Epitympanic Diaphragm: Endoscopic Functional Tympanoplasty

Sreerama Murty Boddepalli[1] Rajesh Boddepalli[1]

[1]Department of ENT, Suraksha Health Park Hospital, Visakhapatnam, Andhra Pradesh, India

Address for correspondence Sreerama Murty Boddepalli, DLO, MS, Department of ENT, Suraksha Health Park Hospital, Marripalem, Visakhapatnam 530018, Andhra Pradesh, India (e-mail: murthy.ent@gmail.com).

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Abstract

Background Simple closure of tympanic membrane perforation is not a successful myringoplasty. It has to obey a lot of functional aspects of the middle ear cleft. Certain factors play a role in failure cases. The endoscopic functional myringoplasty or tympanoplasty is a clear visualization of all the parts of the middle ear; examination and removal of the disease from the hidden parts of the middle ear, examination of inter-attico-tympanic diaphragm; and removal of blocks, if any, in isthmus, to reestablish the gas exchange pathways and finally preserve the middle ear mucosa at maximum to further restore the ventilation.

Methods Endoscopic tympanoplasty was performed in 100 patients with large tympanic membrane perforations and patent eustachian tube, using 4-mm “0” and “45” degree endoscopes by proper visualization of the tympanic diaphragm and isthmus in every patient and clearing its blockage if present.

Results Among the 100 patients, 78 had epitympanic diaphragm blockage at the level of isthmus, 5 patients were found with closed tensor tympani folds, both vertical and horizontal without any ventilatory routes in them. Although in all the patients the eustachian tube was patent, we found majority of them had a dysventilation at the level of the epitympanic diaphragm. Thus, by performing endoscopic ventilatory pathway clearance and tympanoplasty, we achieved 94% positive results.

Conclusion Epitympanic diaphragm is a functional barrier between upper and lower compartments of the middle ear cleft, which play important role in the ventilation and partial pressure regulation, blockage of its isthmus may lead to tympanic membrane retractions and perforations. With the aid of endoscopes of various degrees, removing any pathological blocks, recreating proper ventilation, reestablishing gas exchange mechanism, and maximum preservation of normal mucosa for the gas exchange are the aims of an endoscopic functional tympanoplasty procedure.

Keywords
- epitympanic diaphragm
- myringoplasty
- tympanoplasty

Introduction

Myringoplasty or type 1 tympanoplasty is the most common otologic surgical procedure. It is performed either with microscopes or endoscopes. Unfortunately, even after ideal closure of the tympanic membrane perforation, the maximum success rates even in the best hands are 90 to 92%. “Simple closure of tympanic membrane perforation is not a successful myringoplasty.” It has to obey a lot of functional aspects of the middle ear cleft. Even though the closure of the perforation is complete in first few months after surgery, retraction pockets formation, atrophy of membrane, hearing deficits, and reperforations are common complications in the following years. Therefore, certain unknown factors play a role in these failure cases. If all the holes of the epitympanic diaphragm are blocked by the disease, it

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further leads to retraction of posterosuperior quadrant of the drum, Prussak's space retraction, and further formation of cholesteatoma.

The aim of the endoscopic functional myringoplasty or tympanoplasty is clear visualization of all the parts of the middle ear; examination and removal of the disease from the hidden parts of the middle ear, which are not seen through the microscopes; examination of inter-attico-tympanic diaphragm; and removal of blocks, if any, in isthmi, to reestablish the gas exchange pathways and finally preserve the middle ear mucosa at maximum to further restore the ventilation.

Human Middle Ear: Biologic Gas Pocket

The human middle ear is an isolated biologic gas pocket with its anteroinferior part connected to the nasopharynx through the eustachian tube and its posterosuperior part connected to the mastoid air cell system through the aditus and antrum. The middle ear consists of tympanic membrane, ossicles, and muscles to conduct sound from the external ear to inner ear. However, proper functioning and movement of tympanic membrane and ossicles require inert gas medium and smooth minimal friction of ossicles.

The two main functions of the middle ear biologic gas pocket are:

1. Maintenance of its gas composition, pressure, and volume. The pressure of the middle ear should always be same as that of the ambient pressure.
2. Cleaning the whole middle ear system.

Functional Units of Tympanic Cavity

Functionally, tympanic cavity is divided into posterosuperior and anteroinferior compartments by inter-attico-tympanic diaphragm. There are two small holes in the diaphragm, that is, isthmi through which both the compartments communicate. Both the compartments are functionally well coordinated. The anteroinferior compartment, which includes pro-, meso-, hypo-, and lower retrotympanum, is situated below the diaphragm and lined by secretory ciliated cells that enable the mucociliary clearance. The posterosuperior compartment lies above and posterior to diaphragm and includes the epitympanum, aditus, antrum, and mastoid air cell system. It is covered by vascularized cuboidal epithelium that serves primarily for gas exchange, pressure equalization, and buffering action (►**Fig. 1**).[1]

Eustachian Tube and Middle Ear Pressure

The fibrocartilaginous eustachian tube is closed most of the times, and it certainly does not function as a regular ventilation tube that keeps the pressure equalization between the middle ear and ambient air. Eustachian tube equalizes the pressure inside the middle ear cavity to that of outside only when there is a large pressure difference of greater than 2 kPa by its intermittent tubal dilation

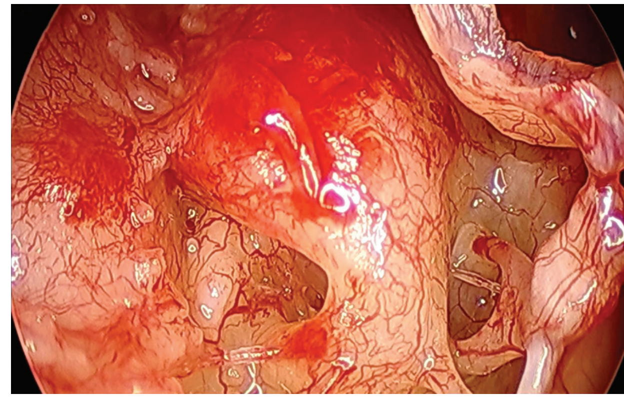

Fig. 1 Functional units of tympanic cavity.

through yawning and swallowing. The normal eustachian tube opening time is 400 milliseconds. It opens once in a minute while awake and during swallowing. During sleep, the tube opens once in 5 minutes. When the middle ear pressure is low due to rapid absorption of oxygen and carbon dioxide into venous blood from the middle ear, the eustachian tube opens by yawning, swallowing, and by autonomic reflex stimulation that are detected by baro- and chemoreceptors (►**Fig. 2**).

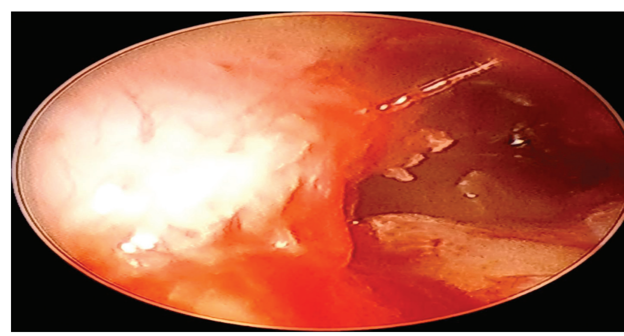

Fig. 2 Eustachian tube and middle ear pressure.

Middle Ear Gases Partial Pressures: Surgeon's View

Middle Ear Gases

The gases that are present in the middle ear cleft are identical to those found in the blood and atmosphere. These include oxygen (O_2), carbon dioxide (CO_2), nitrogen (N_2), and water vapor (H_2O). Their relative amounts are expressed by their partial pressures. The different partial pressures of various gases present in an ambience constitute total gas pressure of the given ambience. The normal air volume of middle ear cleft, on average, is 6 mL.[2]

Partial and total pressures (in mm Hg) of air, blood, and middle ear lumen are shown in (►**Table 1**).[3]

Nitrogen: Human Middle Ear Friend

Nitrogen is neither produced nor consumed at the level of middle ear cleft. Most of the middle ear pressure is governed by nitrogen (620 mm Hg). Nitrogen provides relatively prolonged partial pressure to the middle ear, thus acting as a friend to human ear. Nitrogen constitutes the dominant

Table 1 Partial pressures (mm Hg) of physiological gases of middle ear and surrounding structure

	Saturated air (37°C)	Arterial blood	Mixed venous blood	Middle ear
pO_2 (mm Hg)	150	93	38	40
pCO_2 (mm Hg)	0	39	44	50
pH_2O (mm Hg)	47	47	47	47
pN_2 (mm Hg)	562	575	575	623
Total pressure (mm Hg)	760	754	704	760

component of middle ear air, diffuses very slowly into venous blood, and lingers most of the time in the middle ear.

Gas Exchange

The middle ear cleft is separated from blood circulation by its lining called mucosal epithelium, the lining of blood vessels, and some connective tissue. The constant exchange of gas through the mucous depends on the type of lining cells.

The diffusion rate is characteristic for a particular gas.

- Oxygen diffuses from the middle ear to surrounding blood vessels very rapidly.
- Nitrogen diffuses very slowly from the middle ear to blood vessels, sometimes in days.
- Carbon dioxide and water vapor diffuse from venous blood to the middle ear in a puffed manner and at slower rates than oxygen.

The intramiddle ear cleft pressure must be equivalent to the atmospheric pressure (760 mm Hg) to vibrate tympanic membrane and ossicular system in an optimal manner.

Hydrops Ex Vacuo Theory

Ex vacuo theory postulates that a constant absorption of gas leads to a negative pressure in a closed middle ear cavity, that is, a blocked eustachian tube. Nowadays, this theory is not consistent with recent experimental studies that show, besides the eustachian tube, there are other pressure regulating factors in the middle ear among which the main factor is the gas exchange. The turnover of the middle ear gas by diffusion is a bidirectional process that may even show positive balance.

These findings show that there should be a free communication between upper posterior gas exchange compartment and lower anterior mucociliary compartment to maintain optimal gas pressure in the middle ear cleft. This, in turn, causes proper vibration of tympano-ossicular system and prevents negative pressure inside the middle ear cleft.

Epitympanic Diaphragm: Inter-Attico-Tympanic Diaphragm

Anatomically and functionally, attic (upper posterior compartment) and mesotympanum (lower anterior compartment) are divided by epitympanic diaphragm.

Epitympanic diaphragm consists of four ligamental folds and two membranous folds along with the malleus and incus (►**Figs. 3** and **4**).

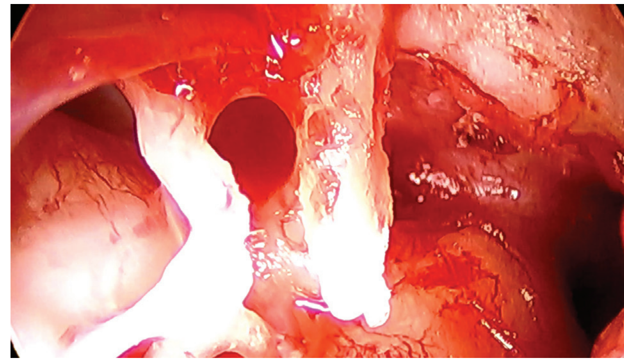

Fig. 3 Epitympanic diaphragm.

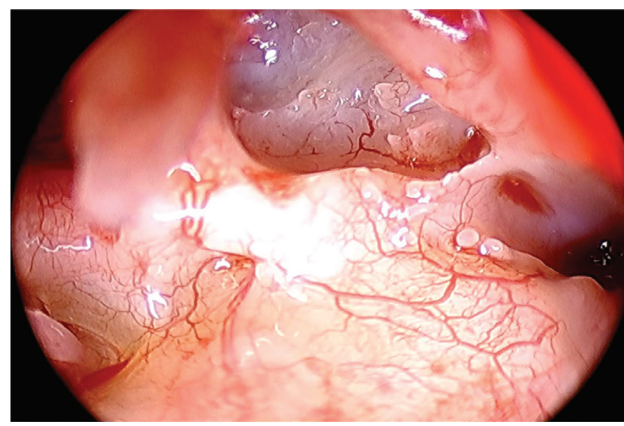

Fig. 4 Deep supratubal recess.

Attic and mesotympanum are communicated through small holes that are present in epitympanic diaphragm—tympanic isthmi.

The ligamental folds of epitympanic diaphragm include the following:

1. Posterior malleolar ligament.
2. Lateral malleolar ligament.
3. Anterior malleolar ligament.
4. Posterior incudal ligament.

The membranous folds of epitympanic diaphragm include the following:

1. Lateral incudomalleolar fold.
2. Tensor fold.

Posterior Malleolar Ligament

Annulus fibrosis is a dense fibrocartilaginous ring to which the radial fibers of tympanic membrane attach. The inner radial fibers attach pretympanic spine posteriorly and passes anteriorly to attach the neck and posteromedial aspect of upper third of malleus handle. It is the posterior malleolar ligament and forms the medial boundary of posterior pouch of Von Troeltsch, whereas the lateral boundary is formed by the tympanic membrane. Posterior pouch is the main route of ventilation to Prussak's space. By its regular contraction, posterior malleolar ligament encourages air passage and helps to ventilate Prussak's space. Unfortunately, this ligament is rarely seen through the microscope (►**Fig. 5**).

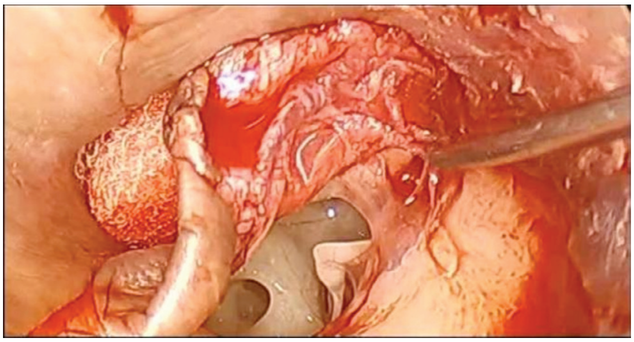

Fig. 5 Posterior malleolar ligament (PML).

Lateral Malleolar Ligament

Lateral malleolar ligament forms the roof of Prussak's space. It attaches malleus at the junction of the head and neck and radiates upward to attach entire bony rim of notch of Rivinus. Sometimes, there is dehiscence in this ligament through which Prussak's space communicates with the lateral malleolar space (►**Figs. 6** and **7**).

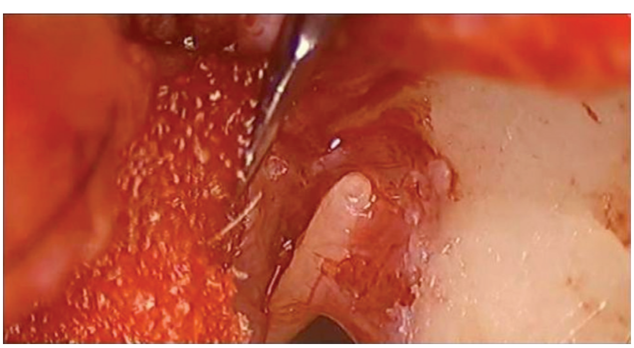

Fig. 6 Lateral malleolar ligament.

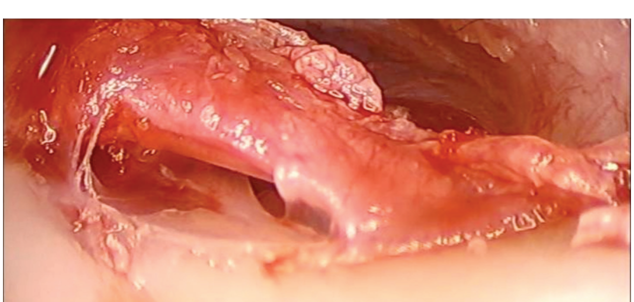

Fig. 7 Posterior pouch of Von Troeltsch.

Anterior Malleolar Ligament

Together with posterior malleolar striae, anterior malleolar ligament serves the axis of rotation of the ossicles. This ligament posteriorly attaches the neck and anterior malleolar process of malleus to the anterior tympanic spine. Along its medial border, chorda tympani and anterior tympanic artery pass.

Posterior Incudal Ligament

Tip of the short process of incus is firmly fixed to the surrounding bone laterally and medially by posterior incudal ligament.

Membranous Folds

Lateral Incudomalleolar Ligament

Lateral incudomalleolar ligament (LIML) is a thin transparent membranous fold that starts posteriorly from lateral portion of posterior incudal fold and continues directly anteriorly between incus short process and lateral attic wall up to the posterior edge of malleus. Thus, the fold separates the upper and lower incudal spaces. The thickness of LIML is 0.2 mm (►**Fig. 8**).

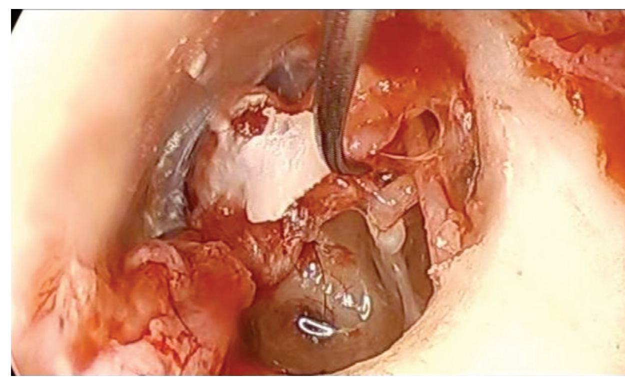

Fig. 8 Lateral incudomalleolar ligament (LIML).

Tensor Fold

Tensor fold is a thin membranous fold with variable anatomic position. It is superiorly a convex membrane extending medial to lateral from tensor tympani canal to lateral part of attic. Posteriorly, it is attached to the tensor tendon and cochleariform process, whereas its anterior attachment is to the roof of zygoma. When this fold is positioned horizontally, there is a small supratubal recess and large anterior epitympanic space. However, if the tensor fold is placed vertically, the supratubal space is large with small anterior epitympanic space. In 70% of cases, this fold is completely closed, and the ventilation to anterior tympanic space is through the anterior isthmus.

Tympanic Isthmus

The tympanic isthmus is a narrow elongated space in the tympanic diaphragm that connects the attic to mesotympanum. The entire attic is ventilated through the tympanic isthmus. It extends from the tensor tympani tendon anteriorly to the posterior incudal ligament posterosuperiorly and pyramidal eminence posteroinferiorly. The distance from tensor tympani tendon to the anterior edge of the posterior incudal ligament is around 6 mm. The tympanic isthmus is limited medially by attic medial wall and laterally by short process, the body of incus and head of malleus. Tympanic isthmus is divided into anterior isthmus and posterior isthmus by the long process of Incus.

Anterior Tympanic Isthmus

The anterior tympanic isthmus is a very important route for aeration and is situated between the tensor tympani tendon anteriorly and incudostapedial joint posteriorly. The diameter of the space is 1 to 3 mm (►**Figs. 9** and **10**).

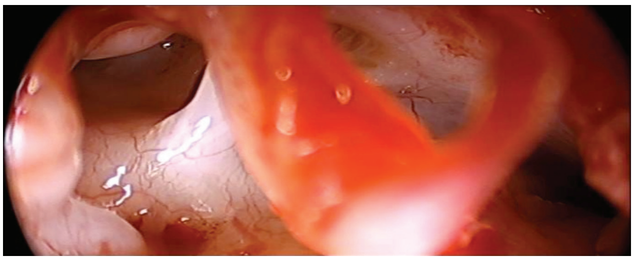

Fig. 9 Anterior tympanic isthmus.

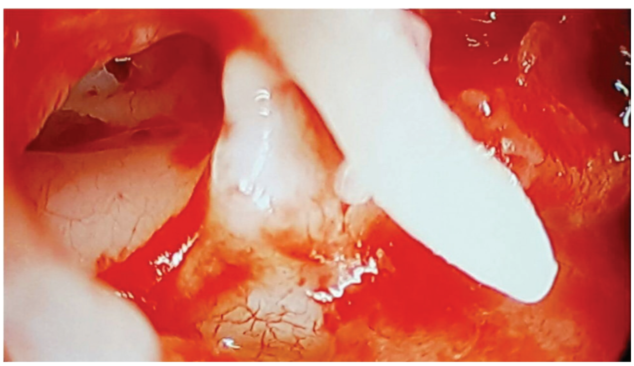

Fig. 10 Anterior tympanic isthmus (magnified view).

Posterior Tympanic Isthmus

The posterior tympanic isthmus is less important space situated between the short process of incus and the stapedial muscle.

According to Palva, posterior tympanic isthmus is a narrow space that lies posterior to the posterior incudal ligament and the tip of the incus. It communicates to the epitympanum via incudal fossa with mesotympanum. The supratubal recess is visualized using a 45-degree, 3-mm endoscope by placing the endoscope anterior to the handle of malleus tensor tympani. Fold is inspected if necessary. The fold is perforated to have good ventilation to the anterior epitympanic space.

By placing the 45-degree endoscope in between the handle of malleus and long process of incus, the cog, vertical tensor fold, and anterior tympanic isthmus are visualized, and any blocks present are removed. Visualization of the posterior tympanic isthmus requires initial removal of posterior scutum, and by placing the endoscope above the isthmus posticus, facial nerve, dome of lateral semicircular canal, aditus, and antrum are visualized and any pathologic tissue, if present, is removed (►**Fig. 11**).

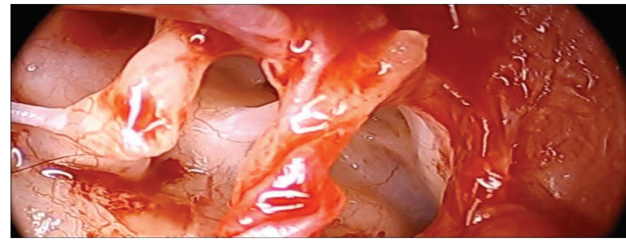

Fig. 11 Posterior tympanic isthmus.

Discussion

Middle ear cleft is an isolated biologic gas pocket that contains four main gases, namely oxygen, carbon dioxide, nitrogen, and water vapor. The total pressure of the middle ear should always be equal to that of the atmospheric air. Functionally, the middle ear cleft is divided into posterosuperior and anteroinferior compartments by epitympanic diaphragm. Anteroinferior compartment (mesotympanum) is lined by ciliated epithelium that serves as the mucociliary cleaning apparatus. The posterosuperior compartment (attic and mastoid) is meant mainly for gas exchange and pressure regulation. For optimal function of tympano-ossicular system, the ideal pressure of 760 mm Hg is necessary in the middle ear cleft. The pressures are maintained by oxygen, carbon dioxide, water vapor, and nitrogen in the middle ear. Eustachian tube is the main ventilatory tube for middle ear cleft, but it is not an active ventilatory tube. It opens passively intermittently whenever the pressure decreases in the middle ear. The other main route for gas exchange and pressure equalization in the middle ear is the exchange of gases between the middle ear air and mucosa and blood vessels surrounding the mastoid air cell system. From the middle ear, oxygen diffuses rapidly to the surrounding lining mucosa and blood vessels due to the difference in diffusion rates. Carbon dioxide is rapidly diffused from blood vessels to the middle ear in a puffed manner. Nitrogen-in the middle ear cleft diffuses very slowly and lingers in the middle ear for prolonged time, acts as the primary gas for providing major partial pressure inside the middle ear.

Epitympanic diaphragm is a dividing septum between upper and lower compartments of the middle ear. Tympanic isthmus, an opening present in epitympanic diaphragm, is the main communicative pathway between mucosa-clearing compartment and gas exchange compartment through which main ventilation occurs to attic and mastoid air cell system. If any obstruction occurs in the tympanic isthmus, the partial pressure inside the ear lowers and dysventilation occurs. Visualization of epitympanic diaphragm and clearance of disease, if any, in the tympanic isthmi are important for regulating the pressure, proper ventilation, and gas exchange. Unfortunately, epitympanic diaphragm and tympanic isthmi are not visualized through the microscope, and disease clearance in these parts is not possible unless it is done radically. Microscopic mastoid antral control and water flow tests do not reveal any pathology in tympanic isthmus.

The main advantage of endoscopic functional tympanoplasty is visualization of all parts of the middle ear, including epitympanic diaphragm, tympanic isthmus, and supratubal recess; complete removal of disease and preservation of middle ear mucosa to maximal extent with reestablishment of ventilatory and gas exchange function of upper unit of the ear; and proper pressure equalization of the middle ear cleft to maintain an ideal atmosphere for proper vibration of tympano-ossicular system and sound conduction.

Conclusion

So far, abundant literature and clinical findings are available for the biomechanics of tympano-ossicular system of lower functional compartment of the middle ear cleft. The gas exchange in the upper compartment requires more information. Presence of gas with optimal pressure in this biologic gas pocket is essential for optimal vibration of tympano-ossicular system. Epitympanic diaphragm acts as a functional barrier between upper and lower compartments of the middle ear cleft, which play important role in the ventilation and partial pressure regulation. Unfortunately, this epitympanic diaphragm is not visualized through the microscopes. It is possible to see epitympanic diaphragm and remove any pathology in the isthmus tympani using various degrees of endoscopes. Removing any pathologic blocks, recreating proper ventilation, reestablishing gas exchange mechanism, and maximum preservation of normal mucosa of the gas exchange are the main aims of the endoscopic functional tympanoplasty procedures.

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