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Shedding light on the tympanic membrane, a brief history of the description and understanding of its anatomy

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STATEMENT

Authors' contribution:

Robin Baudouin MD: study design, writing, literature search, data collection

Françoise Denoyelle MD, PhD: study design, writing

François Simon MD: study design, writing

ABSTRACT

Objectives. For centuries, the tympanum has remained the only visible structure of the organ of hearing. The aim of this study was to trace the understanding of the tympanic membrane (TM) from Antiquity to the early 20th century.

Methods. We conducted a review of primary and secondary historical and scientific literature describing the TM anatomy.

Results. Although ancient polymaths sensed that sounds were vibrations that could spread in the air and be perceived by the hearing organ, numerous were the misconceptions about the tympanum until the Renaissance human dissections. The tympanum was correctly described only centuries later when technological advances enabled otologists to understand it as a fundamental part of the hearing organ.

Conclusions. The TM history reflects key stages in medical knowledge, limited for centuries, a great technological leap was possible in the 19th century contributing to the emergence of otologists and laying the foundations of modern otology.

Key-words: Tympanum, history, anatomy, Otorhinolaryngologic Diseases,

INTRODUCTION

The tympanic membrane (TM) or eardrum has been for centuries the only window through which to inspect the hearing organ. From early Antiquity and the polymaths' first descriptions, little progress was made until the great anatomists of the Renaissance. Major breakthroughs in the understanding of the TM anatomy later took place in the 19th century.

The objective of this paper was to trace the progress of the description of the TM from Antiquity to the early 20th century. We chose to focus on the key steps, to identify how underlying historical context (beliefs, misconceptions or technology) influenced the understanding of the TM anatomy.

METHODS

A search for scientific medical or historical literature was conducted using PubMed, Google Scholar and the *Bibliothèque Inter-Universitaire (BIU) Santé* catalogue of the medical faculty of the *Université de Paris*. Screening was performed using the following key-words: eardrum, tympanic membrane, tympanum, tympanoplasty, hearing theory, audition, otolaryngology history, Hippocrates, Aristotle, Galen, Avicenna, Vesalius, Fabricius, Fallopio, Shrapnell, Toynbee and Politzer. For primary sources, when a text was identified as pertinent, we used the Medica® digital library of the *BIU Santé* of the medical faculty of the *Université de Paris* to access and read the full text. If the text was not available, a manuscript was searched for over internet. For texts found in Latin, Greek, Arabic, French, Italian or German, official translations to English were used. Selected texts from primary sources and data from secondary articles were gathered and organized in a chronological order and then by connected theme.

RESULTS

From ancient polymaths to great Renaissance anatomists

In Antiquity, the tympanum was thought to be an interface between two worlds: the human being (outer) and the soul (inner) world. This concept remained entrenched for centuries (1).

It is uncertain that the Egyptians described the TM but they talked about ear diseases in medical treaties thousands of years before Hippocrates (2), although it is he who is generally credited with the first description, depicting a dry thin-spun web (3). Ancient Greeks

discussed the anatomy and function of the ear as philosophers, in their quest to understand the mystery of the senses. Hearing was a singular sense, likely to perceive the visible (human) as well as the invisible (the gods') worlds. Harmony was an audible gift the gods gave to humanity, to soothe the disturbances of the human soul (4).

Ancient Greeks understood that sounds were vibrations that could spread in the air and be perceived by the hearing organ. Empedocles (5th century BC) described the ear as a bell comprised of a "*fleshy twig*" (5) able to receive sounds and by its proper vibration, transmit them to an aerial cavity (the middle ear). TM perforation was thought to induce deafness as inner air could leak out: the TM had an incidental role, sealing off the inner ear like a lid on a pot. In their treatises, Aristotle and Galen described it as an interface (it was named *meninx* or *meninga* for membrane) and mentioned its vulnerability, however neither gave the TM (or the ossicles) a distinct anatomical terminology, failing to identify its crucial role in transmitting vibrations to the inner ear. The concept of vibration was understood, the organ was yet to be identified.

Throughout the Middle Age, the legacy of the *meninga* lived on. The great Persian physician Avicenna (10th – 11th century AD) bestowed on the TM a key role in his theory of audition but as a perceptive organ proceeding from the nervous system like the cranial nerves: "*And the ear hole leads to a pocket of stagnant air (the middle ear) and covered with a bundle of nerves (the ear drum)*" (6). By analogy, he compared the eardrum to the iris (7).

The first breakthrough occurred in 16th century Renaissance Italy with the development of human cadaveric dissections.

Gabriel Fallopius is often credited with the birth of the term "tympanum" in *De observationes anatomicae* (1562): "*tympanum (...) ego appelavi*" from the Greek *tumpanon* (drum) as an analogy to its function (8–10) However, Andreas Vesalius (1514-1546) coined it in his 1543 edition of *De humani corporis fabrica*. "*Quemadmodum in tympanis fidem*" said Vesalius describing the first ossicle (the malleus) anchored in the TM's width (11). In the 1543 edition of *De humani corporis fabrica*, Vesalius drew Figure 8, Book I figuring the hearing organ with the TM captioned as "*B: Membrane drawn across the foramen that leads from the ear into the cavity carved in the temporal bone for the organ of hearing*" (figure 1) (12).

The emulation, created by these newly lawful human dissections all taking place in a close geographic area, enabled rapid progress surpassing, in a few decades, centuries' worth of Ancient knowledge (mostly obtained from animal dissection). The understanding of the importance of percussion in the transmission of sound, from scant TM vibrations, transmitted to the ossicles and then to the oval window, arose simultaneously (13,14).

Duverney's *Traité des maladies de l'ouïe* (1683) (15) was the first otological treatise in a vernacular language and combined prior anatomical discoveries to his own observations. Duverney thoroughly detailed the TM (figure 2): "*This septum is an almost round membrane, dry, thin, firm, transparent and engaged in a groove carved in the circumference of the end of the bony duct (...). Although this membrane is stretched, it does not make a straight plane, but it is curved inside being pulled by the handle of the hammer*" (translation from French by the authors). Duverney called the TM "*tambour*" (drum) and correctly conveyed the concept of vibration and resonance. He did not make of the TM an extension of nervous tissue and correctly identified its epidermic nature. The TM still had a protective role but also a proper mechanical role amplifying and transmitting vibrations: the TM was the first component of the hearing machine. However, he was wrong when he wrote that the TM could be bent by the tensor tympani muscle to alter vibrations (its protective against acoustic trauma was unknown).

Indeed, as *in vivo* detailed TM observation was not possible at those times, cadaveric specimen study - subject to desiccation or to poorly controlled preservation procedures - could lead to erroneous observations. A famous example is the so-called Rivinus' foramen (16). Johannes Augustus Rivinus the Younger (1692–1723) reported in his book *De Auditus Vitiis* (1717) an observation his father Augustus Quirinus Rivinus the Older (1652–1723) made in a letter: "*I studied the organs of hearing by dissection. At length, in the year 1689, in the month of September, I found the opening that I had long sought, it was in the tympanic membrane itself (...) near the head of the malleus...*" (17). The controversy lasted almost three centuries and this foramen existence was widely accepted as plausible. However, the contemporary Antonio Maria Valsalva (1666–1723) - who had been informed of Rivinus' theory before his son published the letter in 1717 - thought it was an artifact brought about by the specimen conservation before *post mortem* examination and did not draw it in his book *De Aure Humana Tractatus* (1704) (figure 3) (18). In 1869, Adam Politzer (1835-1920) wrote: "*Above the short process, according to Bochdolek, is a short canal, the foramen of Rivini,*

which was formerly considered an artificial opening in the membrane. This foramen, however, does not appear to be constant” (19). It was not only the use of the first otoscopes but even more the use of microscopic otoscopy that allowed, in the second half of the 20th century (20), to confirm that Valsalva was right about Rivinus, father and son. Nowadays, any tympanic perforation is considered pathological: the first otologists, even the greatest, would not have unanimously thought so.

The 19th century and the birth of otology

A second surge in knowledge took place during the 19th century, following technological progress. Otologists such as Floriano Caldani, Joseph Toynbee, Henry Jones Shrapnell, Alexander Prussak and finally Adam Politzer were amongst the first to use self-lit endoscopes to examine the TM. While aurists previously had to examine ears with cones and lenses reflecting the sun rays, it was only in 1730, that Archibald Cleland (1700-1771), a Scottish physician in the British army, invented the first candle-lit otoscope to examine soldiers exposed to loud explosions (21). Later, the French military surgeon Jean-Pierre Bonnafont (1805-1891) invented the first lateral light source with an opening in the reflecting mirror allowing the direct examination of the TM (22). This invention was then improved with the Edison electric light filament.

In 1794, Floriano Caldani (1772-1836), anatomist from the famous University of Padua where Andreas Vesalius taught, published his *Osservazioni sulla membrana del timpano e nuove ricerche sulla elettricità animale lette nell' Accademia di Scienze Lettere ed Arti di Padova*. These two reports read in Academic session in 1790 and 1791 were the first to report the fibrous structure of the TM with two layers (“*due strati di fibre*”) of concentric and radial fibers (“*Uno degli strati è di circolari concentriche, l'altro di radiate*”). He rejected the nervous origin of Mondino, that still was taught in the early 19th century (p5) and insisted on the novelty of his observation having used a microscope (“*non ponno vedersi senza l'ajuto del microscopio*” p6) (23). Initiating the shift from Italy to northern Europe, the German anatomist Samuel Thomas Sömmerring (1755-1830) further described the TM with accurate illustrations in his atlas, *Abbildungen des menschlichen Hörorgans*, published in 1806 (figure 4) (24).

Shortly later, Henry Jones Shrapnell (1792-1834) published a detailed description of the TM in the *London Medical Gazette* (1832). Shrapnell identified the *pars flaccida* which “*occupies*

the anterior superior angle, and so much of the membrana tympani as is above the tubercle of the malleus, and the ligament in which it is hung” and still bears his name (figure 5) (25). He further described the fine three layered structure of the TM and reported that the *pars flaccida* microstructure was not composed of muscle fibers as contemporaries said (such as Sir Edward Homes) (25) but of a tangle of conjunctive fibers. For Shrapnell, the TM had elastic properties but no contraction capability.

Famous during his lifetime and considered as the father of British otology, Joseph Toynbee (1815-1866) (figure 3) was well known for his collection of over 2000 temporal bones, allowing him to identify numerous anatomical variations. In 1838 and 1839, he anonymously published letters in *The Lancet* challenging those he called quack aurists (26). His approach was based on methodical and accurate observation of his patients, crossed with meticulous specimen dissection, drawing for the first time pathology and treatment inferences from TM anatomy (27).

Toynbee described that the TM was constituted of five superimposed layers (from outside to inside: *“the epidermis, the dermoid layer, the radiate fibrous layer, the circular fibrous layer and the mucous layer, with its epithelium”*) and identified the cutaneous nature of the external layers: *“Between the epidermoid and radiating fibrous layers of the membrana tympani, there is a distinct and completed lamina of membrane which is continuous with the dermoid layer of the meatus”*. He understood and emphasized the impact of this observation: *“A knowledge of the existence of the membrane here described is of interest to the anatomist, who recognizes in it the secreting organ of the epidermoid layers of the membrana tympani; and to the surgeon, who by its presence is able to understand phenomena occurring in certain diseases of the ear which have been hitherto incomprehensible to him”*. He described retraction pocket phenomenon but was wrong in assigning it to an *“ulceration of the fibrous laminae”* he developed as: *“the (...) inflammation of the dermoid layer, which spreads first to the radiate fibrous and thence to the circular lamina. The laminae, being weakened by ulcerative process, fall inwards as far as the promontory, to which they often ultimately adhere, and, when an orifice has been thus produced, its margins are not unfrequently drawn into the shape of a funnel, whose inner part adheres to the tympanic walls”* (28). These observations led him to propose an ingenious way to restore hearing in TM perforations, using an Indian rubber disc which would be placed on the eardrum and was removable thanks to an attached silver wire (26).

In the late 19th century, progress would shift back to the European continent with Alexander Prussak and the great Adam Politzer (figure 6). Politzer (1835-1920) synthesized knowledges about the TM. He definitively described its normal shape: “*not stretched as a perfect plane upon the end of the external meatus, but (...) arched in such a manner that its concavity is presented outward, while its convexity is turned toward the inner wall of the tympanum...*”. Contrarily to Toynbee, he reduced to three the number of layers: “*a middle fibrous -the so-called lamina propria membranae tympani, an external dermoid and an internal mucous layer*” but acknowledged that the lamina propria had “*two separable laminae -an external radiate, and an internal circular*” (19).

However, although he progressed significantly in understanding Eustachian tube permeability and catarrh (29,30), he did not understand its link with the so-called cholesteatoma disease which has been coined by Johannes Müller (1801-1858) in 1838 and that he considered to be a “*glandular neoplasm of middle ear mucosa*” (31).

The famous Russian otologist Alexander Federovitch Prussak (1839–1897) who attended Politzer’s lessons in Vienna, pursued the anatomical study of the TM, giving his name to the “*triangular shaped free space*” in the outer part of the attic between Shrapnell’s membrane, the neck of malleus medially and the lateral process of malleus inferiorly (32,33). His work completed the microscopic anatomical understanding of the *pars flaccida*, and helped end the debate on the foramen of Rivinus.

Politzer was not only the first modern otologist, but also the first historian of otolaryngology: recognizing the decisive works of his predecessors (34) and helping to trace the progress in the understanding of the TM. He synthesized in detail the knowledge of the normal TM anatomy, now established, but especially the first pathological TM description, in publishing in 1865 the first otoscopy atlas: “*Die Beleuchtungsbilder des Trommelfells im gesunden und kranken Zustande*” (30,35) (Figure 7). Otolaryngology as a specialty was born with the TM.

CONCLUSION

From early Antiquity, when polymaths poetically portrayed the tympanic membrane as a gateway to other worlds, to the great anatomists of the Renaissance who identified the ear as parts of a complex mechanical object, the understanding of the eardrum remained limited for

centuries. A great technological leap was possible in the 19th century with new self-lit otoscopes contributing to the emergence of otologists, clinicians who would dedicate their life to the study of the ear. A reproducible scientific approach, crossing microscopic anatomical studies and patient care, progressively shed light on the TM in all its complexity. This provided better insight in TM physiology and pathology, paving the way for modern otology.

FIGURE

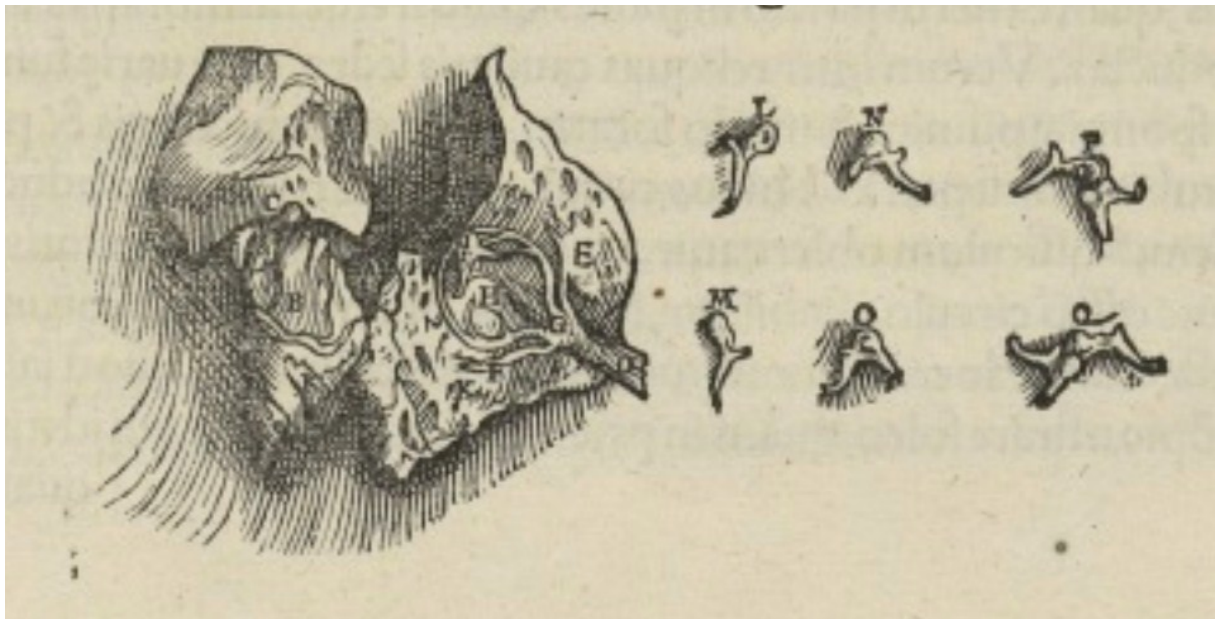


Figure 1. In the 1543 edition of *De humani corporis fabrica*, Vesalius drew Figure 8, Book I featuring the temporal bone and TM with the following caption “*B: Membrane drawn across the foramen that leads from the ear into the cavity carved in the temporal bone for the organ of hearing*”.

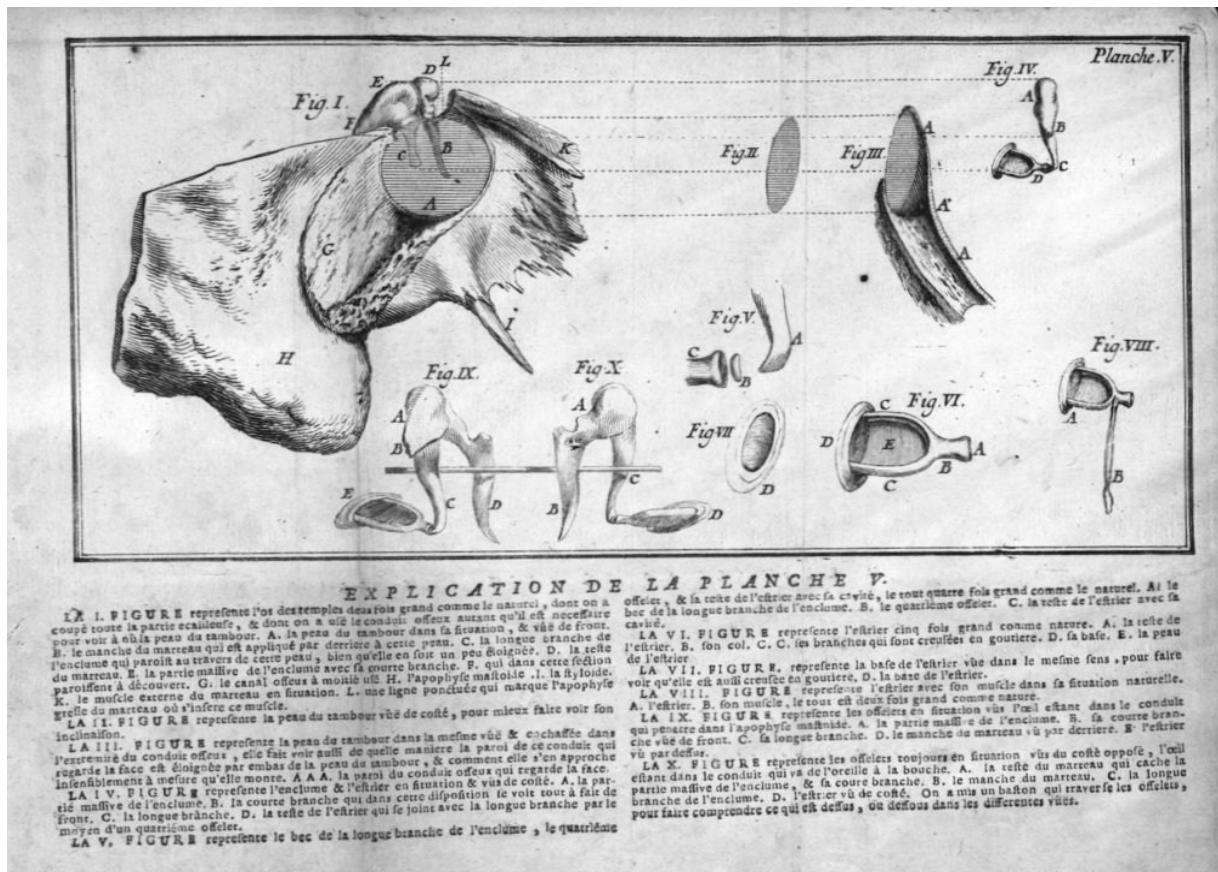


Figure 2. Duverney's *Traité des maladies de l'ouïe* (1683) was the first otological treaty in a vernacular language. Duverney thoroughly detailed the TM he called "tambour" (drum) and correctly conveyed the concept of vibration and resonance. Note that in Fig.V, the bone marked as B is mistakenly taken for a 4th ossicle (which is in fact the lenticular process of the incus). BIU Santé, Université de Paris.

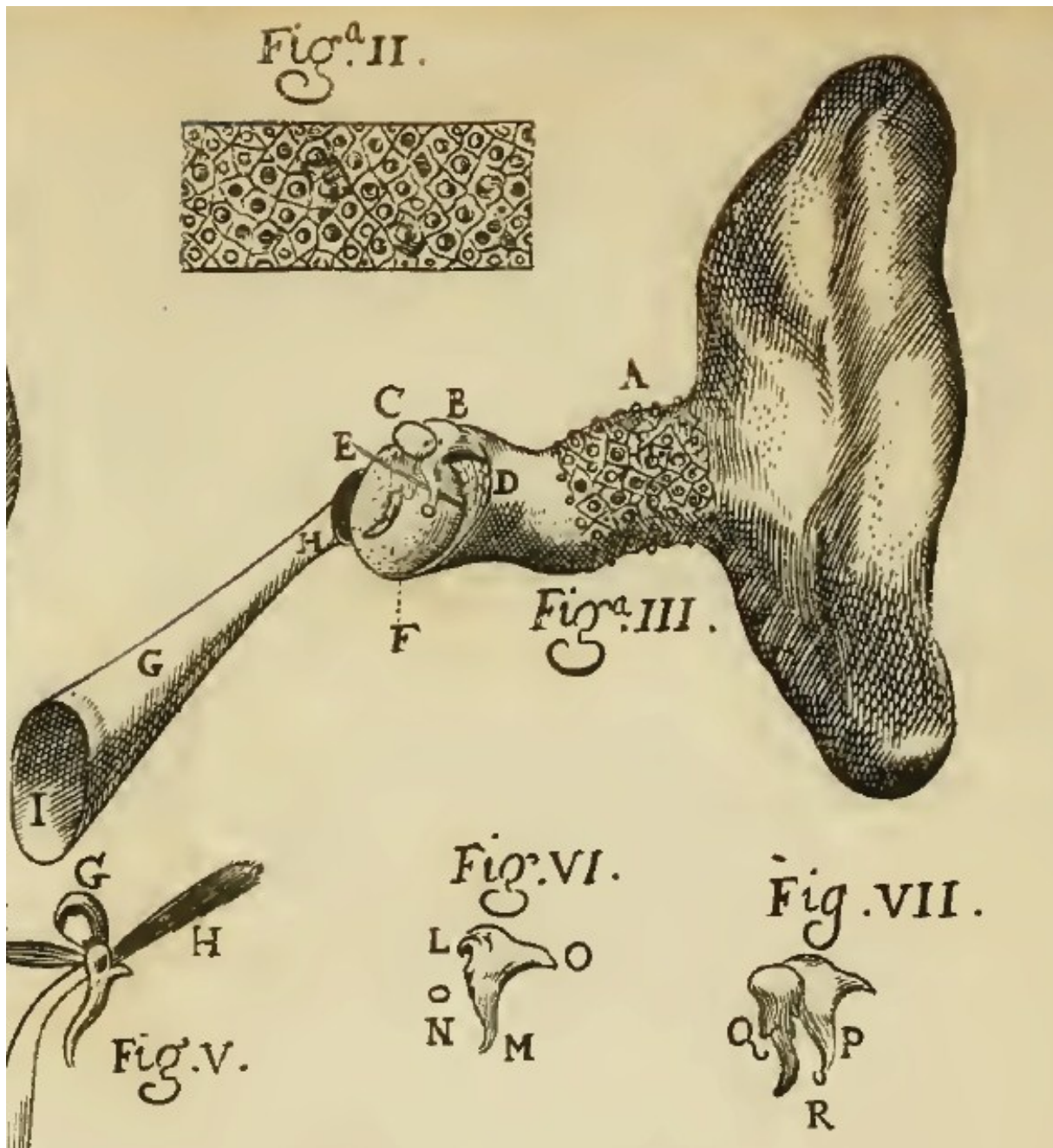


Figure 3. Antonio Maria Valsalva's *De Aure Humana Tractatus* (1704) table III. Valsalva was aware of the contemporary Rivinus' theory but thought it was an artifact brought about by the specimen conservation before *post mortem* examination and did not draw it in his book. A. *Glandulae meatus auditoria cum corpore suo reticulari*. B. *Incus*. C. *Malleus*. D. *Processus brevior incudes* (short process of the incus). E. *Chorda tympani*. F. *Membrana tympani*.

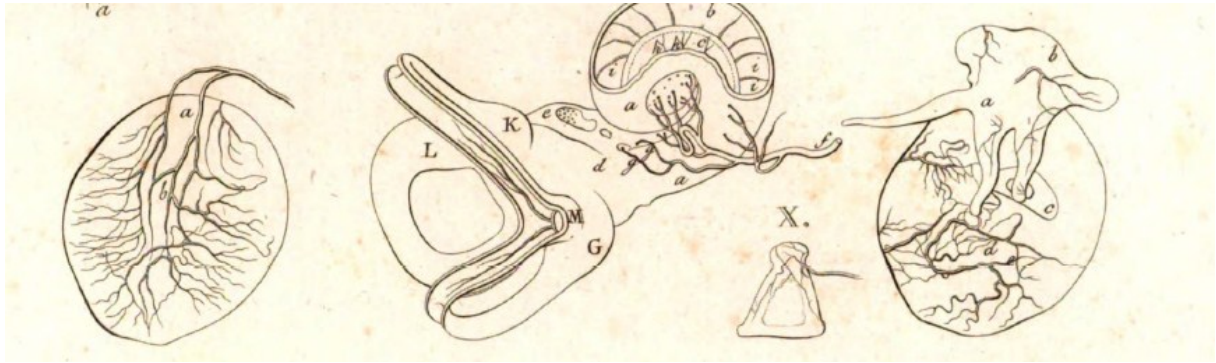


Figure 4. Samuel Thomas Soemmerring's *Abbildungen des menschlichen Hörorgans* (1806) table IV. He described the TM with accurate illustrations in his atlas in particular its vascularization. Note this illustration is one century later than Valsalva's *De Aure Humana Tractatus* (1704), with considerably more details.

Fig. 2.—Internal view of the *membrana tympani*, right ear.

- B, *Membrana flaccida* much developed.
 C, Dotted line, completing an oval figure.
 E, *Processus gracilis* entering the glenoid fissure.

Fig. 3, Cat; Fig. 4, Rabbit; Fig. 5, Dog;
 Fig. 6, Sheep; Fig. 7, Rat; Fig. 8, Ox;
 C, Appearance of muscular fibres in the meatus externus; Fig. 9, Profile of the internal surface of the *membrana tympani*; C, Manubrium; D, Head; E, Neck; F, Tubercle of the *os malleus*.

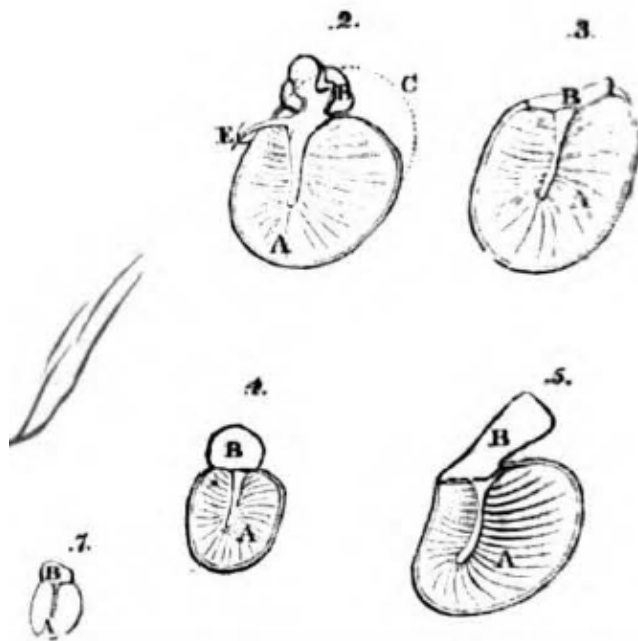


Figure 5. Mr. Shrapnell on the *membrana tympani* in the *London Medical Gazette* (1832). Shrapnell identified the *pars flaccida* which still bears his name.



Figure 6. Adam Politzer (1835-1920) photographed by Rudolf Krziwanek (1843-1905). He synthesized in detail the knowledge of the normal TM anatomy and the first pathological TM description, in publishing in 1865 the first otoscopy atlas. He is known to have also been one of the first historians of otolaryngology.

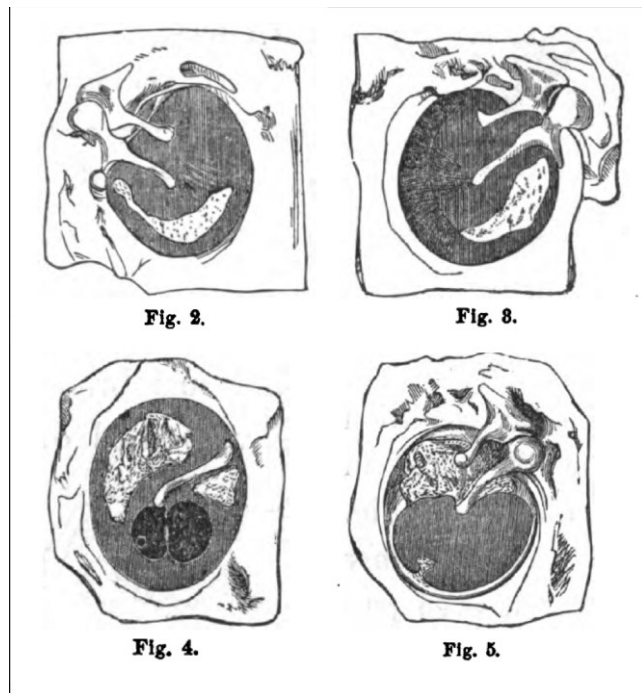


Figure 7. Adam Politzer's english book *The Membrana Tympani in Health and Disease* (1869), followed four years later his first otoscopy atlas: "*Die Beleuchtungsbilder des Trommelfells im gesunden und kranken Zustande*" (1865). At that time, otology was born as a specialty. Fig. 2: "*membrana tympani with crescentic chalky with deposit*". Fig. 3: "*calcareous deposit*" in the inner side of a 24-years girl's TM. Fig. 4 and Fig. 5: "*calcareous deposits*" and perforations.

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