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INTEGRATED STUDY MASTER'S THESIS

Eustachian Tube Dysfunction: Pathophysiology, Diagnostics and Treatment Modalities. A Literature Review

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Abbreviations

ET - Eustachian tube

ETD - Eustachian tube dysfunction

OETD - Obstructive Eustachian tube dysfunction

PETD - Patulous Eustachian tube dysfunction

BCETD - Baro-challenge-induced Eustachian tube dysfunction

ETDQ-7 - Eustachian Tube Dysfunction Questionnaire-7

mTVP - Tensor veli palatini muscle

mLVP - Levator veli palatini muscle

ME - Middle ear

TM - Tympanic membrane

OM - Otitis media

MEp - Middle ear pressure

AR - Allergic rhinitis

BDET- Balloon dilation of the eustachian tube

TTAG - Tubo-tympano-aerodynamic-graphy

TMM - Tubomanometry

DSVE - Dynamic slow-motion video endoscopy

INCS - Intranasal corticosteroids

MWA - Microwave ablation

PETR - Patulous Eustachian tube reconstruction

Abstract

Objective: Eustachian tube dysfunction is problematic to diagnose and this otologic problem burdens many patients yearly. Finding the correct diagnosis for Eustachian tube dysfunction is later essential for the selection of the treatment. The aim of this literature review is to show diagnostics difficulties and find a proper treatment methods according to the different Eustachian tube dysfunction subtypes.

Methods: Recent articles are gathered from existing literature regarding Eustachian tube dysfunction pathophysiology, diagnostics and treatment modalities.

Results: Eustachian tube dysfunction is usually divided into three most common subtypes. These include obstructive type, patulous type and baro-challenge-induced type. A diagnostic pathway with multiple objective tools helps to differentiate between the types. Surgical treatment currently overrides medical management, but if combined it may show better results. Eustachian Tube Dysfunction Questionnaire-7 can be used to evaluate the effectives of the surgical procedures, noting it is a subjective tool.

Conclusions: This literature review shows the importance of finding out and diagnosing the underlying pathophysiology to initiate proper treatment to enhance the quality of life.

Keywords

Eustachian tube, Eustachian tube dysfunction, Middle ear, ETDQ-7, Balloon dilation of the eustachian tube (BDET), Tuboplasty

Abstract in Lithuanian

Tikslas: Ausies trimito disfunkciją labai sudėtinga diagnozuoti, ko pasekoje sudėtinga efektyviai gydyti otologinius pacientus. Tikslios Eustachijaus vamzdžio disfunkcijos diagnozės nustatymas būtų esminė sąlyga tolimesniam gydymo metodui pasirinkti. Šios literatūros apžvalgos tikslas – parodyti diagnostikos sudėtingumą ir rasti efektyvius gydymo metodus, atsižvelgiant į skirtingus Eustachijaus vamzdžio disfunkcijos potipius.

Metodai: Surinkti naujausi straipsniai iš esamos literatūros apie Eustachijaus vamzdžio disfunkcijos patofiziologiją, diagnostiką ir gydymo būdus.

Rezultatai: Eustachijaus vamzdžio disfunkcija skirstoma į tris dažniausius potipius: obstrukcinis, atviras ir slėgio sukeltas. Literatūros duomenimis chirurginis gydymas yra efektyvesnis už medikamentinį, tačiau jų derinys gali būti dar geriau. Eustachijaus vamzdžio disfunkcijos klausimynas-7 naudojamas chirurginių procedūrų veiksmingumui įvertinti, tačiau reikia atkreipti dėmesį, kad tai yra subjektyvi priemonė.

Išvados: Ši literatūros apžvalga atskleidžia, kaip svarbu suprasti ausies trimito patofiziologiją, siekiant efektyviai gydyti šia patologiją.

Keywords in Lithuanian

Eustachijaus vamzdis, Eustachijaus vamzdžio disfunkcija, vidurinė ausis, ETDQ-7, Eustachijaus vamzdžio balioninė dilatacija, tuboplastika

*This page has been translated from the English abstract into Lithuanian with partial assistance from DeepL translator and edited for consistency.

1. Introduction

1.1 Background

Eustachian tube dysfunction is characterized by its impact upon middle ear physiology and it presents active challenges in terms of accurate diagnosis and effective management. Eustachian tube dysfunction (ETD) occurs when the Eustachian tube fails to function as it should. (1) The core functioning of ET is to secure proper clearance, ventilation and protection of the middle ear. Maintaining optimal ear health, which is vital for good hearing, balance and overall well-being, depends on these functions. When these functions are impaired, it can lead to a range of middle ear issues. These include hearing difficulties, aural fullness, pain and discomfort, which significantly impact daily activities and generally the quality of life. (1,2)

Eustachian tube dysfunction accounts for roughly 2 million doctor visits each year for adults older than 20 years and about 2,6 million in both children and teens. (3) This shows how common and widespread the condition is across ages. National data shows that about 4,6% of the USA adults have Eustachian tube dysfunction. In older adults over 65 years, the numbers are even higher. (4) Also, ETD appearance is about 5,4% in those with upper airway and digestive tract malignancies and over 9% in those with upper airway and digestive tract cancers. (5) In addition, more than two fifths of the rhinology clinic's patients who suffered from sinonasal disease also scored high in the Eustachian Tube Dysfunction Questionnaire-7 showing ETD symptoms. This shows a substantial burden of ear related complaints among this population. (6) Specifically, PETD is more common in women. Typically, the condition affects women at a younger age, around 20 years old, while in men this usually presents around 60 years old. (7) ETD presents a public health concern, given its frequency. This is particularly true in aging populations due to its potential to cause persistent discomfort and hearing loss. (1,4,5)

Despite its prevalence and impact, the existing literature on ETD in adults is limited in comparison to the abundance of research focused on pediatric populations. (3) Many conditions are greatly studied in children but extensive studies in adults are lacking, especially in ETD, creating a disparity in our comprehension and management of ETD across different age groups. (5)

The Eustachian tube is a small and narrow tube that connects the middle ear to the back of the throat. (8) Normally, the ET shields the ear from harmful infectious agents, balances middle ear pressure and removes mucus by its mucociliary system. (1) This tube has a rigid bony segment near the ear and a flexible cartilage segment closer to the throat. Both are lined with mucosa and surrounded by muscles that help the ET open during swallowing and yawning. (8,9) Opening and closing of the ET depend on two muscles called tensor veli palatini and levator veli palatini that work coordinately. (2)

In healthy individuals, the tube remains closed most of the time and only opens briefly when required. ET dilates one to two times in a minute and each opening last a few tenths of a second each minute when awake. This lets air enter the middle ear and resists the slow buildup of negative pressure from gas absorption. (8) There is substantial individual variation in Eustachian tube anatomy, such as length, angle and diameter that is based on age and sex. The ET is more like a functional organ, which is essential for its role in ear health and disease. (10)

Eustachian tube dysfunction can be divided into three main groups that all generally affect the tube's ventilatory role. In dilatory or obstructive dysfunction the tube fails to open normally due to muscular failure or anatomical blockage. Patulous dysfunction is the opposite type where the tube stays abnormally open. (1) Baro-challenge-induced dysfunction is similar to obstructive type but happens during rapid pressure changes, such as in diving or flying. (1,11)

ETD is often underdiagnosed or mistreated, which can lead to hearing loss with a reduced quality of life. ETD proves to be difficult to detect and measure with accuracy. (1) Core assessment combines subjective and objective findings. A subjective ETDQ-7 questionnaire reports symptoms and their severity. Objective evaluations include otoscopy, tympanometry, audiometry and nasal endoscopy. Additionally, specific tests such as Valsalva maneuver combined with other tests, tubomanometry, sonotubometry, tubo-tympano-aerodynamic-graphy, impedance testing, nine-step inflation and deflation tests can implicate dysfunction, but no gold standard is yet determined. (12,13) A diagnostic pathway is being proposed to help to identify the ETD subtype. (12) Then proper treatment method can be selected for the proper subtype. (14) Treatment is started with medical management and the choice of the medicine depends on the underlying pathology. Still, balloon eustachian tuboplasty is the most effective for persistent OETD and for BCETD. (15) Other options for obstructive ETD treatment can be tympanostomy, microwave ablation and microdebrider or laser tuboplasties. (16,17) Patulous Eustachian tube dysfunction can be treated with a few different surgical operations. Those include mass loading of the tympanic membrane, injections of bulking materials to the ET's orifice or insertion of a silicone plug to occlude the ET's lumen. (7,18) By better understanding the anatomy as well as physiology of the Eustachian tube, it is possible to apply more personalized interventions and treatment options that may result in better outcomes. Specifically, meaning the size and shape of tools and the operation. (10)

1.2 Objectives

The objective of this thesis is to review and synthesize the existing literature on adult Eustachian Tube Dysfunction. The scope is limited to adult ETD and its subtypes. Pediatric ETD and other otologic or sinonasal disorders are not covered except if needed for context. The aim is to explain what is currently known about ETD pathophysiology, how it is diagnosed and especially what the different treatment modalities are, including the effectiveness and safety. The primary focus is to determine which treatments work best for different subtypes of adult ETD. To improve our comprehension of ETD in adults, this thesis will highlight the present knowledge gaps with attention to diagnostic problems and treatment strategies, aiming to assist in getting a better understanding of this disorder.

2. Methodology

This research is performed as a narrative literature review. Research is conducted by using the PubMed database to collect literature. Literature articles and books are analyzed related to Eustachian tube. The literature is mainly focusing on the ET's anatomy, function, pathophysiology, diagnostics and treatment.

The search is limited to articles published within the last 10 years. Language criteria is set to be in English and only literature involving the adult population is included. Pediatric studies are excluded to keep focus specifically on adults' anatomical and clinical aspects.

Search terms include: "Eustachian tube", "Eustachian tube dysfunction", "anatomy", "treatment", "diagnostics", "pathophysiology" and related combinations (AND/OR) to get to the good results.

Relevant articles are identified by screening titles and abstracts. Full text articles are reviewed based on all their relevance to the objectives within this review, especially those offering insight into the structure, the function and clinical management for the Eustachian tube.

However, access to full-text articles is partially limited due to the university's subscription coverage. As a result, only freely available open access articles and those articles that are accessible through the university's institutional subscription are included. Some articles behind paywalls that are not accessible are excluded from analysis. This limitation may affect the comprehensiveness of the literature included.

Additionally, a few useful articles were discovered through the references of the initially selected paper. This reference-based approach helps identify important studies that were not captured in the initial search. A relevant book source is also found using this approach, which contributed valuable background information to the review.

3. Literature Review Results

3.1 Anatomy and Physiology

The structural design of the Eustachian tube is tied to how it functions. It consists of a larger functional unit that includes the nose, nasopharynx, palate, middle ear and mastoid air cell system. Together, these maintain the air exchange and regulate pressure in the middle ear. (8,9) The tube itself is more like an active structure rather than a hollow pipe. It is lined by respiratory mucosa and supported by cartilage and bone. Soft tissue and muscles surround it that include the peritubal muscles which are called the tensor veli palatini, the tensor tympani, the levator veli palatini and the salpingopharyngeus. (8,9)

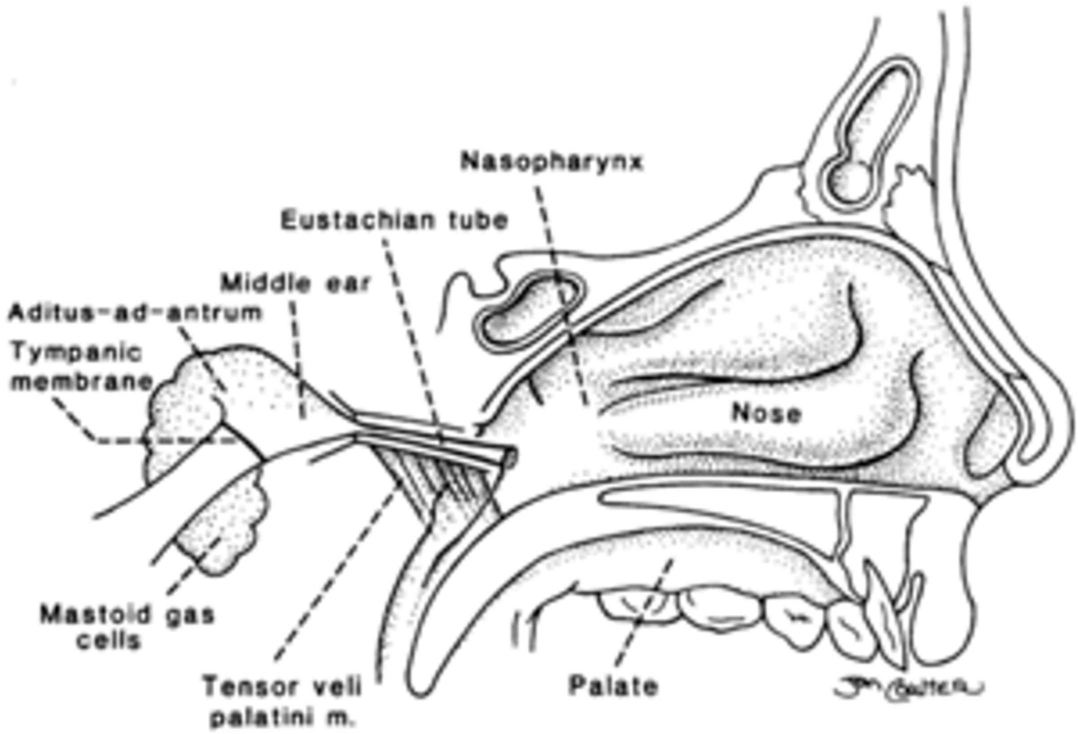

Figure 1: Illustration of structures around the ET e.g. muscles and connection to the nasopharynx. (9)

Structurally, the ET is divided into two main sections. The proximal part is the bony part which makes up one third of it and is called a protympanum. The distal part is the cartilaginous part that makes up the remaining two thirds of ET and leads to the throat, as Figure 1 shows. The narrowest portion is the isthmus, which marks the transition from the bony part to the cartilage part. (8) In adults, the Eustachian tube total length typically ranges from 36-40 mm. The bony part is approximately 12 mm and the cartilaginous part comprises about 24 mm. (19) Additionally, there are some gender differences as males tend to have longer ET than females. (10)

The ET follows a curved course from the nasopharynx to the middle ear passing behind and laterally through the petrous temporal bone. It lies between a 42° and 64° angle. (9,10) In adults, the cartilaginous portion creates an angle of 30° to 40° degrees with the transverse plane and about 45° degree with the sagittal plane that gives it a downward and lateral orientation. (9) There are variations in the ET shape, which are important to take into consideration when planning invasive surgical procedures. (10) ET length decreases slightly with age, while the naturally air-filled portion increases. (10) In younger individuals, the ET cartilage tends to be more oval and smaller compared to adults, whereas in elderly people the ET shrinks in length. (10,19)

The flexible cartilage part is supported by muscles that open and close the tube. The rest of the tube remains closed because naturally, the mucosal walls are pushed towards one another and they form a functional valve which can be opened when needed. (8,20) The cartilaginous portion grows until adult age is reached and later in elderly age this part can become calcified impairing the function of the tube. The osseous portion forms the part that touches the middle ear and is immediately right next to critical structures which are the internal carotid artery and the labyrinth. (9) The medial pterygoid portion of the tensor veli palatini besides its function to open and drain the tube, it has clinical implications because the cartilaginous and bony sections are landmarks in surgical approaches during procedures of the middle ear and cranial base. Because the bony portion is located medially to the internal carotid artery, this is important in endoscopic and microscopic procedures. (19)

The ET's lumen is lined with pseudostratified ciliated columnar epithelium, which has hair-like projections to clear and transport material from the middle ear to the nasopharynx. (8) Goblet cells that secrete mucus are responsible for one fifth of the epithelial cells and are particularly abundant in adults. (9) This epithelial lining is not only for mucociliary clearance but also provides a protective wall limiting infections coming to the middle ear from the nasopharynx. (19)

There are four muscles primarily associated with the Eustachian tube. These are the tensor veli palatini, the tensor tympani, the levator veli palatini and the salpingopharyngeus. At rest, the ET remains closed, but during swallowing or yawning muscular contractions allow the ET to dilate in order to equalize pressure. Openings are controlled by mLVP by lifting the soft palate and rotating cartilage and by mTVP by pulling the tube open laterally. (8,9) The mTVP and mLVP work coordinately in a "scissor-like" mechanism to open the ET. (20)

The Ostmann's fat pad is next to the cartilaginous portion and this structure functions as a mechanical barrier. It maintains tubal closure and prevents reflux and secretions going into the middle ear. (9) Ostmann's fat pad decreases in size when moving toward the isthmus and this way supports the closure of ET. (20) The ET is not opening constantly by all swallowing or yawning. In awake healthy adults, the tube opens spontaneously 1,4 times per minute briefly and the frequency decreases during sleep. (8)

The Eustachian tube performs multiple functions. Primarily, it regulates middle ear pressure relative to environmental changes, mucociliary clearance, facilitates drainage of the middle ear fluids and serves as a protective wall against upper respiratory pathogens and unwanted sound conduction. (1,8) To preserve good auditory function and protect inner ear structures, ET is maintaining stable pressure inside the middle ear, even when outside pressure is fluctuating. (8,9) Beyond pressure regulation, the ET must perform protective functions to maintain proper middle ear health. The ET constructs the only anatomical pathway between the protected middle ear and the nasopharynx that makes a critical link between a sterile and non-sterile space. In its resting condition when ET is closed, it prevents throat secretions, bacteria and acoustic vibrations from entering the ME as an important protective mechanism. (8,21) Additionally, the ET's mucosa contributes to local immune defense while its ciliated epithelium transports secretions out to the throat. (8,21) Effective mucociliary clearance and gas exchange support the sterile conditions in the ME and prevent pathogenic biofilm formation. During the brief times when ET opens, gas exchange between the ME and nasopharynx rebalances pressure and optimizes hearing conditions. (1,8) Usually, ETD is caused by more than one system failing in ET functions. (22)

The mastoid gas cell system and tympanic cavity occupy most of the pneumatic space in the temporal bone. They are involved in pressure regulation and clearance. As shown in Figure 2, the tympanic cavity is divided by the interatticotympanic diaphragm, which separates it into anterior and posterior compartments. The anterior compartment, responsible for mucociliary clearance, includes the protympanum, mesotympanum, and hypotympanum. The posterior compartment is for gas exchange and is lined with highly vascularized cuboidal epithelium. (8)

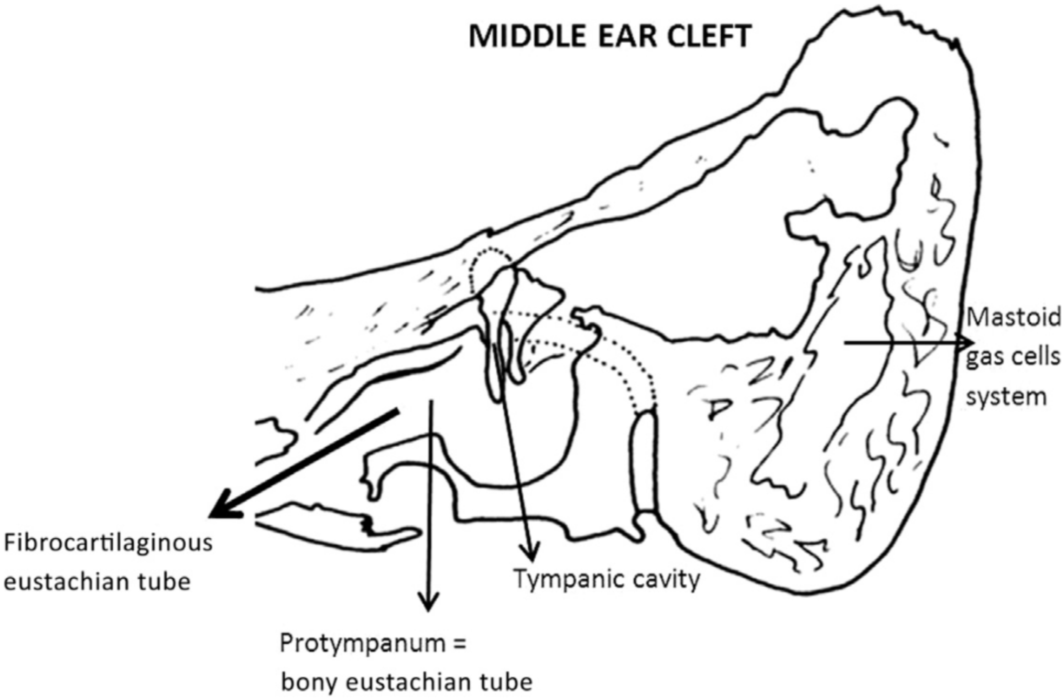

Figure 2: Middle ear anatomy of ET. (8)

Middle ear pressure is regulated by two primary mechanisms that are gas exchange through the middle ear mucosa and periodic openings of the Eustachian tube. (1) The gas within the middle ear and mastoid cells resembles exhaled air, mostly being nitrogen and containing a bit of oxygen, argon and carbon dioxide. (9) Due to nitrogen's slow absorption into the bloodstream creates a negative pressure in the middle ear unless ET opens regularly to balance the pressure. (8,9) The mastoid's honeycomb architecture creates a large surface area for transmucosal gas exchange and it helps to maintain middle ear pressure stable. (8) Doyle's modeling demonstrates that removal of these air cells during mastoidectomy lowers the critical surface area to volume ratio, which compromises the system's availability to buffer pressure fluctuations. (23) During inflammation the mastoid's buffering function can be affected. Because the middle ear cavity has limited airflow and cannot resemble its shape, it relies on slow diffusion of gases and adjusting the air volume in its compartments to settle the internal pressure. (8)

In addition, Ars et al. found in the study that ET's opening is not only passive but also that sensory feedback may open it. Neural pathways run in the mucosa that have specialized receptors such as chemical receptors and pressure sensing receptors. They monitor gas composition and pressure changes. These receptors in the middle ear deliver information via the trigeminal (V) and glossopharyngeal (IX) nerves to trigger the opening of the ET. (8)

The Eustachian tube is a fine biomechanical structure in the middle ear. (20,24) Its function relies on structural complexity, muscle contraction, mucosal health and neural feedback mechanisms. (8,9) Without this, the middle ear cannot function properly and dysfunction of the ET and related symptoms start to arise. (1) This can even lead to different ear pathologies. (1,21)

3.2 Classification and Mechanisms of ETD

Eustachian tube dysfunction can be classified by multiple different ways. (1) It can be organized into clinical classification, temporal classification or mechanistic subtypes where the latter is emerging from new research. (1,2) Clinicians typically categorize ETD into three major types that each have a specific clinical presentation but also huge similarities. Among these, the obstructive ETD shows up the most in everyday otologic practice. In this type, the tube fails to open. The second subtype is patulous ETD, where the tube fails to close and thirdly there is baro-challenge-induced ETD which manifests while fast ambient pressure changes. (1,22) Mechanistic subtypes show endotypic subcategories for clinical subtypes. (2) In addition, major types can be further classified temporally as acute and chronic ETD. (1,22)

3.2.1 Obstructive Eustachian Tube Dysfunction

The dilatory or obstructive ETD means that the ET is not opening normally. There is some kind of impairment that eventually leads to failed middle ear pressure regulation. This form can be further subdivided into three mechanical patterns. They are called anatomical obstruction, functional obstruction and dynamic dysfunction. (1) When there is an anatomical obstruction, there is a physical narrowing or blockage in the tube's lumen or at the nasopharyngeal opening due to inflammation, tumor, enlarged adenoids, mucosal swelling or scarring. (1,22) Functional obstruction to occur the tube must be unimpaired but the muscles that open the tube have frail functioning properties. Dynamic muscular dysfunction keeps the tube closed despite normal structures. The problem lies in the mTVP muscles, which have ineffective function to open the tube. (1) In the ICD-10 classification, these conditions are represented by specific codes H68.0 which is inflammatory dilatory dysfunction and H68.1 which is obstructive Eustachian tube disorder. (1)

To look closely, OETD can result from allergic or non-allergic mucosal inflammation such as allergic rhinitis or sinusitis. (1) The "unified airway" model of the upper and lower respiratory tract as being one single system allows possible inflammation to progress everywhere in the system from the nasal cavity to the middle ear and Eustachian tube. (22) Several key mechanisms underlie allergic pathologies in OETD. Inflammatory mediators stimulate mucus production during inflammation and disrupt the ciliary transport system which leads to problems with clearing secretions in the ET. These mediators diminish surfactant which lowers surface tension and cause active tube opening to be disturbed, leading it to be collapsed. In addition, chronic inflammation can spread to nearby structures and late-phase allergic reactions can prolong swelling and even further impair ventilation. (22) ETD appears to arise from combinations of several allergy-related routes. It was found that there is not enough research conducted in this area but research demonstrates links between AR and ETD. The underlying mechanism connecting allergy to ETD is still incompletely understood. (25)

3.2.2 Baro-challenge–Induced Eustachian Tube Dysfunction

Baro-challenge-induced ETD is one of the ETD subtypes, which resembles the obstructive ETD type the most. The difference is that BCETD occurs only when there is a change in the ambient pressure, especially when flying or diving. Patients are symptom free in normal ground level. (1,26) Under fast and significant pressure changes, the ET momentarily fails to ventilate that prevents normal and required pressure equalization. A few predisposing factors for this condition are individuals with subclinical ETD that is not seen at rest, anatomical variations surrounding the tube or nearby structures, mild mucosal inflammation and a history of otitis media or allergy related ETD that causes symptoms only under pressure. (11)

3.2.3 Patulous Eustachian Tube Dysfunction

Patulous type of Eustachian tube dysfunction (PET) is characterized by the tube remaining untypically open when in the resting position. (1,14) When the tube is persistently open, it permits air and acoustic energy between the middle ear and throat, which can produce its characteristic symptom such as autophony. (7) The condition is associated with four main mechanisms. The first being degeneration or thinning of supporting tissues, which is notably Ostmann's fat pad. Secondly, intrinsic mechanical or structural abnormalities in the tube, thirdly postural factors that increase venous congestion and lastly systemic hormonal changes, as seen during pregnancy or huge weight loss. (7,14,25)

The development of PET is many times linked to a substantial reduction in body mass that causes the peritubal Ostmann's fat pad to lose its size. As this fat pad diminishes, it increases possibilities that ET remains open abnormally. Ostmann's fat pad is an important and vital structure that helps to close the ET. (7,14) Clinical triggers to cause this can be bariatric surgery, hemodialysis, pregnancy and various types of fasting or diets or long-term illnesses. (7,25) Furthermore, intensive sports can exacerbate symptoms even more via dehydration. This reduces the water content in the fat pad and further impairs the main function. (14)

Beyond the fat pad, surrounding tissues may lose structure and integrity due to scarring or atrophy leading to have very little force to close the tube. These changes are often due to aging, trauma, neuromuscular dysfunction or repeated inflammatory events such as middle ear infections. Still, in many cases the specific cause stays idiopathic. (7) This loss of structural support predisposes the tube to remain open intermittently or even persistently. (1) Anatomical problems from birth or later acquired can also have some role in this patulous dysfunction. For example, a defective irregularity in the anterolateral wall of the ET may disrupt stable pressure balance which keeps to the tube's lumen open. (7)

Patient symptoms are typically dependent on the posture. Usually, the supine position to lie down or bending forward improves the symptoms. This is due to the shift in position that introduces venous congestion and tissue swelling in the area, which effectively compresses the ET closed. (7,14) Additionally, systemic factors like hormonal changes during pregnancy or the use of oral contraceptives can influence ET function by altering tissue hydration state and muscle tone. (7,25) Other physiological stressors including gastroesophageal reflux, stress and specific neuromuscular disorders may also manipulate the volume and function in peritubal tissues. (25)

3.2.4 Temporal Classification

Clinicians categorize ETD temporally as acute or chronic that is dependent on how long the symptoms have persisted. Three months is the cut-off point that defines acute or chronic ETD. If symptoms persist over three months, it will be called chronic and if less than three months then it is acute. This classification is used for all three major subtypes, OETD, BCETD and PETD. (1,22)

3.2.5 Endotypes of ETD

One research paper introduces a new proposed classification model. It highlights ETD endotypes instead of known phenotypes. These endotypes show individual pathophysiological mechanisms leading to the dysfunction of ET. Knowing these makes targeted treatment more effective and safer. Some treatment options according to this classification are not so compatible for all endotypes. (2)

Doctors have not yet started to use this endotype-based modelling. More studies are needed before it can be taken into everyday practice. These newly discovered endotypes divide further into patulous and obstructive ETD classification. Patulous ETD is divided into semi-patulous ETD, which has less prominent symptoms. In semi-patulous form the Eustachian tube stays open time to time and diagnostic testing shows reduced opening and closing pressure creation compared to normal ears. More common obstructive ETD forms are subdivided into many categories by the primary obstruction mechanism. The obstructive group is further organized into five different functioning categories that are structural narrowing (ETD-S), mucosal inflammation (ETD-I), mucosal adhesion (ETD-A), deficient dilatory muscle action (ETD-M) and extrinsic lymphoid compression or restrictive (ETD-R) type. (2)

The structural narrowing (ETD-S) is caused by intraluminal fibrosis or extrinsic compression. This mechanism produces elevated opening pressures and high resistance that make the tube resistant to normal dilatory efforts. This endotype resembles the anatomical obstruction subtype of obstructive ETD, which is currently recognized in clinical practice. Inflammatory ETD (ETD-I) develops when the mucosa in the nasopharynx or mucosa around the tube becomes inflamed that is commonly due to infections and chronic inflammatory triggers. Clinical evidence in endoscopy shows visible edema or mucous secretions around the ET's tube. Restrictive type (ETD-R) is uncommon in adults and mostly in children whom the adenoid or peritubal lymphoid tissue creates extrinsic pressure on the tubal orifice. Adhesive ETD (ETD-A) type manifests as "sticking" of the inner walls due to thick secretions, insufficient surfactant or a problem in mucosal tension. Finally, the Muscular ETD (ETD-M) type is associated with functional failure of dilatory muscles. This primarily affects the muscles that widen ET while swallowing which are the mTVP and mLVP. By progressing past general approaches, these endotypes have similarities to the currently used classification but are further classified. This framework facilitates more accurate diagnosis and allows more personalized and rational management strategies that target the specific biologic cause of the dysfunction. (2)

3.3 Risk Factors and Associated Complications

Common contributors to ETD are smoking, upper respiratory tract infections, including allergic and vasomotor rhinitis, structural abnormalities such as congenital or traumatic nasal deformities and repeated episodes of barotrauma. These structural and modifiable risk factors can contribute to ETD and its associated complications which are being reviewed in the following subchapters. (27,28)

3.3.1 Risk Factors

Smoking is one of the crucial risk factors for Eustachian tube dysfunction. The smoke from cigarettes damages the tube's mucosa and disrupts its clearance mechanisms. It also has inflammatory and immunosuppressive effects which altogether lead to a bigger risk of ET obstruction and infections. A study found that 59% of smokers showed tubal impairments compared to 19% of non-smokers. This shows clear evidence of tobacco use and ME pressure equalization. (29) In addition, the beneficial adaptation to pressure equalization via the Valsalva maneuver is diminished in smoking aviation personnel. (27) AR is also a risk factor for ETD and house dust mites are a central trigger of AR. Dust mites can cause inflammation and swelling of the nasal mucosa. (28) This can lead to narrowing of the ET lumen or impaired tubal opening. (27) This again leads to poor ventilation and pressure imbalance in the ME. (28) Other major risk factors are respiratory infection, structural anomalies and recurrent barotrauma. (27) It is found that women who suffer from many upper respiratory tract infections per year have a higher risk of middle ear barotrauma. (11) Repeated barotraumas may worsen the mucosal edema each time and progressively deteriorate tubal function. This predisposes such persons to a recurrent barotrauma. (27)

3.3.2 Associated Complications

Barotrauma is a common medical complication in diving. This is caused by inadequate ET function during pressure changes. The most reported symptoms are ear pain and a sensation of pressure. A study states that episodes of symptoms mostly occur in descent and in shallow waters. Other symptoms are hearing loss, tinnitus, vertigo and tympanic membrane perforation. Duration is described as brief, which only lasts up to two minutes. The article discovers that the strongest indication of barotrauma is when Valsalva or Toynbee techniques are not working in order to equalise pressure. (11) It is found that repeated exposure to pressure changes enhances ME pressure equalization in aviation and diving personnel via the Valsalva maneuver. This suggests a type of occupational adaptation which offers protection against barotrauma. A recurrent barotrauma can similarly affect ME volume and TM elasticity. (27)

ETD can lead to middle ear effusion when the ET fails to ventilate the ear properly. The effusion, in turn, can predispose patients to OM, which include the middle ear infection and mastoiditis. Fluid accumulation in the middle ear affects normal vibration leading to a conductive hearing loss. (30) More severe but less frequent complications include perilymphatic fistula, facial nerve baroparesis and even temporal bone fracture with intracranial sequelae. (11) If left untreated the mild ear symptoms can progress to substantial otologic, neurologic and intracranial complications. (11,30)

3.4 Clinical Presentation

The manifestations of Eustachian tube dysfunction vary between the major three most common ETD subtypes. Diagnosis is difficult due to similarities in symptoms and clinical findings with other sinonasal and otologic pathologies. There are a few signs that may be more prominent for a specific type, which helps the differential diagnosis. (1,31)

3.4.1 Symptoms and Clinical Signs

Patients with eustachian tube dysfunction may experience a diverse range of clinical indicators that often change in frequency and intensity, which makes the precise diagnosis only based on anamnesis alone difficult. (1,2) Most frequently reported complaints are aural fullness and pressure in the ear, which patients describe as congestion or as having their head below water. (1,21) Otalgia and conductive hearing disturbances such as muffled or diminished hearing are also frequently observed symptoms. (1,2,21) Patients additionally reported various auditory sensations including popping, clicking, cracking sounds or persistent ringing as tinnitus. (1,21) A symbol sign of PET symptom is autophony, where the patient abnormally feels internal body sounds. These specifically are their own breathing, heartrate or vocalization that are due to the ET's failure to close. (2,21,32) In addition, the inability to effectively "pop" the ear to equalize pressure during altitude changes such as during flying or diving, is a significant sign of this condition. (2)

Physical assessment of ETD is crucial for diagnosis and validating the symptoms reported by patients. (1) Physical examination via otoscopy may show TM retraction, effusion or atelectasis which tells about poor ventilation and negative MEp. (1,2,21) In more chronic cases, these findings may progress to more severe pathologies such as TM perforation or cholesteatoma. (2) Another visible sign is TM movement with respiration. This can be seen directly during otoscopy or microscopy. In some cases, this sign is considered diagnostic for PET. (1,14) Additionally, patients may feel symptomatic relief during clinical examination when changing to the supine position or when manual pressure is applied to the neck. (32) Tympanometry is a standard supportive objective tool and it is used to support diagnosis. It detects negative peak pressure in the affected ears. In some patient this can be normal despite profound symptoms. (1,32) This is especially true in baro-challenge-induced cases where findings are normal under normal conditions and only vary during atmospheric pressure changes such as diving or flying. (21)

3.4.2 Differentiating between ETD Types

Typically, patients with OETD report symptoms being aural fullness or internal pressure in the ear, sensation of "clogging" or feeling of being submerged. This is often accompanied by other auditory irritations such as mild ear pain, muffled sounds, tinnitus or rhythmical popping and clicking noises. (1,22) These obstructive symptoms may worsen with colds, sinusitis or when triggered by allergic rhinitis. (6,21,28) In more chronic processes, more severe problems may arise for example otitis media with effusion, persistent tympanic membrane retraction or cholesteatoma. (2,33)

Autophony is a classic indicative sign of PETD. It is often described as an echoing sensation resembling talking into a hollow container. (7,21,32) This perception also involves atypical perception of internal sounds, as already mentioned, intensified awareness of own vocalization, respiratory noises and heartbeat. (7,32) Sitting position shows to exacerbate symptoms the most. (7,14) Autophony may be tested when the patient is lying down and see if symptoms improve. (32) Symptoms match with otoscopy or tympanometry results as the clinician can see visible rhythmic movement of the eardrum that occurs in sync with the patient's respiratory cycle. (1,14) Some patients may develop habitual sniffing as a compensatory habit in order trying constantly close the ET and reduce echoing in hearing. Patients may also adopt a nasal vocal resonance to dampen the volume of their voice while speaking. (7) Additionally, asking patients if they have lost a significant amount of weight recently can give a hint of PETD formation due to Ostmann's structure shrinkage. (14,32)

Individuals with baro-challenge-induced ETD are completely free of symptoms at rest under stable atmospheric conditions. Clinical manifestations only arise when the patient is exposed to barometric pressure changes such as those occurring during diving or flying. (21,34) Most frequent complaints are same as in OETD. In rare and severe cases patients may suffer from sensorineural hearing loss, vertigo or facial palsy. (1,35) The fundamental failure is to balance the ear pressure with active swallowing, yawning or the Valsalva maneuver. The challenge is in diagnostic testing due to otoscopy and tympanometry being usually normal and no complaints outside previously mentioned activities. (1,35) If baro-challenge is prolonged and unresolved for a longer period of time, this may potentially result in a temporary acute barotrauma, middle ear effusion or even haemotympanum. (1)

3.4.3 Impact on Quality of Life

Eustachian tube dysfunction can significantly lower the quality of life. As producing interfering symptoms which profoundly affect with daily activities. People who work on communication dependent jobs, voice autophony is especially a troubling symptoms to deal with since it interrupts social interactions and work performance. (7,32) In cases of baro-challenge-induced ETD, this may restrict flying or diving activities. This again may limit recreational travel and professional opportunities. (1,34,35) The clinical burden of ETD is underscored which is pointed out by 2 million annual otologic visits in the USA, which implicates the bothersome of the ETD related symptoms. (3,6) Furthermore, research comparing chronic ETD to other chronic conditions found that there is a huge burden on quality of life, close to similar to a disease burden comparable with asthma or gastroesophageal reflux disease. (36)

3.5 Diagnostics

At present, there is no single diagnostic test to confirm Eustachian tube dysfunction. Clinical evaluation plays an important role to the initial framework, but objective diagnostic tools are required to support the diagnosis and separate subtypes. Diagnosis is important for proper treatment selection later. The absence of a universally accepted gold standard makes the diagnostic process more multifarious. Proper diagnostics rely on detailed history, clinical findings and targeted testing. (1,12)

3.5.1 Clinical Evaluation

Clinical evaluation is the first part of the diagnostic pathway of ETD. It is targeting to gather information on the patient’s history, self-reported symptoms and examination to determine if objective testing is needed. As there is no universal gold standard for diagnosis which emphasizes the importance of clinical judgement in decision making. (1) A detailed anamnesis helps to distinguish between ETD subtypes and mimicking disorders. Typical complaints are already outlined in chapter 3.4.1. It is important to note that symptoms remain unspecific for ETD. (1)

Evaluation from a clinical perspective is more of a grouping of patients into ETD subtypes rather than diagnosing. As mentioned previously, otoscopic findings may point out direction of which ETD subtype to suspect. (1) PETD is characteristic of TM movement during breathing, symptoms relieved while lying down and worsen after weight loss or dehydration. (14) OETD typically manifests as negative MEp or effusion. (1) Localization of pain to the external auditory canal has shown correlation with obstructive ETD. (31) While baro-challenge-induced ETD shows normal findings at rest but symptoms are triggered by pressure changes. (1) Simple maneuvers such as the Valsalva or Toynbee may provide additional information on the ET functioning and patency. The ability to exert autoinsufflation during the maneuvers suggests the ET opening. It is important to note that this is not always reliable and healthy individuals may fail to perform this, too. (1,37) This provides guidance for which objective tools are the most appropriate for confirming ETD types. (1)

3.5.2 Diagnostic Tools

The first diagnostic tool is patient reported outcome measures (PROMs). These are questionnaires that are designed to assess symptoms. The most common are ETDQ-7 and CETDA. (12) ETDQ-7 is a seven-item ETD questionnaire and was developed in 2012. (38) It is filled separately for each ear. Another questionnaire to be used can be CETDA, which stands for Cambridge Eustachian Tube Dysfunction Assessment. (39) Findings show that these questionnaires correlate with each other but do not correlate with objective eustachian tube function tests. (12) These have good value to note otologic problems but specificity is weak and they are not helpful for diagnosing ETD. (12) These questionnaires can be used to evaluate the severity of symptoms, but it cannot differentiate between PETD or OETD. Patients with baro-challenge-induced ETD, the questionnaire shows small changes after intervention suggesting it may have some value for evaluating treatment outcomes. Findings remain limited, though. (40)

ETDQ-7 can be used after balloon dilation of the ET to measure treatment outcomes or to help select patients who need surgery. (12,38) The ETDQ-7 assesses ear related symptoms that patients report and analyses the severity of them. Symptoms assessed are pressure, pain, clogged feeling, previous colds, popping, tinnitus and muffled hearing. Scores below 2 indicate mild symptoms, 3-5 indicate moderate and 6-7 indicate severe symptoms. Every 7 items are assessed as 1 meaning no symptoms to 7 meaning severe problem and their mean is calculated. (41) The ETDQ-7 questionnaire can be found in the annexes.

The Japan Otological Society's (JOS) diagnostic criteria to confirm definite PET consists of a tubal obstruction test where a cotton swap or jelly substance is applied into the ET opening. If this short occlusion provides symptom relief, PET is confirmed. If not, differential diagnosis must be considered. This test is also performed before PET Kobayashi plug surgery to indicate if the surgery shall be successful. The surgical part is discussed later. (7) Once PETD is objectively confirmed, a specific questionnaire, the Patulous Eustachian Tube Handicap Inventory (PHI-10) can be used to assess the severity of PETD and also to measure later treatment outcomes. (7)

Objective tests provide measurable data on ET openings. Tympanometry is a form of impedance testing and is the first-line diagnostic test to be implemented, especially if OETD is suspected. It is a non-invasive test that measures middle ear pressure and reveals middle ear effusions. (12,37) This test has high specificity, nearly 100%, but sensitivity is low. When MEp is -50 daPa patients can be diagnosed with OETD. Other test in this case is not needed. If results are normal, it does not rule out ETD and more testing is required. Also, habitual sniffing should be taken into consideration because it may temporarily create OETD even when the patient is suffering from PETD. (12) To test for a true PETD, longer measuring tympanometry can be used to confirm it, where it changes in TM immittance using a 226 Hz probe tone. (32) Beyond tympanometry, additional objective tests such as sonotubometry, tubomanometry, tubo-tympano-aerodynamic-graphy (TTAG) and impedance testing with the Valsalva maneuver are used to evaluate ETD (12,13)

Sonotubometry is a non-invasive and physiological test that evaluates active ET opening during swallowing. It can be applied even with a perforated tympanic membrane compared to impedance testing where the TM must be unbroken. (13) On the other hand, sonotubometry is contraindicated in patients who have a pacemaker. (12) During sonotubometry a 7 kHz band limited noise is delivered via one nostril and in the same ear canal is a microphone measuring changes in sound level against a 50 dB SPL baseline. The ET is assessed during dry or wet active swallowing and during the passive Valsalva maneuver that is repeated three times. ET is defined as open when the sound pressure level (SPL) exceeds 5 dB. (13)

Tubomanometry, TMM, is an objective measurement tool of both spontaneous muscular activity and passive ET opening. This test is quite direct, but it still requires specific skills to perform in order to achieve trustworthy results. (13,33) Research demonstrates that tubomanometric middle ear measurements show consistent results without comparing patient demographics and correlate to clinical assessments, such as traditional Valsalva maneuver. (33) During the measurement, a two-pronged applicator is used to introduce managed pressures between 20-50 mbar into the nasopharynx. A positive pressure transmission results indicates that the tube is open and lack of pressure means that the tube is closed or obstructed. (13)

Impedance testing with the Valsalva maneuver is sensitive and it allows for continuous monitoring of tympanic membrane flexibility to evaluate passive ET opening. (13,42) During this test, a 226 Hz probe tone at 85 dB SPL is being supplied to ear canal and proper ear canal shift over 0.05 ml shows tubal patency during the Valsalva maneuver or sniffing. (13) This objective tool is especially effective to diagnose PETD when combined with tubo-tympano-aerodynamic-graphy, TTAG. Unfortunately its clinical use is not always available due to its higher cost. (12,13)

Tubo-tympano-aerodynamic-graphy, TTAG, is a manometric procedure that records how breathing induces pressure fluctuations in the ear canal and nasopharynx. (13) Measuring synchronous respiratory movements of the tympanic membrane shows why this test is considered a highly accurate diagnostic tool for PETD evaluation. That's why this is a good tool helping to diagnose PETD. (12,13) To perform this test, sensors are placed in the nostril and ear canal to capture changes during sniffing or Valsalva maneuver. When the ear pressure exceeds 10 daPa from the baseline, ET can be confirmed open. (13)

Research suggests that sonotubometry and TMM are better diagnostic tools for OETD. Additionally, to achieve truly the most trustworthy results considering OETD diagnosis, both sonotubometry and TMM should be performed and results in both tests shall be positive. (12)

The Nine-Step Test is a tympanometric test to measure ET function. In order to measure it, positive and negative pressure changes are introduced into external ear canal. This test evaluates how middle ear pressure is equalized by swallowing. (12,43) This test can potentially be used to differentiate OETD and PETD. In both conditions the highest peak pressure difference is lowered but the resting middle ear pressure stays normal in PETD and in contrast decreases in OETD. Furthermore, during this test there are pressure changes which mimic the mechanism how baro-challenged-induced ETD is born, meaning this can be helpful to aid BCETD diagnosis. This test is still only suitable if the patient's tympanic membrane is not broken. (43)

Pure tone audiometry or Rinne's and Weber's tuning fork tests can be used as a support for the diagnosis, but it doesn't provide much diagnostic information. Some grade conductive hearing loss can be detected in patients. Hearing loss may be one of the ETD symptoms but it can also be from other otologic reasons, too. (1)

The diagnostic process for Eustachian tube dysfunction is led by a structured approach that uses specific objective findings to separate subtypes from each other. Results from the tests guide established a four stage diagnostic pathway which is seen in the Figure 3. This model is proposed by Smith et al. that is also supported by the consensus recommendations by Schilder et al. (1,12)

Stage 1 begins with the assessment and aims to differentiate obstructive and patulous ETD. In Stage 2, when OETD is suspected and TM is intact, tympanometry is performed first. If results stay normal or patients suffer from habitual sniffing, sonotubometry and tubomanometry should be performed next. If both these tests show positive results, OETD can be diagnosed with confidence. In case specialized tools are not available, the Valsalva maneuver can be used for evaluation as an alternative. (12) While suspecting PETD, the classic sign is to note TM movement via otoscopy during breathing is synchronous. This diagnosis is made by using impedance and TTAG tests and especially when combined with provocation in case the first round results come back negative. If tests are not available, forced breathing with otoscopy observation can be used. In any case, if the primary tests for OETD or PETD are negative, other subtype tests should be implemented. (12)

In Stage 3, the test should be repeated if the previous tests are negative. PETD symptoms can be provoked by exercising and then testing again. Finally, at Stage 4, if no clear objective findings, patients may be labeled with diagnosis as "ETD unlikely" or "possible ETD" when other diagnosis options are needed to explore. (12) If symptoms are only occurring during ambient pressure changes, baro-challenge ETD can be diagnosed. (1)

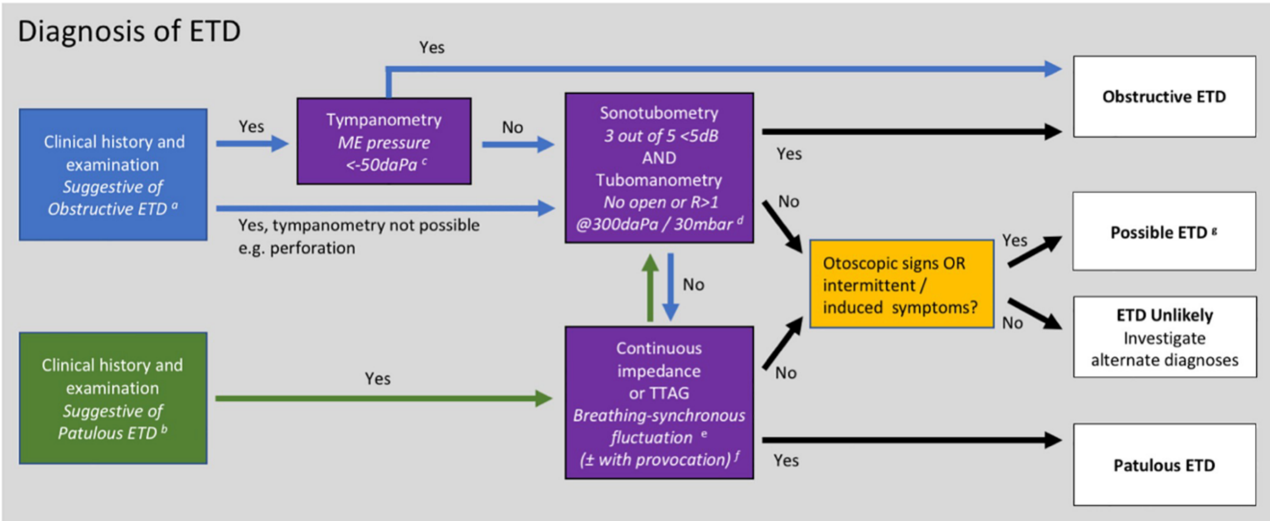

Figure 3. Table of proposed diagnostic pathway of ETD. (12)

A pressure chamber test is good to determine a definite diagnosis of BCDET, especially for occupational personnel in aviation or in diving. (44) This procedure is performed in a hyperbaric room where tympanometry records are recorded simultaneously when the patient is doing swallowing maneuvers. (21) Additionally, the pressure chamber test provides objective measures of Eustachian tube opening pressure, ETOP. This test can be used to evaluate treatment results of BDET, too. (35)

Latest research regarding imaging and visualization of ET, mainly concentrates on magnetic resonance imaging (MRI), Valsalva maneuver assisted computed tomography (CT) and dynamic slow-motion video endoscopy (DSVE). (37,39) Even though Valsalva-CT shows ET's anatomical structures, its clinical value is limited because results do not show functional information nor correlate to subjective symptoms as in ETDQ-7 scores. (39,45) In addition, CT imaging causes ionizing radiation that limits its unnecessary usage and that's why it is usually reserved for complex abnormalities or head trauma cases. (39)

Diagnostic endoscopy includes nasal endoscopy and laryngopharyngoscopy that allows to rule out nasopharyngeal pathology. It also shows inflammation of the medial ET and evaluation of nasal cavity and pharynx to mark risk factors for ETD such as AR, chronic rhinosinusitis or reflux. (46) Dynamic slow-motion endoscopy (DSVE) shows potential as a real-time method which helps to visualize the opening orifice of ET and evaluate its movement during swallowing and yawning. (42) This diagnostic technique has shown to be promising since it provides information that other tests cannot. It allows clinicians to directly observe real-time analysis and point out possible pathologies. DSVE can be used for grading of the dysfunction and revealing i.e. mucosal inflammation and assessing the tube's functional status for preoperative and postoperative interventional surgeries. (37)

3.5.3 Differential Diagnosis

Making a proper diagnosis is important and especially treatment wise in ETD. If the ETD subtype is diagnosed wrong, treatment can cause more harm to the patient or exacerbate symptoms. (14) Temporomandibular Joint (TMJ) disorders can also cause aural discomfort that mimics ETD. Patients who can self-localise site of pain may help to distinguish between TMJ and ETD. Preauricular pain is more likely linked with TMJ compared to OETD's deep ear canal pain. (31) Other potential diagnoses with similar clinical presentation can include for example oropharyngeal or nasopharyngeal tumours, otologic diseases such as Ménière's disease and inner ear fistula. Proper examination is to rule out other disorders. (1,31)

3.6 Management

The choice of management of ETD is determined by its underlying subtype as being obstructive, baro-challenge induced and patulous. Also, the severity plays a role and how chronic symptoms are present. (12,47) Management options start from conservative and medical management and possibly include surgical management that will be described in upcoming sub chapters. (47,48) Due to the lack of complete understanding of ET pathophysiology, the management also does not have a gold standard. The physician evaluates which treatment option would be the best one. (12,47,48)

3.6.1 Conservative and Medical Management of Obstructive ETD

In adults who suffer from obstructive ETD, doctors usually begin the treatment with medical management with intranasal steroids and nasal decongestants as their current use is the first-line therapy. Many patients with this condition show swelling of the mucosa around the ET's opening. This inflammation is frequently associated with other conditions such as AR and pharyngeal reflux. The initial step is trying to treat the underlying cause. (16,47) A study investigated nasal fluticasone effect on chronic ETD. Results found that 79% of patients' symptoms improved after 1 month of use of the nasal corticosteroid inhalation spray. In addition, 36% of patients' symptoms normalized based on ETDQ-7. (49) This exhalation delivery device (EDS-FLU) deposits fluticasone more posteriorly into the nasal cavity that includes the nasopharynx near the ET's opening. This may enhance its effect on local inflammation. It is noted that this study had some limitations due to a small sample size. (49) Other studies have not demonstrated effectiveness of INCS in chronic ETD since evidence stays limited. (47,48) Subacute ETD improves with the usage of INCS, but it remains unclear if the reason for it is that allergic and infectious factors are clearing up. (47) One study shows that INCS together with surgical treatment has superiority to other treatments. (50) Oral decongestants seem to be ineffective in ETD symptoms if caused by viruses. (47)

Nonpharmacological strategies include Buteyko breathing, the Valsalva maneuver and the use of a Politzer device, which raises pressure in the nasopharynx forcing air into the ME. (21,47) The Buteyko breathing method uses shallower and slower breathing with short pauses to reverse chronic hyperventilation. This pattern is thought to raise carbon dioxide and nitric oxide levels, which can increase ME pressure and help ET to open more easily. At the same time patients receive symptom relief. (48) Interestingly, the intranasal steroid budesonide produced significant symptom relief when used together with the Buteyko method but still no normalization of tympanograms. (47,48) On the other hand, INCS combined with Buteyko breathing has no effect if OETD manifests with a middle ear effusion. (48)

The Politzer device is meant to autoinflate the ME by supplying positive pressure to the nasal cavities while the patient is swallowing. (47) This device improves symptoms in subacute ETD even though the Valsalva tactic provides better symptom relief compared to politzerization. During the Valsalva maneuver patient is holding one's nose and exhaling against closed mouth which equalizes MEp. (21,47)

Overall, none of the medical management has shown to be better by another. Combination therapy with INCS and Buteyko breathing appears more effective than steroids alone. If medical management fails, the patient shall be considered for surgical treatment. (47)

3.6.2 Conservative and Medical Management of Patulous ETD

Patulous ETD management often starts by completely removing exacerbating medications such as decongestants, topical nasal steroids and diuretics including caffeine. General measures cover proper hydration and regular use of saline nasal drops or irrigations. (7,14,18)

Patients are advised to avoid weight loss and to maintain good hydration, especially during strenuous exercise or in hot weather in order not to lose volume of the Ostmann's fat pad. (7,14) Other conservative options include substances that thicken the mucus, topical estrogen and locally irritating drops such as Lugol-gel, Bezold powder or sodium iodide. These agents cause swelling of the mucosa around the ET which makes ET's opening smaller. Unfortunately, their effect is over quickly. (7,18) Although weight gain can be a proposed part of the treatment, still it is not recommended and only in rare cases considered in definitively underweight patients. (18)

A simple mechanical approach is to put a paper patch to the TM. For selected patients, a 5mm circular piece of "steri-strip" is placed on the posterior-superior quadrant of TM. This can improve symptoms of aural fullness. (7) Many patients notice that symptoms get easier when lying in supine or bending forward which is due to venous congestion around the ET which helps to close its lumen. These positional changes do not address the underlying dysfunction. (7)

Additionally, as being used during diagnostics, a swab or jelly can be inserted to occlude the ET. This provides short-term relief in difficult cases and results reveal important information for later surgical interventions to be successful. In case it helps the patient, then other PETD interventions are expected to have better results. (7)

3.6.3 Surgical Management of Obstructive ETD

Eustachian balloon dilation is currently the first choice of invasive treatment. Other invasive options include placement of ventilation tubes via myringotomy and various ET targeted tuboplasties such as microwave ablation, microdebrider tuboplasty and laser Eustachian tuboplasty. (21,35,41)

Eustachian balloon dilation is indicated for refractory OETD when medical management is not sufficient. (47,51) This procedure is minimally invasive and designated as safe due to the low risk of complications and the technical procedure success rate being 100%. (41,51) The aim in this procedure is to dilate the cartilaginous part of ET which is edematous due to inflammation. This will restore the function of ET as being pressure equalization and fluid drainage. (52,53) This procedure is suitable for patients with OETD, BCETD and for those who have linked ear pathologies contributing to ETD. These pathologies can be chronic serous otitis media where fluid is in the ME and adhesive otitis media with tympanic membrane retraction. (15,52)

Preoperative examination is done before the BDET surgery and includes clinical assessment, microscopic examination, endoscopy and additionally audiometric tests. In addition, the Valsalva or Toynbee maneuver performance is evaluated. (21) The transnasal endoscopy is used to visually to evaluate the opening of ET. (21) CT or MRI might be added to improve safety measures and help with the decision of the surgical approach. (54) BDET can be performed via either transtympanic route or the more common transnasal route. The transnasal approach also has less risk of damaging the internal carotid artery. (21,54) CT of the temporal bone creates a good picture of the bony anatomy of ET and its relationship to the internal carotid artery. (54) MRI shows cartilaginous area in greater detail which is the insertion place for the dilation balloon. Also, MRI gives more information if trying to confirm ETD mimicking conditions called endolymphatic hydrops or nasopharyngeal carcinoma. (54) MRI can help distinguish mucosal or inflammatory obstruction from structural causes. (53) Overall, CT and MRI can identify the obstruction site and the type and provide meaningful information for the surgical approach. Imaging is recommended prior BDET operation as a preoperative work-up. (54)

Balloon dilation can be performed under general or local anaesthesia (51) and it can be performed in an operating theatre or in an outpatient setting. (41) If the procedure is performed with general anesthesia in the operating room, then usually the patient lies in a supine position. (51) Balloon dilation performed in an outpatient setting under local anesthesia shows low VAS pain scores around 4 out of 10. This shows that patients tolerate this procedure well. (41)

BDET protocol starts with pre-operational workup. Oral pre-medication includes a sedative or anxiolytic that is followed by topical nasal decongestants and anesthesia. Typical medications may be a combination of opioids and acetaminophen or benzodiazepines with lidocaine containing nasal sprays or nasal packing with a lidocaine-naphazoline solution. This topical anesthesia will additionally cause vasoconstriction that helps to keep good visualization of the surgical field minimizing bleeding. (41,51) To deepen anesthesia, anesthetic pledgets with or without epihinephrine can be applied and then injecting lidocaine cum adrenaline around the sphenopalatine area, inferior and middle turbinates to achieve the wanted anesthetic effect. (41) After several minutes, the nasopharynx is examined again with an endoscope to double check that no other pathologies are being found before the balloon catheter is inserted. (51)

Balloon dilation is carried out by using endoscopic visualization (53) and commercially available CE approved devices are being used. Several catheters are approved in Europe which all work in similar fashion. (51) The standard preparation includes the balloon catheter to be connected to its inflation device and primed with sterile saline solution which is cleared from air to have optimate pressure control. Then inflation and deflation cycles are repeated once or more depending on the device manuscript. (51) The balloon sizes may differ between regions. Devices used in Europe have a balloon usually around 3mm in diameter compared to the USA where the balloon diameters can be over 5 mm. (34) Commercial systems commonly used to perform BDET are the XprESS ENT Dilation System (Entellus Medical/Stryker, USA), the Spiggle & Theis Tubavent Short system (Germany) and the Medtronic NuVent system (Ireland). (51)

The balloon catheter is inserted with the endoscopic guidance through a nostril to the nasopharynx. The device is guided through ET orifice into the cartilaginous section of the ET and pushed up to the bony isthmus as shown in Figure 4. (15,51,55) When the device is in the right position, the balloon is inflated with sterile saline or water to 10-12 atm pressure and held for one to two minutes before deflation and removing it. As already mentioned this can be repeated few times depending on the manufacturer's guide. (41,51,53) After the catheter removal, the nearby areas are being inspected endoscopically for any mucosal injury or bleeding. (51) The balloon's main idea is to widen the cartilaginous part of the tube and promote renewing effect on dysfunctional mucosa. Compression and microbleeding in the area cause scar tissue formation that stabilizes the tube's wall. (17,50,53)

Figure 4: The cartilaginous segment of ET in BDET. (53)

The XprESS ENT Dilation System has two main variants. One configuration has a distal catheter portion bent into 45 degree angle. This limits the insertion too deep and helps the operator to insert the catheter into the correct position. Furthermore, the rounded tip of the catheter allows the surgeon to feel resistance when reached the cartilaginous portion. (41) The XprESS LoProfile model uses a fixed 70 degree angle distal segment with combined LED light fibers to transilluminate the ET region. This allows the correct placement of this catheter under endoscopic control. (51) Both systems have balloons 5-7 mm in diameter with a 20mm length and an optional 8 mm length choice for the basic configuration. (41,51)

In addition to the balloon catheter, the set includes an inflation syringe, extension tube and a folding tool. (51) After the device is prepared for use, its function is checked before inserting it into the patient. The inflation of the balloon is being demonstrated and tested in Figure 5. Once the catheter is in the cartilaginous portion of the ET, the inflation can be started. The balloon is gradually inflated over a few seconds to reach 12 atm and kept inflated for 2 minutes before deflation and taking the device out. This protocol can be repeated if necessary. (41,51)

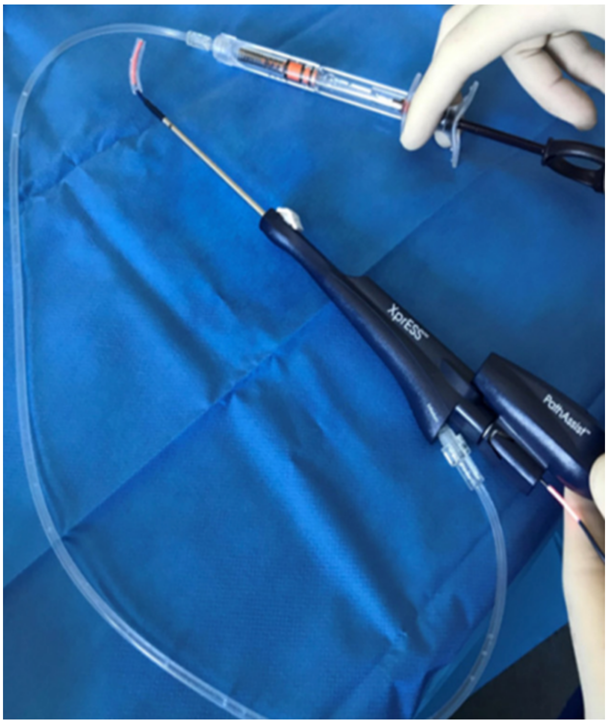

Figure 5: The XprESS balloon inflation being tested. (51)

In the Tubavent Short system, a sterile balloon measuring 3,28 mm in diameter x 20 mm in length is installed on a catheter and introduced through a 70 degree nasal canula which is put at the ET's opening with its tip directed laterally and superiorly. (51) Figure 6 demonstrates how a reference mark is placed on the catheter to know the correct depth when to inflate the balloon. (51) Under endoscopic visualization, the canula is brought into the nasopharynx and the catheter is strolled into ET until the flagged portion reaches the canula entry point. In this device the balloon is pressured to

10 atm for 1-2 minutes. (51,53) Inflation is performed 2-3 times and between and after the balloon is always deflated for 5 seconds. (51)

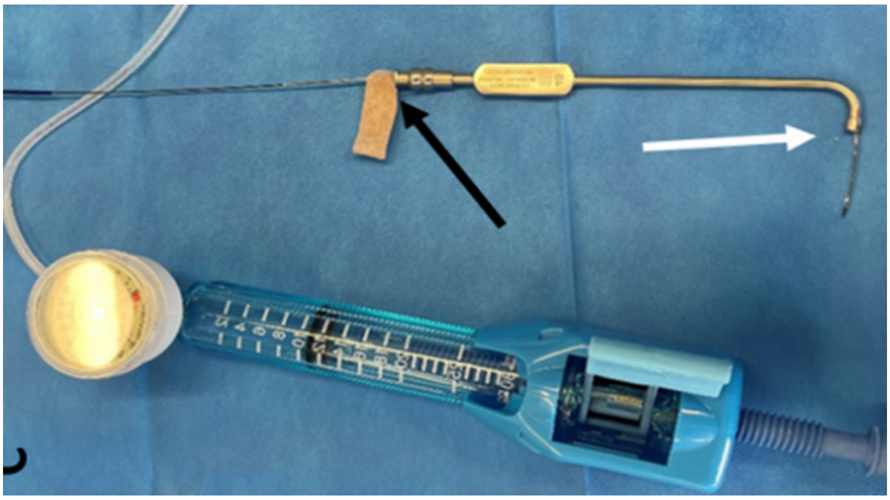

Figure 6: The Tubavent short system balloon with a catheter marked (51).

The NuVent dilation system uses a probe and syringe balloon mechanism similar to the XprESS device, but without a combined LED illumination system. (51) This system has a 6 x 16 mm balloon added to a probe connected to a pressure control syringe as seen in Figure 7. With endoscopic guidance, the device is similarly, as in the XprESS, positioned to correct place and the balloon is inflated to 10 atm for about 2 minutes before being deflated and withdrawn. (51)

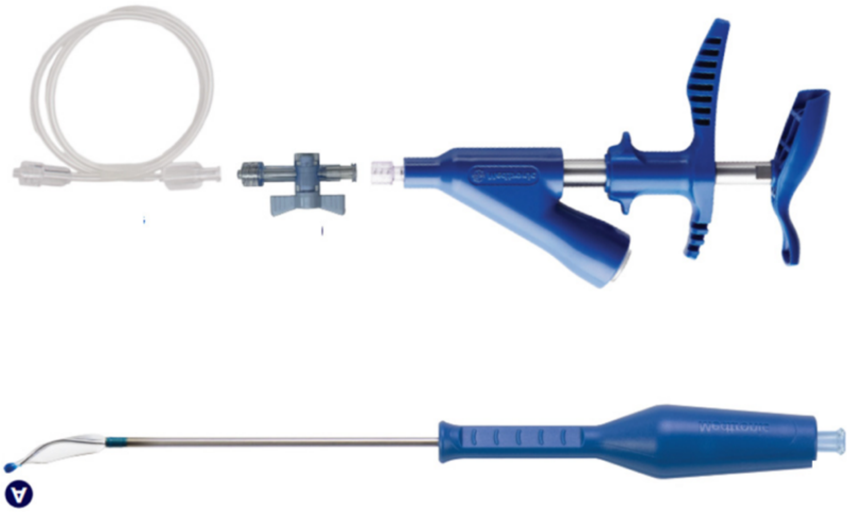

Figure 7: The NuVent dilation system. (51)

Postoperative care includes screening for complications and usually no long hospital stay is required. In published research, this procedure is commonly done in day surgery settings which means patients are released later in the same afternoon when a discharge check up in the outpatient setting is not showing any complications. In case of more serious complications such as subcutaneous emphysema, a hospital stay is required. (51,53) Swain et al. summarises post operative care with regular Valsalva exercises with short courses of nasal decongestants and corticosteroid sprays to control mucosal inflammation and possible allergies during the healing period. (53) Though, it is recommended to avoid Valsalva maneuver awhile after middle ear surgery. (56) Postoperative visits are scheduled after one week and two weeks from the operation. Longer follow-up after two months includes repeat audiometry, symptom assessment and endoscopic evaluation of the ET's opening. (53) Lin et al. instead outline one week course of oral antihistamines with Valsalva maneuvers with follow-up times after 1, 3 and 6 months where ETDQ-7 and otologic examination and tympanometry are checked to measure healing outcomes. (55) Postoperative management and evaluation after BDET currently lacks a unified protocol. However, Kwak et al. consensus recommends to check ETDQ-7 questionnaire, Valsalva maneuver, otoendoscopy, tympanometry, anamnesis and pure tone audiometry. Folllow-up duration varied but commonly used now is 12 months. (56)

Reported adverse events of balloon dilation range from minor to more serious and include possible damage to the carotid artery and creation of PETD, bleeding and periauricular emphysema. (41) To minimize and avoid carotid artery damage, CT is done preoperatively. (54) Other uncommon complications can be acute otitis media, transient lingual dysesthesia, worsening tinnitus, hemotympanum and subcutaneous emphysema. (51) Still, across studies the most reported complication after BDET was subcutaneous emphysema, even though its occurrence is rare. (57)

Short-term ventilation tubes used to be the main surgical treatment option for ETD, but now they are mostly replaced by BDET. (16) Myringotomy is an old traditional treatment method for ETD. In the study by Lin et al., the operation was performed under general anesthesia. Using a microscopic view to visualize the tympanic membrane better and after cleaning the ear canal, a small radial incision is created in the anteroinferior quadrant of the membrane to ventilate the middle ear. (55) Myringotomy with tympanostomy tube insertion temporarily improves symptoms of ETD because it allows the middle ear to be ventilated and allows effusion to drain out. Still, this type of treatment does not treat the underlying cause or fix the ET's function. Repeated tube insertions may be mandatory if dysfunction persists, but cumulative procedures may injure TM over time. (53) A study shows that myringotomy with BDET compared BDET alone did not receive better results in ETDQ-7 scores. (55) Furthermore, myringotomy and tympanostomy can add risk to persistent perforation, bleeding, infection or scar tissue formation (53,55) and TM perforation may even predispose to conductive hearing loss. (21)

Microwave ablation, MWA, is a method to treat ETD that uses dielectric heating. (17) It uses a microwave antenna that provides fast high temperature to surrounding tissues. The temperature is around 65-100 Celsius degrees. That gives an ablated zone in the posterior mucosa and submucosa at the orifice of ET. This device's antenna itself is approximately 9 cm long with a tip of 1 mm in size and length of 2 mm in size that allows for exact application. Ablation is delivered in multiple cycles of few short seconds to minimise burning of the tissue. Each application is stopped when the tissue is whitish from its color which indicates successful ablation. (17) This procedure is performed under general anesthesia and in a supine position. Similar nasal packing preparation to nasopharynx is used as in BDET to optimise bleeding to minimal and get better visualization. (17) Patients are usually discharged after one day follow-up with prescribed short course of oral antibiotics and daily nasal irrigations until the first follow-up visit at one week mark. (17) MWA can be considered a more practical treatment method compared to microdebrider tuboplasty or laser tuboplasty because a single instrument probe can both remove hypertrophic tissue and control bleeding. This gives the operator a technical upper hand. To note that excessive intraluminal heating could promote scar formation and even impair ET function. Symptoms to be relieved and ET function to normalize can take 6 to 30 months. (17)

Microdebrider tuboplasty and laser Eustachian tuboplasty are similar to MWA but lack some of its useful features. In microdebrider tuboplasty, a blade usually approximately 3-4 mm in diameter are used to shave hypertrophic mucosa and submusosa from the posterior wall of the cartilaginous ET segment, but this procedural technique is associated with a notable bleeding risk during the operation. (17) Laser treatment uses a laser to remove tissue and can lead to creation of some black crust that can impair the visualization of the surgical field. (17) Among small case series, both microdebrider tuboplasty and laser Eustachian tuboplasty give symptom relief for patients and objective improvements in the middle ear ventilation and hearing. Even though this study had some limiting factors and considerable methodological bias, neither treatment choice is preferred over the other for chronic adult ETD. There is no data showing evidence that these methods would be better than BDET. (58)

3.6.4 Surgical Management of Patulous ETD

When medical management fails to control patulous ETD symptoms, several surgical options can be considered. These include tympanic membrane mass loading, ET injections, shim insertion, plug surgery or reconstruction and in some cases complete obliteration of the ET. These methods are being considered if medical management is not showing results. (7,18,59) TM manipulation and plug surgery are performed via the transtympanic route and the others via the transnasal route. Figure 8 illustrates these surgical options. (7)

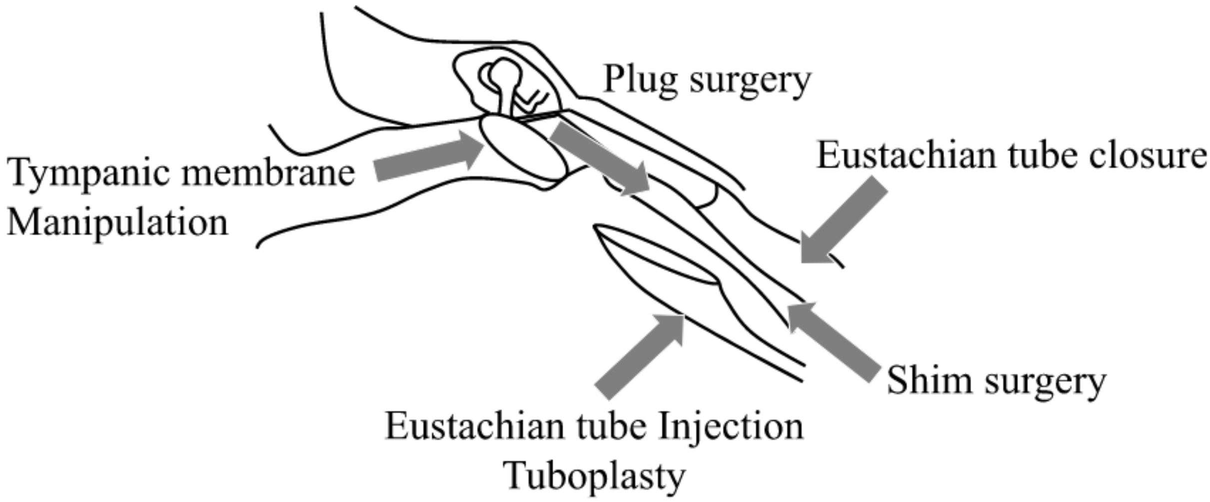

Figure 8: Illustration of different surgical methods for PETD from Ikeda et al. (7)

The tympanic membrane can be “mass loaded” with a small patch or Blue Tack resembling material to stiffen the TM, which limits excessive motion and by it increases its impedance. (7) Both ET injection and shim insertion are considered minimally invasive procedures. (7,18) Transpalatinal injection approach conducted with local anesthesia appears to give better results than transnasal or transoral injections due to patient given feed back at the procedural moment. (7) Injection materials consist of fat, cartilage, calcium, hydroxylapatite and polydimethylsiloxane which are placed submucosally to create a bulk to ET. The injections might be less durable than shims due to the tissue’s capacity to hold the injectable material compared to the shim method. (7,18) Because these materials can over time be absorbed, patients may need many surgeries or repeated injections. (7) Earlier use of Teflon for ET injection material is not used anymore due to its fatal complications of embolic events when a piece of material entered to the carotid circulation. (18)

Shim surgery uses a transnasal-transoral approach with endoscopic guidance to insert a catheter filled with bone wax into the full length of the ET lumen. When the wax hardens, it creates a partial flexible closure to the tube. This method is considered reversible since the shim can be removed. This procedure has a positive outcome but predisposes to OM effusion and the need for tympanostomy tubes since it can occlude the tube. A study shows it has a low rate of failure over 12 months but reported still 12% dislodgement of the shim via coughing or sneezing. (18)

In the Kobayashi plug surgery, which is the preferred plug surgery method today, a silicone device is inserted into the ET's tympanic orifice in order to block it. (7) This specific 23 mm plug has two sided protrusions to avoid dislodgement. There are different sizes by the diameter and the correct size is evaluated by preoperative CT imaging. (7) This procedure is performed under local or general anesthesia to ensure adequate pain management. A solution of 2% lidocaine is injected around the ET and after myringotomy is made in the anterosuperior quadrant of the TM. An endoscopic evaluation of the shape and size of the tympanic orifice and bony portion of ET is done and then the plug is inserted. Some resistance around the isthmus indicates that the plug size is correct. (7) This method provides options for patients who are otherwise difficult to treat. (7) No severe complications are being reported, except that in some cases middle ear effusion or TM perforation can occur. (7)

Tuboplasty surgery for PETD known as Patulous ET reconstruction (PETR) aims to narrow ET without completely blocking it. Different tactics include moving the inner cartilage wall or creating a pocket under the submucosa with the filling materials that can be cartilage, acellular dermal matrix, fat or silicone. (18) Obliteration refers to a complete occlusion of ET and is reserved as the last resort for PETD treatment. This method has a high risk of inducing otitis media with effusion or the need for tympanostomy tubes. (18) In rare cases, muscle TVP can be manipulated by changing its muscle tone surgically, which may change ET's patency. (18,59)

3.6.5 Baro-Challenge-Induced ETD Management

Treatment for a baro-challenge-induced ETD is similar to OETD treatment since BCETD type is considered being a further subtype of OETD. (35) Medical management includes nasal decongestants and steroids. Usually, not enough symptom relief is gained and myringotomy or tympanostomy may provide some help. Unfortunately, if this type of ETD bothers divers and pilots, tubes are contraindicated and may halt their profession. In divers, ventilation tubes can allow water into the ME and by that increase chance of developing OM and vertigo induced by temperature changes. (26,35,44) Effective treatment is important to professionals working under barometric changes due to their demanding work. Severe otologic symptoms may cause even death. (44) BDET surgery targets the ET itself that fixes the underlying problem and allows scuba divers and experts to get back to their professions. (26,44)

3.6.6 Emerging Therapies

Emerging treatment options for adults in ETD may include biologic therapy. Biologic therapy with dupilumab is not currently labeled as a therapy directly for ETD, but in a study, it shows to reduce ETD otologic symptoms when it is used for patients suffering from chronic rhinosinusitis with nasal polyposis and comorbid ETD. Results show lower ETDQ-7 scores and otologic symptoms improved at the same rate as an endoscopic sinus surgery would help. Concluding dupilumab could represent non-surgical method later in the future for ETD symptoms. (60)

Additional interesting experimental treatment options that are mentioned in the literature include pharmacological approaches of surfactant therapy where animal data show faster symptom relief and reduced ET opening pressure. A human study did not show if it was beneficial to use surfactant. (47) Another animal-based data shows use of immunomodulatory oligonucleotides, where rodent models show better clearance of ME negative pressure and enhance passive ET opening. This remains in preclinical settings and is not close to being used for humans. (47)

3.6.7 Effect of Treatment on Quality of Life

Procedural interventions that target to restore ET function especially BDET show large and continuous reductions in symptoms and in ETDQ-7 scores over follow-up. (15,41,61) Among many studies balloon dilation shows to be favourable, safe and effective treatment method. (41,53) In studies with 12 and 29 month follow-up after BDET, results show improvements in Valsalva maneuver to pop ears open, ETDQ-7 scores, tympanogram normalization and tympanic membrane position. (41,61) Outcomes are improving over 12 to 24 months after BDET operation. (15) These findings support the efficacy of this treatment (41) and particularly improve quality of life in persistent cases. (61) Known complication rates are low and recovery back to normal life is fast. (53) Yet there is limited findings on repeated BDET procedure in case symptoms reoccur and this needs more research to be conducted. (51) Balloon dilation achieves better symptom control compared to medical management but may have limited access due to its cost in many regions. (47,48)

In professional or recreational aviators and divers who suffer from baro-challenge-induced ETD, BDET has provided major symptomatic relief. After operation ETDQ-7 scores dropped from 4,33 to 2,19 and over 92 % normalization of symptoms allowing patients to return back to work. (34,44) These results support BDET to be better treatment for patients with baro-challenge related symptoms. (34) Adverse events in the procedures have been reported to be minor indicating that it is beneficial to have the surgery because it outweighs the risks. (41)

Alternative tuboplasty approaches such as MWA have also shown subjective and objective improvements up to 30 months suggesting its efficacy and improving quality of life in ETD patients. ETDQ-7 scores start to show improvements after 6 months already post operation. (17) Adjunctive mechanical maneuvers and devices such as the Valsalva and Politzer techniques provide modest benefit. (47) In addition, a behavioral breathing technique called the Buteyko method added to pharmacological medications shows better ETDQ-7 results at 6 weeks mark and tympanogram results at 12 weeks from the treatment. (47,48)

The median symptom free phase after patulous ETD operations is 5 months. Patients after calcium hydroxyapatite injections last symptom free approximately 3 months and after ET obliteration over 20 months. A major part of the shim insertions provide symptom resolution after 12 months compared to injection and PETR that had a higher risk of failing. (18) PETD surgeries are well tolerated and total obliteration of ET cleared symptoms, but this can easily cause ME effusions that again cause fullness and autophony. Many patients choose multiple procedures meaning not one PET surgery is working perfectly but well enough to improve life quality. (18) The Kobayashi plug surgery shows over 70-80% success rate and no major complications except ME effusion and TM perforation 10% to 20%. (7)

4. Discussion

The pathophysiology of Eustachian tube dysfunction is widely studied but remains incompletely understood. Its challenging anatomical location significantly restricts comprehensive study. Nevertheless, current understanding is sufficient to guide clinical diagnostics and treatment strategies. Still, considerable uncertainties exist regarding diagnostic and treatment modalities, especially given the existence of demonstrably more effective alternatives than many first-line treatments are and what diagnostic options are available compared to more exact ones. (1,12,47,51)

ETD is a disorder of middle ear pressure regulation due to failure of ET's ventilatory, protective and clearance functions. It is categorized into dilatory/obstructive, baro-challenge-induced and patulous subtypes. (1) Modern mechanistic research distinguishes between the observable phenotype and the underlying mechanism of ETD. This involves identifying specific endotypes that can be stricture/structural, restrictive/adenoid-related, muscular, inflammatory, adhesive and patulous types. Each of these types have different underlying pathologies and treatment implications. (2)

ETD stays hard to diagnose because its clinical presentation can represent many otologic problems. Its subtypes are difficult to differentiate because their symptoms are similar in each type. (1,22,31) Currently, not all clinics have all the preferred equipment to make an ETD diagnosis from the three accepted subtypes. (12,13) The acceptance of newer subtype classification has not yet been taken into use in clinical practice. (2) This could be explained since the diagnosis is currently hard and the already mentioned lack of equipment per clinic. (12,13)

Many studies highlighted the importance of patient anamnesis. (1) Then followed by diagnostic tympanometry, which is usually the first-line option since it is available in many clinics. To help diagnose, a diagnostic pathway was proposed by Smith et al. to guide the objective testing after anamnesis and clinical signs. Because no gold-standard diagnostic tool exists, objective tools are a must-have. The pathways are proposed to address this gap. (12)

The ETDQ-7 questionnaire documents subjective symptom severity but cannot differentiate between OETD or PETD. Still this questionnaire can be useful later to measure surgical outcomes or to decide on surgical candidates. (12,38) This questionnaire does not correlate with diagnostic tests and has no diagnostic value. (33,38)

When following the suggested diagnostic pathway, the path is chosen based on patient symptoms and clinical signs. According to them, the physician may pick the most useful objective test to evaluate ETD. These tests are sonotubanometry, tubotympanometry, TTAG and impedance testing. As already mentioned, not all clinics have these tests available, which is the reason why a universal diagnostic method is hard to set. Studies showed that CT and MRI imaging did not show diagnostic value but DSVE offered clinically relevant information when evaluating ET orifice or mucosal and inflammatory status. (37,46) DSVE could be helpful but one study showed it did not show enough evidence to help diagnose PETD. (7)

There are some improvements in the research when comparing older to newer publications. From the start Schilder et al. emphasized that clinical findings and symptoms are enough for diagnosis (1) but newer research showed that objective measures are needed. (12) Tympanometry alone is not enough to diagnose ETD but results may hint that more investigations are needed. (12) Smith et al. 2018 pointed out that sonotubometry and TMM perform better for OETD while TTGA and impedance testing perform better for PETD. (12) Oehlandt et al. noted that TMM is proper for ETD diagnosing if the test is performed by a well-read specialist because it needs a proper technique to succeed. (33) A correct diagnosis is important because wrong treatment may do more harm to the patient. (14)

Treatment is not set in stone for each type but more like a case-by-case decision, starting from medical treatment before surgical options. (12,47) A study suggests that treatments according to endotypes could create a more straightforward approach to diagnosis and treatment. (2)

There is currently no definitive treatment plan book for ETD and decisions concerning treatment are made by clinicians based on individual patient characteristics. (47,48) For OETD, intranasal corticosteroids have produced inconsistent results and it remains unclear whether these medications have an effect on the underlying pathology. More detailed research is needed to clarify the INCS role in treating ETD. (47) One study shows positive results in symptom relief with nasal fluticasone (49) and another shows the benefit of INCS when they are combined with surgical treatment. (50) Overall, the evidence does not yet support a clear recommendation and more studies should be conducted because this begs the question of whether pharmacological treatments are truly effective or ineffective, even though they are considered first-line treatment for ETD and especially OETD. (47) Some improvements have been noted when INCS are combined with a specific breathing technique, Buteyko breathing, which suggests a possible complementary benefit for patients with symptoms. (48) There are no major differences between the different medical management options when comparing them. (47)

In contrast, medical management for PETD aims to increase mucosal edema in order to make the ET lumen tighter. Pharmacological agents include mucous thickening agents and topical irritants. The effect of these are short. A paper patch over TM showed temporary relief to symptoms and changing position to lying face down helps to close ET due to gravity pulling fluids. (7,18) This latter option remains impractical. All findings suggest that medical management for OETD and PETD does not sufficiently indicate the underlying dysfunction and frequently are insufficient therapy alone.

When medical management fails, surgical options are considered. Balloon Eustachian tube dilation, BDET, is considered the most effective surgical treatment for OETD and BCETD. (15,47,52) Other alternatives include myringotomy with tympanostomy tube insertion or various tuboplasty techniques. (21,35,41) BDET has demonstrated a success rate approaching to 100% in some studies. (42,51) Multiple studies indicate that BDET is effective, safe and at the moment superior to other available treatment options. Outcomes improve progressively within 12-24 months after operation. (15,41) Despite its benefits, it remains costly and not universally accessible (48,49) and there is limited evidence if BDET should be performed again in case symptoms reoccur. (51) Nevertheless, taking into consideration its high success rate and low risk profile, it outweighs associated limitations. (41) Preoperative imaging, such as CT or MRI, is recommended to confirm the patient's individual anatomical variation. Especially to know where the internal carotid artery lies, so major complications can be avoided and the artery can be left untouched. (54)

Currently, there are three different BDET devices used in the EU that differ a little bit from each other due to technical variations. BDET may be performed under local or general anesthesia. (41,51) Although patients under general anesthesia have to remain longer in the day surgery settings. (53) Local anesthesia is a safe and effective approach to perform the BDET procedure. (41) When considering the high costs associated with ETD diagnostics and BDET itself, performing it this way could reduce overall treatment burden and provide practical and economic advantages. In case patients experience anxiety, mild sedation could be used to complete the procedure while still avoiding the risks of general anesthesia. Also, the development of more accessible and accurate diagnostic tools at the clinic level could further help to make this approach preferred.

One of the other surgical treatment like microwave ablation, can be effective and potentially inexpensive. (17) In contrast, for the patients who refuse surgery or for whom surgery is contraindicated, Buteyko breathing can possibly offer some relief when added to medical therapy. (47,48)

Surgical treatment options for PETD differ from those for OETD. Possible operational interventions include tympanic membrane mass loading, ET injections, shim insertions, Kobayashi plug surgery and reconstructive or obliterative tuboplasty, which are reserved for cases unresponsive to medical therapy. (7,18,59) ET injections are not definitive solutions because the material may be absorbed over time. (7) Shims can dislodge or require removal but they have gathered positive outcomes in patients showing symptom resolution after a year. (18) The Kobayashi plug has demonstrated promising results in difficult patient cases and no major complications have been reported. The success rates are up to 80%. (7) Reconstructive or obliterative tuboplasty represents a last resort option but carries more risk. However, some PETD surgeries may worsen autophony symptoms and patients often require multiple procedures, which shows how difficult this is to treat. (18)

For patients with BCETD, accurate diagnosis and effective treatment are critical since ETD may expose them to occupational hazards in diving and aviation. (44) BDET stays the only effective long-term treatment option for this patient group. (26,44)

Newer and experimental therapies have been proposed for ETD treatment. A biologic drug, dupilumab, showed improvements in otologic symptoms when ETD is associated with chronic rhinosinusitis (60). Still, current results don't give enough information to formally recommend this drug. Other experimental treatment options mentioned in the literature are the use of surfactant. It shows optimistic results in animal models but is not yet validated in human studies. (47)

5. Conclusions

Eustachian tube dysfunction is a disorder of middle ear pressure regulation which is caused by protective, clearance and ventilatory failures. (1) The three main Eustachian tube dysfunction subtypes are obstructive, patulous and baro-induced dysfunctions. In addition, current research notes endotypes that are structural, muscular, restrictive, adhesive, inflammatory and semi patulous. (2) Diagnosis is challenging because symptoms overlap between subtypes and other otologic problems. Also, many clinics lack advanced objective tools and that's why tympanometry remains the most widely used tool. Sonotubomanometry, tubo-tympano-aerodynamic-graphy, tubotympanometry or dynamic slow-motion video endoscopy may be used as a supplement for confirming diagnosis if available. (12) The Eustachian Tube Dysfunction Questionnaire-7 records symptom severity but cannot differentiate between patulous or obstructive Eustachian tube dysfunction and it correlates poorly with objective measures. (12,33,38) Medical therapy offers limited, short-term and inconsistent symptom relief. (47) If conservative treatment fails to give symptom relief for patients suffering from obstructive or baro-challenge-induced eustachian tube dysfunction, Eustachian tube balloon dilation is the most effective and safe surgical option. It provides long-lasting functional improvements even though it has a higher cost and limited accessibility. (15,47,51) Preoperative imaging is recommended to avoid harming important anatomical structures. (54) Patulous Eustachian tube dysfunction requires more invasive interventions such as shims, plugs or tuboplasties. They come with variable outcomes and a greater risk of reocurrence. (7,18) There are emerging treatment studies especially on promising biologic drugs, but these treatments are not yet specifically recommended for ETD, though they are used for other sinonasal diseases. (60) Overall, accurate diagnosis and proper endotype based treatment are essential to avoid ineffective or potentially harmful interventions. (14) Continued clinical research is important to find specific diagnostic criteria, validate emerging technologies and optimize individualized treatment strategies for all Eustachian tube dysfunction subtypes.

6. Limitations

The university's subscription coverage limits the access to full text articles. Therefore, only open access articles that are accessible for free and articles that the university's institutional subscription made available are included. Some articles that are behind paywalls and could not be accessed are not included in the analysis. This limitation may influence the scope of the literature and the choice of the articles. Also, the ETDQ-7 questionnaire is a subjective tool which has some problems. Potentially misreading of the question or bias toward socially desirable responses can affect the end results.

7. Recommendations

Future research should focus on enhancing diagnostic precision for ETD. Especially, to look more into the endotype identification prior to starting the treatment. In order to make clinical decision making more consistent, there should be standardized diagnostic protocols and more access to objective diagnostic tools, which again would acquire more funding to the clinics.

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10. Annexes

Over the past month, how much has each of the following being a problem for you?	No problem		Moderate problem			Severe problem	
1. Pressure in the ears?	1	2	3	5	4	6	7
2. Pain in the ears?	1	2	3	4	5	6	7
3. A feeling that your ears are clogged or "underwater"?	1	2	3	4	5	6	7
4. Ear symptoms when you have a cold or sinusitis?	1	2	3	4	5	6	7
5. Crackling or popping sounds in the ears?	1	2	3	4	5	6	7
6. Ringing in the ears?	1	2	3	4	5	6	7
7. A feeling that your hearing is muffled?	1	2	3	4	5	6	7

Annex 1: Eustachian Tube Dysfunction Questionnaire-7 (ETDQ-7). (39)