# From catheterization to crenotherapy: historical and functional perspective on the Eustachian tube

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***Abstract***

The Eustachian tube has played a surprisingly central role in the development of modern otology. Although often overshadowed by the clinical study of the inner ear and tympanic cavity, it was the Eustachian tube and its treatment that led to the establishment of Otology as an independent medical discipline in the early 19th century. This article aims to retrace this evolution, beginning with the historical, anatomical, and physiological background of catheterization techniques, continuing with the functional anatomy of the peritubal muscles, and concluding with a discussion of the most common middle ear pathologies. It also highlights the modern rediscovery of thermal therapy as a potential ally in the management of Eustachian tube dysfunction.

**Key Words:** Eustachian tube, middle ear muscles, peritubal muscles, Eustachian tube catheterization, birth of otology.

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## A forgotten beginning: catheterization and the birth of otology

It is little known that the roots of otology lie not in surgery or hearing aids, but in a simple and elegant procedure: Eustachian tube catheterization.[1] Until the 17th century, the function of the Eustachian tube was widely misunderstood.[2] Aristotle believed that the air within the ear was "innate" and not in communication with the outside world, a belief that persisted for centuries; he had also identified the auditory tube, as a canal that connects the eardrum cavity with the palate, without however recognizing its function later discovered by Bartolomeo Eustachi in the 16th century.[3] However, he continued to support the concept of "innate air" and considered the tube merely as a pathway for draining pathological material from the tympanic cavity. It was only with Duverney's work in 1683 that its ventilatory role was hypothesized, with the idea that the Eustachian tube was constantly open. Valsalva, in the early 18th century, described a muscle responsible for opening the tube, paving the way for the famous Valsalva maneuver, still in use today.[4] Eustachian tube catheterization marked the first significant surgical advance in otology and arrived in the 18th century.[5] The procedure was first described in 1724 by Edmé Gilles Guyot, Postmaster General of Versailles, who presented it to the Royal Academy of Sciences in Paris. His method involved inserting a curved tube through the mouth to reach the Eustachian tube, where water could be injected. Later, British army surgeon Archibald Cleland (1700–1771) suggested inserting the catheter through the nose. The nasal catheterization technique was later championed by Antoine Petit in 1753 and Jonathan Wathen in 1755, both of whom credited themselves with its discovery. These procedures, initially cumbersome and not without discomfort, marked the first functional approach to ear pathology.[6] In 1836, Deleau emphasized the role of atmospheric air in middle ear function, highlighting the importance of the Eustachian tube for hearing. The term "otoscope" was coined by Joseph Toynbee in 1850 to describe a device used to auscultate the movement of air during insufflation. In 1862, John Brunton improved the device, adding magnification and standardizing its use. Finally, in 1863, Adam Politzer introduced a portable balloon for swallowing insufflation, allowing air to enter the middle ear without catheterization. This simplified and patient-friendly technique, known as Politzerization, quickly gained global recognition and marked a breakthrough in functional otology.

## The Eustachian tube: anatomy, function, and clinical relevance

The Eustachian tube plays a fundamental role in the physiology of the middle ear, not only ensuring the equalization of intra- and extra-tympanic pressure but also providing protection against middle ear infections.[7] It is known that in adults, the tube measures about 36 millimeters and is composed of two main segments: a bony part and a cartilaginous part.[8] The bony part, which represents about one-third of the total length, is proximal and connects directly to the middle ear cavity. The remaining two-thirds form the cartilaginous segment, which opens into the nasopharynx and is supported by a semi-rigid cartilaginous structure.

During growth, the Eustachian tube undergoes several anatomical and functional changes.[9] In children, the tube is considerably shorter, about 18 millimeters, and has a more horizontal orientation than in adults, forming an angle of about 10 degrees with the base of the skull. This horizontal orientation, combined with a narrower lumen and more flexible cartilage, facilitates the stagnation of secretions and the ascent of pathogenic bacteria from the nasopharynx into the middle ear.[10] Furthermore, in the pediatric population, the muscle structures responsible for opening the tube are not yet fully developed, limiting the effectiveness of the tube's opening mechanism. With growth and development, the tube lengthens, and its orientation becomes more oblique, forming an approximate angle of 45 degrees with the cranial base. Its lumen becomes wider, and the cartilaginous portion stiffens, which improves its ability to open by decreasing its tendency to collapse. At the same time, with physiological growth, the muscular apparatus of the tube also develops, enhancing its opening efficiency during physiological actions such as swallowing or yawning. These developmental differences explain the high incidence of otitis media in children compared to adults, since their anatomical and physiological characteristics predispose the environment to infections.

The function of the Eustachian tube is actively regulated by different muscles connected to the soft palate and the pharynx.[11] The most important of these is the tensor veli palatini muscle, which is directly responsible for opening the tube during acts such as swallowing or yawning. It is innervated by the mandibular branch of the trigeminal nerve (V3). It works in synergy with the levator veli palatini muscle, a muscle that elevates the soft palate and indirectly contributes to the tubal opening of its lower portion. Further muscle contributions are given by the salpingopharyngeus muscle, which is a small muscle bundle that originates from the cartilaginous portion of the Eustachian tube and is part of the lateral wall of the pharynx. Its main function is to raise the pharynx during swallowing and encourage the opening of the tube. The salpingostaphylinus muscle, which is considered by many an anatomical variant of the salpingopharyngeus muscle, also originates near the Eustachian tube, but is part of the soft palate. It participates in the movements of the palate and indirectly contributes to the opening of the tube, in synergy with the other muscles of the palate and the pharynx. The tensor veli palatini, salpingopharyngeus, and salpingostaphylinus muscles are innervated by the vagus nerve via the pharyngeal plexus.

Internally, the Eustachian tube is covered with a ciliated pseudostratified epithelium typical of the respiratory tract.[12] This lining contains different types of cells, including ciliated cells, goblet (caliciform) cells, which produce mucus, and basal cells, which act as stem cells responsible for epithelial renewal. The coordinated beating of the cilia pushes the mucus towards the nasopharynx, facilitating the clearance of debris, pathogens, and secretions from the tube. The mucus produced by the goblet cells forms a protective barrier that traps irritating agents and microorganisms, also providing immune protection through secretory immunoglobulin A (IgA) and other antimicrobial factors. Close to the middle ear, in the bony portion of the tube, the epithelial specialization decreases, with a lower density of ciliated cells. Through this sophisticated epithelial and muscular system, the Eustachian tube performs three fundamental physiological functions: it allows the ventilation of the middle ear, provides protection from nasopharyngeal secretions and pathogens, and supports the drainage of fluids from the middle ear to the nasopharynx.

When one of these three mechanisms is compromised, mucociliary clearance, muscle dysfunction, or epithelial inflammation, a condition of Eustachian tube dysfunction arises, which can lead to consequences for the middle ear such as discomfort, dampened hearing, or recurring infections. In such cases, the clinician, especially when facing recurrent symptoms, must pay close attention to the proper evaluation of the tube and its three physiological mechanisms.

## The stapedius muscle and the malleus muscle or tensor tympani

Equally relevant is the study of the functionality of the middle ear muscles. While stapedial reflexology has an indispensable role in standard audiological evaluation,[13,14] the study of the functionality of the tensor tympani muscle has not yet been included in a current evaluation. The tensor tympani muscle, innervated by the trigeminal nerve, contracts in response to loud sounds and during activities such as chewing or swallowing, tensing the tympanic membrane and providing acoustic protection. While the stapedius reflex is routinely assessed through acoustic reflex testing, functional evaluation of the tensor tympani remains challenging due to its anatomical position and the complexity of isolating its specific contribution to middle ear mechanics. Recent research suggests that tensor tympani dysfunction may contribute to certain forms of tinnitus and hyperacusis, particularly in cases where patients experience symptoms triggered by their own vocalizations or jaw movements. Unlike the stapedius muscle, which primarily responds to external acoustic stimuli, the tensor tympani appears more responsive to somatosensory inputs and voluntary muscle contractions, suggesting a complementary but distinct role in middle ear function and auditory processing.

## When the system fails: pathologies of the Eustachian tube

Eustachian Tube Dysfunction (ETD) can present in various forms, depending on the underlying mechanism.[15] The most common type is obstructive ETD, in which the tube fails to open properly. Patients typically report a sensation of ear fullness, hearing loss, or autophony. In contrast, patulous ETD refers to a condition where the Eustachian tube remains abnormally open. This leads to disturbing symptoms such as hearing one's own voice (autophony) or loud breathing, perceived internally. A mixed form of dysfunction can also occur, in which episodes of inappropriate tube opening alternate with obstructive features. A less commonly recognized but clinically important variant is epithelial dysfunction, where chronic inflammation of the tubal epithelium impairs mucociliary clearance, compromising the elimination of middle ear secretions.

The consequences of ETD can be substantial, and this becomes particularly relevant especially in children with cleft palate and in general in craniofacial malformations.[16] These include the development of otitis media with effusion, barotrauma in individuals exposed to pressure changes such as air travelers or divers, and even chronic otitis media in longstanding cases.[17] For this reason, a careful evaluation of the type and mechanism of ETD is essential in guiding appropriate management and preventing complications.

In 2015, the Cambridge group published a systematic review of the available tests for evaluating Eustachian tube function.[18] From this analysis, it became clear that no single test can currently be considered the gold standard. Optimal assessment of Eustachian tube function requires a combined approach that integrates symptoms, validated questionnaires, and instrumental tests.

These tests are generally divided into two main categories: objective evaluation of the tube's mechanical function and subjective assessment based on patient-reported symptoms. Among the instrumental tests, tympanometry is one of the most widely used because it is quick, non-invasive, and accessible. It measures tympanic membrane compliance in response to pressure changes, detecting signs such as negative pressure (type C curve) or middle ear effusion (flat curve). It has good sensitivity (81%) but limited specificity (67%), meaning it is effective at detecting pressure changes but does not reliably identify the underlying cause of dysfunction.[18] There is a great deal of literature data in this regard and the data obtained are considered a realistic assessment of the functionality of the middle ear; keep in mind that variations have been reported in women during the menstrual cycle.[19]

Valsalva and Toynbee maneuvers are frequently used in clinical practice to assess tubal patency using autocompression or swallowing techniques, often under otoscopic observation. The Valsalva maneuver involves forcibly exhaling with the nose and mouth closed, increasing nasopharyngeal pressure to open the tube. The Toynbee maneuver creates negative pressure while swallowing with the mouth and nostrils closed, allowing air to be drawn into the middle ear. These two are complementary: Valsalva assesses forced opening under pressure, while Toynbee evaluates passive opening during physiological actions. However, their diagnostic accuracy is modest: Valsalva has a sensitivity of 55% and specificity of 63%, highlighting the limitations of these tests when used in isolation, especially due to their variability and patient cooperation requirements.[20]

Sonotubometry is a non-invasive test that evaluates tubal function by detecting the transmission of a sound from the nasopharynx to the middle ear during swallowing.[21] If the tube opens correctly, the microphone registers a signal increase. This test is physiological, simple, and repeatable, but it has low sensitivity (43%) and high interindividual variability, limiting its use as a standalone tool.[18] It does not provide anatomical information but confirms the actual tube opening.

Tubomanometry objectively measures the tube's ability to transmit pressure during swallowing by injecting controlled air into the nasal cavity and recording the response in the ear canal.[22] It provides data on latency and quality of opening. With high specificity (94%) and moderate sensitivity (70%), it is especially useful in confirming suspected ETD, though it requires dedicated equipment and patient cooperation.[18]

Dynamic Slow-Motion Video Endoscopy (DSMVE) has also been described.[23] This advanced endoscopic examination allows real-time visualization of Eustachian tube movements and opening during swallowing. It has excellent specificity (100%) and moderate sensitivity (67%), making it particularly useful in complex cases involving musculo-cartilaginous dysfunctions.[18] However, it requires specialized equipment and training and is limited to expert centers. Its reproducibility is also challenged by observer dependence and a lack of standardization.

The overpressure test evaluates the Eustachian tube's ability to equalize middle ear pressure after the application of positive pressure. If the tube is patent, a measurable pressure change occurs during swallowing. It is simple and non-invasive but provides only indirect information and has limited sensitivity.

The inflation-deflation test is performed only in patients with tympanostomy tubes.[24] By introducing air to create positive or negative pressure in the middle ear, the test assesses whether pressure normalizes after swallowing. Though precise, it is invasive and used only in selected cases.

The PET test is used to diagnose patulous Eustachian tube, a condition where the tube remains abnormally open.[20] It involves continuous tympanometry to detect synchronized pressure fluctuations during breathing. It is highly specific but poorly sensitive, particularly in intermittent cases, and prone to artifacts.

Audiometry, while not a direct test of tubal function, helps detect the consequences of ETD, such as conductive hearing loss due to effusion or poor ventilation. However, it does not clarify the origin of the disorder and must be combined with other evaluations.

The ETDQ-7 (Eustachian Tube Dysfunction Questionnaire-7) is a validated, symptom-based questionnaire composed of 7 items.[25] It is low-cost, easy to administer, and useful for monitoring symptoms over time. It shows excellent sensitivity (100%) but relatively low specificity (67%), making it ideal as a screening or follow-up tool rather than for diagnostic confirmation.

Interestingly, combining multiple tests significantly improves diagnostic performance.[18] The combination of DSMVE + ETDQ-7 reaches a sensitivity of 87% and specificity of 89%, while tubomanometry + ETDQ-7 achieves sensitivity of 92% and specificity of 100%. The best-performing pair is tympanometry + ETDQ-7, with a sensitivity of 94% and specificity of 89%.

Diagnosing Eustachian tube dysfunction requires a multifactorial and integrated approach.[23] The combination of subjective tools (such as the ETDQ-7) and objective techniques (such as tubomanometry, DSMVE, and tympanometry) allows for optimal diagnostic accuracy and improved therapeutic management.

The assessment of Eustachian tube function is complex and requires a multimodal approach. Future research should aim to standardize diagnostic criteria and clinically validate innovative assessment tools.

### *Role of crenotherapy in modern otology*

Thermal water therapy, or crenotherapy, has its roots in an ancient tradition that combines medicine, religion, and symbolism. Hippocrates extolled its beneficial effects in the Corpus Hippocraticum, recognizing the role of water in the treatment and prevention of disease. Throughout the history of religions, water has always been linked to a symbol of purification and regeneration in many religious cultures and has been considered since ancient times a source of life, health, and well-being. In Christianity, water is an element of purification in baptism, a sign of rebirth and grace, but also an instrument of judgment, as in the Great Flood. This dual natural and spiritual significance has accompanied the therapeutic use of water throughout the centuries, uniting religious significance with healing. In ancient Rome, baths were not just places of hygiene but authentic therapeutic and social centers, where the use of warm mineral waters was applied to treat respiratory, skin, and rheumatic conditions. The great imperial baths reflected an advanced organization of public medicine. However, it was not until the 18th century that thermal therapy began to be based on scientific principles, thanks to the first chemical and physical analyses of water and the emergence of hydrological medicine. Today, crenotherapy is the subject of renewed interest, especially in the ENT field, as a complementary, non-pharmacological option for chronic upper respiratory tract conditions, including tubal dysfunction.[26]

Today Crenotherapy exploits the properties of mineral waters rich in sulfur, bromine, iodine, or bicarbonate.[27] These waters exhibit anti-inflammatory, mucolytic, trophic, and immunomodulatory properties, affecting mucociliary clearance, mucus viscosity, and local immune regulation.[28] The main administration methods include nasal douches, thermal aerosols, and tubal insufflations.[29] Nasal douches improve drainage and mucociliary clearance; aerosols reduce mucosal edema and inflammation; insufflations deliver thermal water directly into the Eustachian tube via nasal catheters under controlled pressure.

Several clinical studies have demonstrated a significant improvement in Eustachian tube patency and mucosal function following cycles of thermal insufflations.[30,31] A reduction in the incidence of recurrent otitis media with effusion in pediatric populations has been reported, along with improvements in quality of life among adults with chronic tubal dysfunction.[32,33] In elderly patients with chronic rhinosinusitis, enhancements in olfactory function have been observed, and other studies have shown increased IgA synthesis and decreased IgE levels, leading to improved mucociliary clearance.[34,35]

The most recent systematic review on the topic included 27 experimental and quasi-experimental studies involving over 3,000 patients with respiratory diseases.[36] The results confirmed that crenotherapy leads to a statistically significant improvement in nasal airflow, resistance, mucociliary transport times, and quality of life. It was found to be superior to simple saline irrigation and comparable to topical corticosteroids in selected patients.[37-39] The safety profile was excellent, with a low incidence of adverse effects and good treatment adherence, even in vulnerable populations such as children and the elderly.[36,40]

According to the Italian Ministry of Health, indications for thermal therapy in ENT settings include chronic rhinosinusitis, tubal dysfunction, chronic catarrhal otitis media, chronic pharyngolaryngitis, and simple chronic bronchitis, excluding the most advanced forms of COPD. In light of the most recent evidence, crenotherapy represents a modern, validated therapeutic strategy that is increasingly integrated into multidisciplinary clinical pathways for the management of chronic upper respiratory tract diseases.

Despite some limitations, such as the difficulty in standardizing treatment protocols or measuring long-term outcomes, the potential of crenotherapy is undeniable, especially when used as a complement to traditional ENT care.

## Conclusions

The history of otology is deeply intertwined with that of the Eustachian tube. Once regarded as an obscure anatomical curiosity, it has become, through the advancement of catheterization techniques and the study of muscular physiology, a central focus of medical innovation. Today, as we face an increasing burden of chronic diseases in the field of otolaryngology, the renewed interest in thermal therapies reminds us that the most effective solutions are often those rooted in tradition. With a more refined understanding of Eustachian tube anatomy and function, and by integrating modern diagnostic and therapeutic techniques with established treatments such as crenotherapy, we can offer patients not only safer care but also a sustained improvement in quality of life. These interventions have shown promise not only in managing acute symptoms but also in preventing their chronic recurrence, thereby reducing the long-term reliance on pharmacological therapy and the broader socioeconomic burden of upper airway diseases. Further prospective, randomized controlled studies are warranted to validate current findings, refine treatment protocols, and identify specific clinical indications and patient profiles most likely to benefit from crenotherapy. Standardization of methods and long-term outcome assessments will strengthen the integration of this therapeutic approach into multidisciplinary care pathways, paving the way for a more personalized, evidence-based, and sustainable model of ENT medicine.

## Conflict of interest

The authors declare no potential conflict of interest, and all authors confirm accuracy.

## Ethics approval and consent to participate

Not applicable.

## Availability of data and materials

All data generated or analyzed during this study are included in this published article.

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