Endoscopic Ear Surgery: Critical Review of Anatomy and Physiology of Normal and Reconstructive Middle Ear

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Received: 9 October 2015 / Accepted: 7 December 2015 / Published online: 24 December 2015
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Abstract Middle ear anatomy is complex hence it is difficult to study the microscopic vibration of tympanic membrane and ossicles. The basic research has been done in few centres. Our experience is based on clinical data. The lack of quantitative understanding of structural and functional relationship in the mechanical response of the normal and reconstructed middle ear is major factor in poor hearing results after surgery (Merchant et al. in *J Laryngol Otol* 112:715–731, 1998). The vibration pattern of tympanic membrane changes with different frequencies. It depends upon shape, position and tension of tympanic membrane. Sometimes reconstructed tympanic membrane loses its shape and tension and thus its vibratory response (Pusalkar and Steinbach in *Transplants and implants in otology II*, 1992). Then what should be the shape, position, tension of the tympanic membrane and the ossicles. In order to have a serviceable hearing, dry and safe ear, there is a necessity of answering all these queries by us.

Keywords Endoscopic ear surgery · Tympanic membrane · Ossicles · Vibratory pattern

Introduction

Endoscope ear surgery is not the technique what we normally find and learn from the text books, at least in the beginning of the era of the endoscopic ear surgery. Middle ear endoscopy was first introduced by Mer and colleagues in 1967 but till the last decade endoscopes have been mainly used for diagnostic and photographic purposes. Recently few surgeons have been doing endoscopic middle ear surgery [1] (Fig. 1).

In the 70's of last century, the concept of the ear surgery was dry cavity and dry ear. Some seniors were doing grafting to cover the perforated ear drum and the concept changed to safe ear. Though ossiculoplasty and tympanoplasty was primarily much talked subject but hearing restoration was secondary in nature. Even up to 90's of last century, every third child we saw in our practice used to be with ear discharge.

Now there is dramatic reduction in ear discharge cases. This probably is due to

- (1) Introduction of newer molecules of antibiotics, anti-inflammatory and anti allergy drugs.
- (2) Good health education by medical faculty.
- (3) Practice of hygienic condition by parents.

Nowadays the patient's symptomatology has changed to hard of hearing after one or two bouts of discharge during their childhood and they are desirous of prompt rectification and restoration of hearing. We did reconstructive surgery with our old technique by using the microscope; patients were not satisfied with results.

Then we sat back and started critically reviewing our technique. At that movement we peeped through endoscope into the ear. Better illumination, higher magnification, ability to have repeated observation and better

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Fig. 1 Endoscopic view of middle ear

documentation changed our perspective views regarding the normal anatomy physiology of ear and its reconstructive technique [1].

Anatomy

Ear is series of compartments- external ear, middle ear and internal ear. The external ear permits sound to reach the ear drum, it is elliptical (Fig. 2). Middle ear pneumatic cavity, bounded by bony walls except laterally where, tympanic membrane is located, which is cone shaped, obliquely placed tense and transparent with surface area of 80 sq mms and vibrative area of 55 sq mms. Tympanic membrane is formed by endothelial, fibrous and epithelial layers. Fibrous layer is converging from annulus tympanicus which is tugged into tympanic sulcus and is attached to handle of malleus (Figs. 3, 4).

Eustachian tube is trachea of the ear connecting middle ear to nasopharynx. Tensor palati muscle guards its nasopharyngeal end and acts like sphincter and regulates the air flow [2] (Fig. 5).

Fig. 2 Endoscopic view of external auditory cannal. It is elliptical

Fig. 3 Endoscopic view of tympanic membrane, it is cone shaped, Obliquely placed, tensed and transparent

Fig. 4 Endoscopic view of middle ear (bone), Tympanic sulcus, Oval window and round window, Surface area and plane

Fig. 5 Endoscopic view of eustachian tube opening in middle ear

Round window is covered with semi permeable membrane and takes part in pressure release of inner ear and its surface area is 2 sq mms. Oval window is closed by foot plate of stapes which has surface area of 3.2 sq mm. Ossicles extend from tympanic membrane to oval window.

Fig. 6 Endoscopic view of malleus. Articular surface cover 90 % of its head

Fig. 8 Endoscopic view of stapes. It has only one articular facet on head

Fig. 7 -Endoscopic view of incus. It has four articular facets two on body and one on each in long and short processes

Fig. 9 Endoscopic view of stapes (lateral view). Stapes is not a solid bone instead it is a hollow arch like tyre

The articular facet covers 90 % of surface area of malleus head. Other two bones to have this type of articular facet are Humerus and Femur. They articulate over fixed bones, scapula and pelvis. Both Shoulder and hip joints are dynamic synovial joints and articulate to 360 degrees. Though having same articular facet but malleus will not articulate over medial wall of middle ear (attic region).

It hangs by ligaments in middle ear space, only handle attached to the tympanic membrane and articulate with incus. Incus has four articular facets two on its body which articulates with the malleus head, thus it vibrates along with malleus as a single unit (Figs. 6, 7).

This ossicle also hangs in middle ear space by ligaments, except articulate with fossa incudis by articular facet over its short process, causing axial vibration. Facet over the long process articulate with facet over stapes head. Stapes is not a solid ossicle but is like inverted tuning fork with a foot plate (Figs. 8, 9). All synovial joints, whether they are hinge joints also and move in particular direction.

Where are the Muscles to Cause the Movements?

Two muscles- tensor tympani originate in tympanic canal. Stapes muscle originates in the pyramid and inserted to the ossicles. Thus they take part in the stability and protecting the inner ear against loud sounds but will not cause the movements, because muscles do not originate and insert in the neighboring ossicles.

Then, What Does This Ossicular Chain Do?

Probable it is only a vibration along with tympanic membrane and transforming the vibration to foot plate and cochlear fluid. The chronological reduction of weight of ossicles helps to enhance the stapes linear movement. Mucus membrane is composite having stratified ciliated columnar epithelium and squamous epithelium and quantum of air space is 6 ml in volume including mastoid air cells [2, 3].

Fig. 10 Endoscopic view of middle ear. Stapes long process of incus and tendons of the muscles are visceral contents of the mesotympanum. Chorda tympani and handle of the malleus are in the tympanic membrane

Stapes, long process of incus and tendons of the muscles are visceral contents of mesotympanum. Chorda tympani and handle of the malleus are in tympanic membrane. No mucosal folds in mesotympanum which help in the free air flow (Fig. 10).

Thus annulus, handle of malleus, fibrous layer and two muscles take part in changing the shape and tension of tympanic membrane and ossicles [4]. Malleus and incus acts as a unit and are in horizontal plane whereas stapes in vertical plane and two planes are of 45 degree angulation [3].

Physiology

External Auditory Canal

Ear canal acts as resonator and it resonates between 2000 to 5000 cycles/s.

Middle Ear

If sound energy hits inner ear directly most of energy would be reflected because of resistance of fluid media hence there is need for transformer mechanism that is filled by middle ear (Air media to solid media to fluid media).

The cone shaped, tensed transparent tympanic membrane provides optimal acoustic pick up, at this level first transduction takes place (i.e. sound energy converts to mechanical energy) Vibrative pattern of tympanic membrane is complex and it changes with different frequency [5].

The sound energy that reaches tympanic membrane (vibrative area 55 sq mms) is conducted across the chain and concentrated on stapes foot plate (3.2 sq mm) and the ratio being 17.1:1. Length of handle of malleus is 9 mm

and long process of incus is 7 mm and the ratio being 1.3:1 which two factors combined enhance the sound transmission through the middle ear and overcome the resistance of liquid media.

Middle ear aeration helps for optimal vibration and middle ear muscles provide stability and tension to ossicles and tympanic membrane. After acoustic pickup and transduction of sound energy into mechanical vibration, it passes through the ossicular coupling. Vibration of the tympanic membrane also travels through the air in the middle ear and vibrates both foot plate of stapes and round window membrane. This is called acoustic coupling.

• Net vibrative pressure difference at

Oval window and round window is = Ossicular coupling + Acoustic coupling.

- **Stapes volume vibrative velocity** = Linear vibration of stapes $\times$ area of foot plate.
- **Net Vibrative pressure transfer to the cochlear fluid** = Ossicular coupling + Acoustic coupling $\times$ area of foot plate / Impedance of fluid + annular ligament of stapes.

Following are the functions of tympanic membrane.

1. Lateral border of middle ear.
2. Protects against spreading of the infection from the External auditory canal.
3. Creates air column- thus protects against the entry of nasal regurgitation, autophonia and also clearance of the middle ear.
4. Maximum acoustic pick up.
5. Transduction
6. Middle ear gain
7. Bone Conduction gain.

Certain questions are thus raised during reconstructive surgery.

Question

Whether stenosis of the EAC reduces the resonating quality? Does canaloplasty enhance it? Does mastoid cavity alter it? [3] (Goode et al. 1997)

Answer

1. Middle ear pathology is tackled transmeatally and mastoid post aurally without elevating the meatal skin because Endoscope brings the surgeons eye to tip of the scope, hence the view through endoscope is not restricted by the narrow segment of external auditory canal and anterior and posterior buldge, so no need of

canaloplasty. Doesn't amount to risk of meatal stenosis.

2. Endoscope mounted with camera and visualized through monitor will remove the disadvantage of monocular vision which would have lead to the loss of depth of perception.
3. Endoscope view gives better illumination and higher magnification, it gives flexible movements and middle ear can be observed in different angles and fields easily.
4. Endoscope gives wide angled view which includes the entire tympanic membrane the graft and medial end of external auditory canal at one frame so positioning the graft was much easier and precise.

Question

1. Whether in tympanoplasty removal of annulus from sulcus (inlay and inter lay grafting) changes shape and tension of tympanic membrane?

Answer

Yes. Do not remove the annulus from sulcus either do onlay or inlay to onlay technique.

Question

2. Can the graft which is dry dead inert material (temporalis fascia) and absorbed by phagocyte activity and healed with only endothelial and epithelial layer maintain the tension shape of tympanic membrane?

Answer

The aim of the grafting is epithelization, endothelialization and vascularisation (converting the graft material into fibrous layer). So use the wet graft which is not scraped and crushed, it can act like fibrous layer and over it endothelial and epithelial layer develops. Minimal dissection and creating tympanomeatal epithelial flaps will help in vascularisation.

Question

Is it necessary only malleus is attached to tympanic membrane?

Answer

Yes, it is necessary to have free movements of malleus and incus and it can be achieved only when graft material placed lateral to the handle of malleus.

Question

Whether ratio of tympanic membrane and foot plate of stapes is to be maintained?

Answer

Yes.

Then how to maintain it in stapedectomy? (Rasowsky and Merchant 1995)[6].

Question

Whether middle ear air space & pressure is necessary for vibration?

Answer

Yes. In canal down technique bony canal can be reduced up to annular sulcus only and graft should put over it because at least 0.5 ml of air has to be maintained in the middle ear.

Question

Is it necessary to maintain horizontal plane of malleoincus unit and vertical plan of stapes?

Answer

Needs further evaluation ossicles weight share stout and cramping should be appropriate for free vibration of them in middle ear air chamber. It is an observation that presence of the supra structure of the stapes helps in the good hearing than only a foot plate [7].

The inverted tuning fork shape and the resonance of the stapes are entirely different of columella effect. (How can columellar vibrative pattern replace the pattern of the chain system). Thus, we have limited understanding of mechanics of ossicular reconstruction.

Question

Is it necessary to have muscle attachment to ossicles to maintain shape and tension of the ossicles?

Answer

Yes.

1. Try to preserve the ossicles and muscle attachments. Do not become too radical to middle ear during cholesteatoma clearance because it is very difficult to create muscles, ossicles and their articular surfaces [8].
2. Continuity of the mucosa of middle ear avoids adhesions
3. Patency of Eustachian tube should be maintained by clearing and suctioning the tube.
4. No gel foam in the middle ear- creates instantaneous air chamber, soaked with the blood and swollen gel foam may change position of graft material.

Question

What about the patency of Eustachian tube?

Answer

Should be maintained by clearing and suctioning the tube.

Conclusion

Endoscope view gives better illumination and higher magnification. It gives flexible movements and middle ear can be observed in different angles and fields easily. Shape, position, tension of tympanic membrane and ossicles are at most important to maintain during reconstruction surgery. It is very much difficult to create articular surface of ossicles and muscles to have proper chain movements

along with vibrating tympanic membrane so try to preserve them wherever possible. Creation of near normal anatomy of middle ear in reconstructive surgery will provide maximum hearing improvement.

Lastly this helps in creating good hearing, safe and dry ear. Endoscope ear surgery is far easier than microscopic surgery.

Compliance with Ethical Standards

Conflict of interest None.

Ethical Approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed Consent Informed consent was obtained from all individual participants included in the study.

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