study of “the anatomy of human bodies” as prerequisite for medical licensure in the kingdom of Naples, opened the door to unprecedented advancement in the understanding of human anatomy. The great medieval medical schools in Salerno, Modena, Bologna, Padua, Toulouse, and Montpelier produced many famous physician/anatomists over the next several hundred years, and with the accumulation of knowledge came the natural tendency to question the established doctrine of the day. Many early investigators, such as William of Saliceto and Mondino de Luzzi, struggled to explain their findings at autopsy in the context of Galenic theories of the day.

**The Renaissance**

Most famous among these was an artist/inventor from Florence by the name of Leonardo da Vinci. While many of his anatomical sketches are widely recognized today, it is interesting to note that Leonardo was not known as an anatomist in his time, even though he was compiling an anatomical treatise at the time of his death. Over 200 pages of material were left in the charge of his student, Francesco Melzi, with the express purpose of publication; however, this project was never completed.

In one of his earliest sketchbooks, posthumously titled the Codex Forster III, Leonardo combines his observation on the dissection of the human head with the esoteric writings of his predecessors (Fig. 2). In a more comprehensive study, he illustrates the successive layers of the cranium in both sagittal and axial sections, with stylistic reference to the layers of an onion, an analogy used by many of his predecessors, including Avicenna, Albertus Magnus, Mondino de Luzzi and Guy de Chauliac. (Fig. 3)

If you cut an onion through the middle you will be able to observe and count all the circular layers and cases which cover the centre of the onion. In the same way, if you wish to bisect a human head, you will first cut through the hair, then the skin, then the muscular flesh and the peri-cranium, then the skull, and inside that the dura mater and pia mater, and the brain, thereupon (i.e. at the base) again the pia and dura mater, and rete mirabile and the base, the bone.
Two references in this quote demonstrate Leonardo’s reliance on the principles of Galenic anatomical description and call into question his direct observations at the time of dissection. First, he continues to refer to the tissue between the skin and pericranium as muscular flesh (panniculus carnosus). Second, he mentions the rete mirabile, an anastomotic network of small vessels present at the skull base. Both of these structures have been identified in lower animals, but have later been proven absent in humans.

One of the first investigators to openly challenge the tenets of Galenic anatomy was a student of Mondino’s named Jacopo Berengario da Carpi. In 1522, he compiled his vast experiences in human dissection into his Isagogae breves [A Short Introduction to Anatomy], in which he was the first to call into question the existence of the rete mirabile in humans.

From these arteries [internal carotids], as the authors commonly say, above the bone immediately under the dura mater are formed many very thin branches marvelously united together one upon the other in the shape of a net occupying a large place in front, behind, and at the sides… Yet I have never seen this net… this net is not given in that place between the aura [sic] mater and the basilar bone.2

Most historians agree that the true renaissance in the study of human anatomy began in 1543 with the publication of De humani corporis fabrica [On the Structure of the Human Body], the seminal work of the Flemish anatomist Andreas Vesalius. In this work, he continued the spirit of Galenic skepticism established by Berengario; or, as Gabriel Fallopius later stated, “what Carpi had begun Vesalius perfected.” Vesalius concurred with the contention of the fabrication of the rete mirabile and, as for the panniculus carnosus, confirmed this layer’s absence in man, except for its remnant, the platysma. However, he continued to use the term panniculus to refer to the deep fascia of the head, including the temporal and occipital musculature of the scalp.
What's in a Name?

Although the true structure of the aponeurosis had finally been elucidated, its anatomical name remained ambiguous. The first person to give a unique name to the epicranial aponeurosis was a Venetian anatomist by the name of Giovanni Domenico Santorini. As Professor of Anatomy and Medicine from 1703 to 1728, he made many valuable observations on the muscles of the face, larynx, and penis. In his great work of 1724, Observationes anatomicae, he refers to the tendinous sheath connecting the frontalis and occipitalis muscles as the “Galea tendinosa cranii.” Santorini continued as a practicing physician and anatomist until his death in 1737, with many of his illustrations considered masterpieces of dissection. Many of these were compiled, 39 years after his death, into Anatomici summì septemdecim tabulæ. Anatomical texts written over the succeeding decades even referred to the aponeurosis as the Galea tendinea Santorini, in reverence to the man.

As was typical for the time, acceptance of Santorini’s terminology by contemporary anatomists of the day occurred slowly and irregularly. In the original (1713) edition of The Anatomy of the Humane Body, William Cheselden, a prominent British surgeon/anatomist makes no mention of the terms galea or aponeurosis. However, by the 1741 edition, he recognizes his previous omission.

Occipito-frontalis, is a muscle with four fleshy bellies, commonly named frontales and occipitales…. The tendon of this muscle has been mistaken for a membrane, and been called pericranium, and the true pericranium, periosteum.

However, in Paris, Jean-Louis Petit would refer to the same tissue in his Traité des Maladies Chirurgicales in 1774 as pericranium, an omission his editors would later correct in a footnote, referring to it as “la calotte aponeurotique.”

Although Cheselden had adopted the convention of referring to the galea as an aponeurosis, little had changed with regard to his surgical treatment of this layer, as an example from The Anatomy shows. He presents a case of a delayed repair of a depressed skull fracture in which he open’d the scalp, … and laid the scull [sic] bare about four inches one way, and three the other, and tied the blood-vessels, that I might make the operation without much difficulty soon after. … during a month, the matter ran through all her dressings down her face twice every day, and was exceedingly fetid, and for the space of three months the matter decreas’d very little in quantity, but grew less and less offensive.

Galea in the Modern Age

In 1894, Theodor Kocher, chair of Surgery at the University of Bern and eventual Nobel laureate, published his Chirurgische Operationslehre [Textbook of Operative Surgery], in which he may have been the first to advocate inclusion of the galea in his standard continuous suture line. In 1908, the technique of placing interrupted galeal sutures was briefly mentioned in the chapter on “Surgery of the Head” in William W. Keen’s Surgery: Its Principles and Practice. Then Associate Professor of Surgery, Harvey Cushing casually stated, “It is well to draw together the galea aponeurotica by a few buried sutures before closing the outer layer,” before de-voting the remainder of that paragraph to the discussion of everted subcutaneous sutures. His deeper appreciation for the value of galeal closure would require several more years of experience, including 2 years in allied France.

Dr. Cushing’s experiences at Army Base Hospital No. 5, a World War I casualty clearing station, would prove instrumental in this development. Following his service, Cushing published a consecutive series of 133 cases of wartime penetrating head injuries in which he lowered his operative mortality from 54.5% to 28.8%, an accomplishment he attributed to, among other factors, “closure of the wounds with buried sutures in the galea.” This was a practice that was not completely without prior attempt; however, Cushing was the first to systematically apply it.

It is the writer’s custom to bring the edges of the galea together by a layer of buried fine black silk sutures, so that the external sutures used to approximate the cutaneous edges may be safely removed on the second day. The heavy silkworm-gut sutures usually employed in a single layer, particularly if tied under tension, rapidly cut through and make an uncomfortable wound, an ugly scar, and encourage infection.

In 1915, Cushing published his civilian results with intracranial tumor resection and his operative mortality of 8.4%, representing an incredible advancement over the published 38%–50% rate of most of his contemporaries. He attributed his success to his “stringently sterile procedures, and to the closing of anatomical layers, particularly the galea.”

As has been well documented elsewhere, Cushing advanced the practice of neurosurgery not only through introduction of innovative ideas and techniques, but also by passing those innovations on to the legions of surgeons who would represent the next generation. In this way, primary closure of the galea was passed from teacher to pupil and has become one of the tenets of modern neurosurgical practice.

Conclusions

From Galen of Pergamon to Harvey Cushing at Army Base Hospital No. 5, we have traced a long and fascinating story of the history of the galea aponeurotica. Although now we accept the primary closure of the galea as a central tenet of operative neurosurgery, this small development has taken some of the greatest minds in medicine and surgery thousands of years to demonstrate.

Acknowledgment

We are grateful to Ms. Lindsey Hudson for her assistance with the preparation of the images for this manuscript.

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: Conceptualization and design: Connor, Chittiboina. Acquisition of data: Connor, Chittiboina. Analysis and interpretation of data: Connor. Drafting the article: Connor, Chittiboina. 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: Nanda. Study supervision: Nanda.
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This manuscript was presented at the 2012 Annual Meeting of the American Association of Neurological Surgeons and was awarded the First Place History ePoster award.

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