CHAPTER ONE

Introduction

Knowledge of the structure and function of the Eustachian tube system is necessary to understand the pathogenesis of otitis media, which will result in rational management decisions.

Overview

The contents of this book have been divided into chapters that relate to the structure and function of the Eustachian tube system (ie, the nasal cavities, nasopharynx, palate, Eustachian tube, middle ear and mastoid gas cells), its role in the pathogenesis and management of otitis media, and certain related conditions.

Appropriately, the first section of this chapter provides a glossary of the terms used in this text. The following section relates the historical aspects of the topic, so the reader can appreciate the contributions that our illustrious predecessors made toward our current state of knowledge of the Eustachian tube.

Also presented is the contribution of factors other than the Eustachian tube in the etiology and pathogenesis of otitis media, such as infection owing to viruses and bacteria, the immunology of the host, the role of allergy, and social and environmental factors. This perspective is important at the outset so that the reader does not think that the only factor in the pathogenesis of otitis media is dysfunction of the Eustachian tube.

Chapter 2, “Epidemiology,” summarizes our current state of knowledge of the epidemiology and natural history of otitis media that relates to the Eustachian tube. The data presented emphasize

- The importance of otitis media as a major public health problem, which, in turn, stresses the need to understand the role played by the Eustachian tube in the pathogenesis of this disease
- The risk factors associated with otitis media that have been identified and that are related to the Eustachian tube in the pathogenesis of the disease, such as young age
- The impact of otitis media on our health care budget and at the personal level for patients and their families

Chapter 3, “Anatomy,”

- Demonstrates that the Eustachian tube is not a tube but an organ and stresses the importance of the tube as part of a system with the nasal cavity, palate, and pharynx at its proximal end and the middle ear and mastoid at its distal end (Figure 1–1)
- Describes the developmental anatomy of the tube in relation to its adjacent structures from the fetus to the adult
- Details the unique anatomic differences between the infant tube and that of the adult because these differences are thought to be associated with the increased incidence of otitis media in the infant and young child. Maturation of the tubal structure during the first 10 years of life is considered to be related to improvement in physiologic function.

Figure 1–1. The Eustachian tube as part of a system in which the pharynx, palate, and nasal cavities are at its proximal end and the middle ear and mastoid gas cells are at its distal end.
Chapter 4, “Physiology,” describes

- The physiologic functions of the tube related to the middle ear and mastoid gas (air) cell system: pressure regulation (ventilation), protection, and clearance
- The physiologic gas composition of the middle ear as related to the pressure regulation function of the Eustachian tube
- The developmental, as well as daily cyclical, positional, and seasonal, changes related to physiology
- The possible roles of the tympanic membrane, tensor tympani muscle, and mastoid gas cells in the physiology of the system
- The comparison of the Eustachian tube with the human larynx because the anatomy, physiology, and pathophysiology of the larynx have been the subject of intense investigation over the past century and are therefore better understood than these aspects of the Eustachian tube. Comparisons can be made between these two organs because they both develop from the airway and have similar functions, such as ventilation, protection, and clearance, and the failures of these functions are, to some degree, also comparable. Those who are more familiar with these aspects of the larynx will more readily understand the Eustachian tube with these analogies.

Chapter 5, “Pathophysiology,” includes

- The summation of pathophysiology: a dysfunctional Eustachian tube system is either too closed or too open or abnormal pressure is present at either end
- Information on how abnormal functions of the Eustachian tube structure and function and the middle ear and mastoid gas cell system can result in the disease state
- Presentations on the other pathophysiologic factors related to the Eustachian tube, such as differences in certain racial groups, inflammation owing to infection (viruses and bacteria) or allergy, craniofacial malformations (eg, cleft palate and Down syndrome), nasal obstruction, adenoids, tumor, trauma and surgery of the head and neck, and changes in barometric pressure
- The effect of pregnancy on Eustachian tube function, even though this state is physiologic because pregnant women can become symptomatic owing to alterations in Eustachian tube function

Chapter 6, “Pathogenesis,” describes

- The role of the Eustachian tube in otitis media and related conditions, which is based on experimental data in humans and animals, although some of the mechanisms remain speculative
- The part played by the tube in acute otitis media, persistent middle-ear effusion that follows an acute episode, otitis media with effusion, Eustachian tube dysfunction, atelectasis of the middle-ear cleft, and barotrauma

Chapter 7, “Pathology,” describes the pathologic changes that occur in the Eustachian tube, primarily owing to

- Inflammation
- Cleft palate
- The effects of a tumor

Chapter 8, “Diagnosis and Tests of Function,” presents the currently available clinical and laboratory diagnostic tests of function of the tube.

Chapter 9, “Role in Management of Otitis Media,” describes how the Eustachian tube affects the management of diseases and disorders. The chapter is divided into sections describing nonsurgical and surgical methods of treatment and prevention:

- The possible contribution of Eustachian tube dysfunction in the persistence of middle-ear effusion following an episode of acute otitis media, despite apparent sterilization of the bacterial infection by appropriate and adequate antimicrobial therapy
- The rationale for placement of tympanostomy tubes and explanation of why posttube otorrhea occurs and its management
- The value of understanding Eustachian tube function and tests of function in the decision-making process to remove the tubes
- A detailed description of a surgical procedure to close the middle-ear end of the patulous Eustachian tube

Chapter 10, “Role in Certain Complications and Sequelae of Otitis Media,” includes

- Management of the complications and sequelae of otitis media and Eustachian tube dysfunction in which the function of the tube is considered to be involved in pathogenesis and management decisions, such as atelectasis of the middle ear, retraction pockets, and acquired cholesteatoma
- The role of the Eustachian tube in the management of perforation of the tympanic membrane, as well as acute and chronic otorrhea, which can occur when the tympanic membrane is not intact
- A surgical method to permanently close the Eustachian tube when related to intractable otorrhea in the presence of a radical mastoidectomy
- Descriptions of the recommended surgical techniques to repair a perforation of the tympanic membrane (myringo-
plasty and tympanoplasty) when Eustachian tube dysfunction is still problematic, such as in children

• The part played by the function of the tube in medical and surgical treatment and prevention of retraction pockets and cholesteatoma

Chapter 11, “Future Directions,” is a chapter in which I identify the areas covered by the preceding chapters that are in need of future research, which, it is hoped, will improve the treatment and prevention of otitis media and its complications and sequelae.

Glossary of Terms

It is important to define the terms that are used in this text because some differences remain among health care professionals regarding the meanings of these terms. No organized professional body has agreed on the definitions used, but we have used them in our current texts on otitis media1–5 and to some extent at the International Symposia on Recent Advances in Otitis Media.6,7 The following are stages of otitis media and related conditions:

Otitis media is an inflammation of the middle ear, without reference to etiology or pathogenesis.

Acute otitis media is the rapid onset of signs and symptoms of acute infection in the middle ear.

Otitis media with effusion is an inflammation of the middle ear in which a collection of liquid is present in the middle-ear space and the tympanic membrane is intact.

Middle-ear effusion is the liquid resulting from otitis media. The effusion may be

• Serous—thin, watery liquid

• Mucoid—thick, viscous, mucus-like liquid

• Purulent—pus-like liquid

The effusion can be the result of either acute otitis media or otitis media with effusion.

Persistent middle-ear effusion is an effusion that persists in the middle ear after an episode of acute otitis media.

Eustachian tube dysfunction is an abnormal function of the Eustachian tube but does not imply the type of dysfunction. The type of dysfunction must be specified because there are several ways in which the tube functions abnormally; it can be obstructed or patulous.

Atelectasis of the tympanic membrane–middle ear is the collapse or retraction of the tympanic membrane. Negative middle-ear pressure may or may not be present. It may be generalized or localized, the latter usually being a retraction pocket.

Retraction pocket is a localized area of atelectasis of the tympanic membrane.

Otorrhea is a discharge from the ear that can emanate from the external auditory canal, middle ear, or mastoid.

Chronic suppurative otitis media is a stage of ear disease in which there is chronic inflammation of the middle ear and mastoid air cells and in which a nonintact tympanic membrane (perforation or tympanostomy tube) and otorrhea are present. Chronic otitis media is synonymous with chronic suppurative otitis media.

Cholesteatoma is keratinizing stratified squamous epithelium and an accumulation of desquamating epithelium of keratin within the middle ear or other pneumatized portions of the temporal bone. Chronic suppurative otitis media may or may not be present. Cholesteatoma that is associated with otitis media and related conditions is acquired as opposed to congenital.

The following are terms used in this monograph—and our other texts, chapters, and articles—that describe aspects of the physiology and pathophysiology of the Eustachian tube system and the pathogenesis of middle-ear diseases and disorders:

Eustachian tube is an organ consisting of a lumen with its mucosa, cartilage, surrounding soft tissue, peritubal muscles (tensor veli palatini, levator veli palatini, salpingopharyngeus, and tensor tympani), and its superior bony support, the sphenoid sulcus.

Eustachian tube system is contiguous organs, including the nose, palate, nasopharynx, Eustachian tube, middle ear, and mastoid gas cells (see Figure 1–1).

Auditory tube is synonymous with Eustachian tube.

Pharyngotympanic tube is synonymous with Eustachian tube. This is a new term proposed by the International Federation of Anatomists to replace Eustachian tube.

Pressure regulation is the physiologic function of the Eustachian tube to regulate pressure between the nasopharynx and the middle ear.

Ventilation is used synonymously with the physiologic function of pressure regulation, which is the more correct term for this function of the Eustachian tube.

Protection is the physiologic function of the Eustachian tube in which unwanted nasopharyngeal secretions and sound pressures are prevented from entering the middle ear by the unique structural and functional aspects of the tubal system.

Clearance is the physiologic function of the Eustachian tube in which liquid is drained toward the nasopharynx by the mucociliary system of the tubal lumen and the pumping action of the tube during passive closing.

Drainage is used synonymously with clearance, but clearance is the more precise term.

Prograde is the flow of liquid down the Eustachian tube and is synonymous with clearance or drainage.

Opening pressure is the pressure at which the Eustachian tube opens to applied positive pressure.

Forced opening pressure is used synonymously with opening pressure.

Closing pressure is the pressure remaining in the middle ear following forced opening.
Residual pressure is the pressure remaining in the middle ear following applied positive or negative pressure and after swallowing.

 Forced-response test is a test of Eustachian tube function in which the middle ear is inflated with a constant airflow rate until the tube is opened.

 Passive resistance is the resistance of the Eustachian tube to airflow when active opening (ie, dilation) of the tubal lumen is absent.

 Active resistance is the resistance of the Eustachian tube to airflow during active opening (ie, dilation) of the tubal lumen.

 Sonotubometry is a test of Eustachian tube opening during swallowing in which a sound generated within the nose and nasopharynx is recorded in the external auditory canal.

 Compliance is the quality of yielding to pressure or force without disruption. When related to the Eustachian tube as an organ, it is the distensibility of the walls of the lumen of the tube. The reciprocal of compliance is stiffness of the tube. We have used the expression floppy to describe increased compliance of the tube (decreased stiffness).

 Failure of the opening mechanism is used to describe the pathophysiologic condition in which the Eustachian tube does not actively open during swallowing activity owing to contraction of the tensor veli palatini muscle.

 Functional obstruction is due to failure of the opening mechanism of the Eustachian tube as opposed to anatomic (mechanical) obstruction.

 Anatomic obstruction refers to obstruction of the Eustachian tube, which can be either intraluminal, intramural, or extramural.

 Mechanical obstruction is used synonymously with anatomic obstruction.

 Intrinsic obstruction is synonymous with intraluminal or intramural anatomic obstruction of the Eustachian tube.

 Extrinsic obstruction is synonymous with extramural anatomic obstruction of the Eustachian tube.

 Patulous Eustachian tube is a tube in which the lumen is too open, usually at rest, when the normal tubal lumen should be collapsed.

 Semipatulous Eustachian tube is open at intervals at rest or is almost patulous but has abnormally low opening pressures.

 Valsalva’s maneuver is a test of the patency of the Eustachian tube in which positive pressure is applied to the nasopharyngeal end of the tube by a forced expiration with the nose closed (autoinflation), which normally should result in positive middle-ear pressure.

 Valsalva’s test is a test of the patency of the Eustachian tube that normally should result in positive middle-ear pressure.

 Politzer’s test is similar to Valsalva’s maneuver, but a bag filled with air is used to apply positive pressure to the nose and nasopharynx.

 Politzerization is the method of Politzer to inflate the Eustachian tube and middle ear either for testing tubal function or for treatment of middle-ear diseases and disorders.

 Toynbee maneuver is swallowing with both nares held closed by the thumb and forefinger.

 Toynbee test is used to assess Eustachian tube function in which the subject swallows with the nose obstructed and the pressures in the middle ear are evaluated following the test.

 Toynbee phenomenon describes the effect on the Eustachian tube system when there is nasal or postnasal obstruction and swallowing occurs.

 Aspiration is the indrawing of fluid (gas or liquid) from the nasopharynx into the Eustachian tube–middle ear owing to negative middle-ear pressure.

 Insufflation is the forcing of fluid (ie, gas or liquid) into the Eustachian tube–middle ear by the application of positive pressure in the nasopharynx.

 Reflux is backward flow that, in the context of the pathophysiology of the Eustachian tube, is abnormal flow of liquid (secretions) from the nasopharynx through the tube into the middle ear.

 Retrograde is abnormal flow of liquid backward into the Eustachian tube–middle ear and is synonymous with reflux.

 Reflux otitis media refers to otitis media caused by reflux of nasopharyngeal secretions through the Eustachian tube into the middle ear.

 Historical Perspective

 We stand on the shoulders of those who came before us.

 —Sir Joseph Lister’s (1827–1912) acknowledgment of the contributions of Ignaz Philipp Semmelweis (1818–1865) toward our understanding of infection

 Many historical figures have made invaluable contributions to our understanding of the Eustachian tube. The most notable were Eustachius, Valsalva, Toynbee, Politzer, Rich, Perlman, and Ingelstedt (see the “Encomium”).

 During the approximately 2,400 years since Alcmaeon of Sparta first mentioned the tube, which was later definitively described by Bartolomeus Eustachius as the auditory tube and which now bears his name, much has been written on its anatomy, function, and dysfunction. Alcmaeon thought that the tube that connected the nasal airway and the ear enabled goats to breathe through their ears and through their noses. The existence of the tube from the nasopharynx to the middle ear was vaguely known to the ancients, such as Aristotle, Celsus, and even Vesalius, during the Renaissance, but Alcmaeon and other contemporaries of Eustachius paid little attention to it.
The “Discoverers”: Eustachius, Valsalva, Toynbee, and Politzer

Bartolomeus Eustachius

Bartolomeus Eustachius was born somewhere in Italy circa 1510 and died in 1574; there is no agreement on his date or place of birth (Figure 1–2). He was relatively unrecognized in his time because his fine collection of anatomic plates completed in 1552 remained unprinted and forgotten in the Vatican library until discovered in the early 1700s and presented by Pope Clement XI to his physician, Giovanni Maria Lancisi, who later published them. Eustachius not only discovered the tube, he also described the cochlea, pharyngeal musculature, optic nerves, thoracic duct, adrenal glands, and abducens nerve and gave the first accurate description of the uterus. Many think that he would have been as recognized for his achievements in describing the anatomy of the human body as Andreas Vesalius, who is considered the pioneer in the science of anatomy, if his works had been known during his day. Eustachius was a contemporary of Vesalius but an outspoken critic of some of his discoveries and theories related to the ear.8

Eustachius published the first detailed description of the auditory (Eustachian) tube in 1562 in his thesis Epistola de auditus organis.9 He wrote:

From the cavity of the petrous bone, there in which the auditory passage called concha such a passage toward the nasal cavity is perforated. Others would perhaps think that this passage, about which this dissertation is being written, ends in that place; this is not so, however, for it is augmented by a substance of different nature and is carried on between two muscles of the pharynx and it ends in either cavity of the nose near the internal part of the root of the apophysis of the bone that is shaped like the wings of the bat, and is inserted in a thick revestment of the palate near the root of the uvula. Its substance, where it touches the extremity of the fissure which is common to the temporal and wedge-shaped bones, is cartilaginous, and quite thick; but the substance of the opposite part is not exactly cartilaginous, but is somewhat membranous and becomes thinner gradually; but the internal end of the passage facing the middle of the nasal cavity has a strong cartilage which is very thick and is covered by the mucous membranes of the nares, and is seen at the end of the same meatus as if it were a guardian. It is not round, but is somewhat depressed and makes two angles. It is as large as a writing cane, but is twice as large at the end as at the beginning, which is equally invested by a mucous membrane, which is, however, thinner.9

According to Politzer, Eustachius compared the tube to a writing pen and wrote:

It originates at the anterior course of the base of the skull, and takes an anterior course toward the pterygoid process of the sphenoid bone. It consists of two parts: the first solidly connected with the temporal bone, close to the tympanic cavity; the second soft, partly ligamentous, partly cartilaginous, directed toward the nasopharynx. Cross sections of the tube are not perfectly round and the inner part is twice as wide as the outer. Also, the inner part adjacent to the nasopharynx is lined with mucous membrane and seems to possess a sphincter at its end. The mucous lining is continuous with the nasal mucosa.8

Eustachius described not only the anatomy of the tube but also the physiologic and therapeutic importance of this discovery. However, it was not until the eighteenth century that his discovery of the structure and function of the tube became appreciated.

Antonio Maria Valsalva

A century later, Antonio Maria Valsalva (1666–1723) (Figure 1–3) was born in Imola, Italy. He became notable for his description of the aortic “sinus of Valsalva,” but he is even more famous for his Treatise on the Human Ear. His description of the Eustachian tube is classic, in which he detailed the cartilaginous, membranous, and osseous parts of the tube (Figures 1–4 and 1–5). He discovered and named the dilator tubae of the tensor veli palatini muscle and made note of the insertion of some fibers of the tensor tympani into the membranous portion of the tube (see Chapter 3). He recorded his thoughts on the acoustic functions of the Eustachian tube and supported the
concept of drainage of purulent material from the middle ear. His observations on the function of the Eustachian tube resulted in Valsalva’s maneuver, which he used in clinical practice and which has persisted to this day. In addition to treatment of middle-ear effusion and negative pressure, the maneuver is used as an inflation test for the patency of the Eustachian tube (see the Glossary of Terms). Most likely, the maneuver was described much earlier, such as by Arab physicians of the eleventh century and some of the early Italian anatomists.

Joseph Toynbee

During the nineteenth century, otologists continued the work of Eustachius. Joseph Toynbee (1815–1866) was an early English clinician who published a textbook on otologic diseases. He was a pioneer in the field of aural pathology and described a method for removing temporal bones from cadavers; he performed over 2,000 dissections of the ear. Among his contributions, he studied the muscles that open the Eustachian tube. He is credited with the eponymous test, the Toynbee test (see

FIGURE 1–3. Antonio Maria Valsalva (1666–1723).

FIGURE 1–4. Valsalva’s drawings of the external and middle ear and Eustachian tube with the tensor veli palatini muscle. Reproduced with permission from Canalis RF.

FIGURE 1–5. Valsalva’s drawings of the right and left external, middle, and inner ears, including the Eustachian tubes and the tensor veli palatini muscle. Reproduced with permission from Canalis RF.
The most famous otologist of the nineteenth century was Adam Politzer (1835–1920) (Figure 1–6), who is universally acknowledged as the father of modern otology.\textsuperscript{13} Politzer will be remembered for, among other important contributions, his method of inflating the Eustachian tube–middle ear for treatment of middle-ear diseases (see the Glossary of Terms).\textsuperscript{14} Related to the role of the Eustachian tube in the pathogenesis of middle-ear effusion, his hydrops ex vacuo theory is still considered to be a valid explanation. He wrote: “It is beyond doubt that sometimes in excessive swelling of the tubal mucous membrane and impermeability of the Eustachian tube there occurs in consequence of the consecutive rarefaction of the air in the tympanum, a transudation of serous fluid” (see Chapter 6).\textsuperscript{15} His method of politzerization was recommended to restore middle-ear pressure (see Chapter 9).

Not only was this Viennese clinician a pioneer in otology, but Professor Politzer was also a scholar who could speak many languages. Related to the Eustachian tube, he translated ancient Egyptian writings that may have been some of the earliest descriptions of the auditory tube. In one such text, the following was stated: “Man has two vessel-strands leading to the right ear, filled with Pneuma, ‘breath of life’; two similar strands leading to the left ear conduct the ‘breath of death.’”\textsuperscript{16} However, Politzer made no conclusion from these passages that the Egyptians preceded Eustachius in describing the auditory tube.

Adam Politzer remains a giant among clinicians and investigators who have helped us understand the role that the Eustachian tube plays in middle-ear disease.

The “Pioneers”: Rich and Perlman

Arnold Rice Rich

During the first half of the twentieth century, Arnold Rice Rich, a professor of pathology at Johns Hopkins Medical School, distinguished himself by performing elegant physiologic experiments in which he assessed the function of the muscles of the Eustachian tube and surrounding structures, such as the tensor veli palatini, tensor tympani, levator veli palatini, and salpingopharyngeus.\textsuperscript{16} He was the first investigator to attribute the sole active dilator function of the Eustachian tube to contraction of the tensor veli palatini muscle. Although contested for over 60 years, his conclusions concerning the tensor veli palatini muscle have been confirmed in our laboratory\textsuperscript{17} and in Japan (see Chapter 3).\textsuperscript{18}

Henry B. Perlman

In the midportion of the twentieth century, Henry B. Perlman, a professor of otolaryngology at the University of Chicago, made notable contributions to the understanding of the patulous Eustachian tube, which could be caused by denervation of the tensor veli palatini muscle.\textsuperscript{19,20}

Other Etiologic and Pathogenic Factors in the Pathogenesis of Otitis Media and Related Conditions

The etiology and pathogenesis of otitis media are multifactorial, which includes factors other than the Eustachian tube system, such as infection (usually viral and bacterial), immunologic status, environment, and even social and environmental factors (Figure 1–7). Probably the most important factor related to the increased incidence of otitis media in infants and young children is that they not only have a Eustachian tube that is functionally and structurally immature, they also have an immune system that is immature. When they are exposed to upper respiratory tract infections, otitis media is a common complication (see Chapter 6).

The pathogenesis of acute otitis media is likely to occur with the following pattern in most individuals, especially children: the patient has an antecedent event (owing to infection or
possibly allergy) that results in congestion of the respiratory mucosa of the upper respiratory tract, including the nasopharynx and Eustachian tube. Congestion of the mucosa in the Eustachian tube results in obstruction of the narrowest portion of the tube, the isthmus, and negative middle-ear pressure develops. If prolonged, it is followed by aspiration of pathogens (viruses and bacteria) from the nasopharynx into the middle ear. Because the Eustachian tube is obstructed, drainage and clearance of the middle-ear effusion, owing to the infection, accumulate in the middle ear. Microbial pathogens proliferate in the secretions, resulting in a supplicative and symptomatic otitis media.

The acute onset of otitis media with effusion, although relatively asymptomatic in most children and adults, most likely has a similar sequence of events, but prolonged negative pressure in the middle ear can cause a sterile middle-ear effusion. For children with recurrent episodes of acute otitis media or otitis media with effusion, anatomic or physiologic abnormalities of the Eustachian tube appear to be an important, if not the most important, factor. The patient with such an underlying abnormality of the Eustachian tube may be subject to recurrent episodes of otitis media or persistent fluid in the middle ear.

Abnormal function of the Eustachian tube appears to be the most important factor in the pathogenesis of middle-ear disease. This hypothesis was first suggested more than 100 years ago by Politzer. However, later studies suggested that otitis media was a disease primarily of the middle-ear mucous membrane and was caused by infection or allergic reactions in this tissue rather than by dysfunction of the Eustachian tube. Related to this hypothesis is the concept that nasopharyngeal infection spreads up the Eustachian tube.

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In conclusion, even though factors other than Eustachian tube dysfunction may cause middle-ear disease, abnormality of the tube is the most common because many of the factors listed above can adversely affect the Eustachian tube.