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Introduction

Myringoplasty and tympanoplasty are descriptive terms defining surgical procedures that address pathology of the tympanic membrane (TM) and middle ear. Myringoplasty is an operative procedure used in the reconstruction of a perforation of the tympanic membrane. This assumes that the middle ear space, its mucosa, and the ossicular chain are free of active infection. There is no direct inspection of the middle ear during this procedure implying that the TM is not elevated from its sulcus. Tympanoplasty implies reconstruction of the tympanic membrane but also deals with pathology within the middle ear cleft, such as chronic infection, cholesteatoma, or an ossicular chain problem. To distinguish these two terms further, Rizer (1997) defines tympanoplasty to include all procedures in which "the drum is lifted from its position in the ear canal." Subsequent additional procedures such as grafting the tympanic membrane, alone, or in combination with ossiculoplasty (tympanoplasty with ossicular chain reconstruction), comprise the varying subtypes of tympanoplasty.

Surgery of the TM dates back as far as the 17th century when Banzer (1640) described the first attempt at repair of a TM perforation with a pig's bladder. Over the next century, most of the advances in otologic surgery were focused on the mastoid to treat life threatening infections. In 1853, Toynbee placed a rubber disk attached to a silver wire over a perforation. He reported significant improvement in hearing with this method. Later Yearsley (1863) placed a cotton ball over a perforation and in 1877, Blake proposed the paper patch which is still used today for preoperative evaluation of potential hearing improvement. The earliest treatment of TM perforations with chemical cautery was performed by Roosa (1876) and Okneuff (1895). The term myringoplasty was coined by Berthold in 1878. He placed a court plaster against the tympanic membrane for 3 days to remove the epithelium, and then applied a thick skin graft. Despite success reported in two cases, little more was heard of myringoplasty until Schulhof and Valdez mentioned it in 1944. Wullstein and Zollner are given credit for ushering in the modern era of tympanoplasty in the 1950s. They placed split thickness skin grafts over the de-epithelialized TM remnant. Initially, good results were obtained, however, subsequent graft eczema, inflammation, and perforation were common. During this time, Wullstein (1956)

described five types of tympanoplasty based on the relationship of the grafted TM to the middle ear structures. In 1961, Storrs reported a series of patients in which temporalis fascia was used as an outer surface graft. Over the next three years, this technique became wide spread and resulted in over 90% graft take. House (1961), Glasscock, and Sheehy (1967) further developed and refined techniques used for lateral graft tympanoplasty which are the same techniques used today. The first medial graft tympanoplasty was performed by Shea (1957). He was performing a stapedectomy and by chance, discovered that a medial vein graft was successful in repairing an accidental tear. Storrs later replaced the vein graft with temporalis fascia for use in medial grafting. Over the past three decades temporal fascia has been the most commonly used grafting material in tympanoplasty operations, although tragal perichondrium, periosteum, loose overlay tissue, fat, vein, alloderm, homograft TM, and homologous dura are also employed.

Anatomy and embryology of the tympanic membrane

The tympanic membrane develops from three sources: ectoderm of the first branchial (pharyngeal) groove, endoderm of the tubotympanic recess from the first pharyngeal pouch, and mesoderm of the first and second branchial (pharyngeal) arches. During the fourth week of gestation the first pharyngeal pouch extends laterally to become the tubotympanic recess. This recess is lined with endoderm. It continues to expand creating the middle ear cleft and later the mastoid. It envelops the ossicles and their tendons and covers them with an epithelial lining. The endodermal lining of the tubotympanic recess comes into contact with the ectodermal lining of the first branchial groove to form the first branchial membrane. Mesoderm from the first and second branchial arches then migrates between this membrane to create a three layered structure which becomes the tympanic membrane.

The tympanic membrane is oval in shape with dimensions of approximately 8 mm X 10 mm. It is oriented at approximately 55 degrees with the floor of the meatus. The greater part of the circumference is thickened, and forms a fibrocartilaginous ring (also known as the annulus or annular ligament) which is attached to the tympanic sulcus at the medial end of the meatus (scutum). The annulus and sulcus are deficient superiorly which is known as the notch of Rivinus. The anterior and posterior malleolar folds extend to the lateral process of the malleus from the two ends of this notch. The triangular area created above these folds is known as the pars flaccida and is called such because it lacks the middle fibrous layer that gives tensile strength to the rest of the membrane. This characteristic makes it vulnerable to retraction under negative pressure. The rest of the membrane is called the pars tensa. The handle of the malleus is firmly attached to the inner surface of the TM as far as its center, which projects towards the tympanic cavity giving the TM a conical shape. The point of the cone is called the umbo. The membrane is approximately 130 microns thick. As mentioned before, it is a three layered structure consisting of an outer ectodermal layer composed of keratinizing squamous epithelium, an intermediate mesodermal fibrous layer (which consists of a superficial layer of radial fibers and deep layer of circular fibers), and an inner endodermal mucosal layer. The epidermal layer has migratory properties which gives the TM its self cleaning ability. The epidermis migrates centrifugally from the umbo outward in a posterosuperior direction at about 131 microns per day.

Within the epidermal layer of the TM are Langerhans' cells, which are involved in the immune response as antigen-presenting cells, mast cells, and T lymphocytes.

The blood supply to the outer surface of the TM is derived from the deep auricular artery and the inner surface is supplied by the anterior tympanic artery. Both of these arteries are branches of the internal maxillary artery. The deep auricular artery ascends in the substance of the parotid gland, behind the temporomandibular articulation, pierces the cartilaginous or bony wall of the external acoustic meatus and arborizes on the outer surface of the TM. The anterior tympanic artery passes upward behind the temporomandibular articulation, enters the tympanic cavity through the petrotympanic fissure, and ramifies upon the inner surface of the tympanic membrane.

Somatic sensory nerve fibers to the TM come from the auriculotemporal branch of the mandibular nerve, the auricular branch of the vagus nerve, and the tympanic branch of the glossopharyngeal nerve.

Basic Science – Sound Transmission

The middle ear transforms acoustic energy from the medium of air to the medium of fluid. It is an impedance-matching system that ensures that energy is not lost. This impedance matching is accomplished by the area effect of the tympanic membrane and the lever action of the ossicular chain. Although the area of the adult tympanic membrane is between 85 and 90 mm², only about 55 mm² effectively vibrates (the lower 2/3 of the drum); the stapes footplate is 3.2 mm². Thus, the ratio of the vibrating portion of the tympanic membrane to that of the stapes footplate results in a 17:1 increase in sound energy. Also, because the handle of the malleus is approximately 1.3 times longer than the incus long process, the force (pressure) received at the stapes footplate, through the use of leverage, is greater than that at the malleus by about 1.3:1. Thus, the combined transformer ratio of the middle ear is about 22:1 ($17 \times 1.3 = 22$). This translates to approximately 25 dB.

A simple perforation of the tympanic membrane without other lesions of the middle ear transformer has two different effects on the hearing. First, there is the diminished surface of tympanic membrane on which sound pressure is exerted, causing diminished excursions of the ossicular chain. For a small perforation one millimeter in size Bekesy found that the loss of ossicular motion is confined to sounds below 400 cycles; it is 12 dB for 100 and 200 cycles, 29 dB for 50 cycles and 48 dB for the lowest audible frequency of 10 cycles. The larger the perforation, the greater the loss of surface on which sound pressure can act, with the additional factor that sound pressure entering the middle ear through the perforation acts on the posterior surface of the tympanic membrane against the sound pressure on the outer surface.

The second effect on the hearing of a simple perforation results from sound reaching the round window directly without the dampening and phase-changing effect of the intact tympanic membrane. This effect becomes greater with a larger perforation. Moreover, as the size of the remnant of tympanic membrane decreases, the hydraulic advantage produced by a large tympanic membrane on a small oval window disappears, so that sound reaches both windows with more nearly equal force and at nearly the same time. The resultant cancellation of vibratory movement of the cochlear fluid column produces the maximum hearing loss observed in simple perforation, as much as 42 dB for the speech frequencies.

When healing of a perforation of the tympanic membrane results in the elimination of the air-bone audiometric gap, with the restoration of normal hearing, it is reasonable to assume that the hearing loss was solely the result of the perforation and not due in part to other lesions of the ossicles or cochlea. In general, the larger the perforation, the greater the hearing impairment, but this relationship is not constant and consistent in clinical practice; seemingly identical perforations in size and location produce different degrees of hearing loss. The reasons for the variations in the hearing effects of simple perforations are not easily defined.

Etiology (tympanic membrane perforation)

Perforations in the TM are most commonly caused by infections of the middle ear and less commonly the external auditory canal. Other causes are trauma, and iatrogenic. The vast majority of perforations due to infection are small and heal spontaneously, however, recurrent infections may impair the regenerative process and result in a chronic perforation. Beta-hemolytic streptococci are associated with large central perforations secondary to its necrotizing toxins and proteolytic enzymes. Viruses, mycobacterium species and external otitis have also been associated with TM perforations

Traumatic causes of TM perforations include blunt and penetrating trauma, barotrauma, acoustic injury, blast injury, and thermal injury. Blunt trauma to the head with or without associated temporal bone fractures may result in TM perforations. Longitudinal temporal bone fractures more commonly involve the TM and middle ear structures than transverse fractures. Slap injuries trap a column of air in the ear canal which is compressed against the TM. The most common cause of penetrating TM perforation is self inflicted while cleaning the ear canal with a cue tip or cotton swab.

Thermal injuries to the TM are most commonly seen in steelworkers and welders and result from slag hitting and cauterizing the TM. Lightning can cause TM perforations through thermocoagulation and necrosis.

Barotrauma may cause the TM to perforate as well. Cadaver studies have shown that pressures between 14 and 33 pounds/inch² (average, 25 pounds/inch²) are needed to rupture the membrane. Like-wise, sound pressure can also result in TM rupture. Keller (1958) estimated that 195 to 199 dB was needed for this to occur.

Iatrogenic causes of TM perforations include myringotomy and myringotomy with tube placement, cerumen removal, and hyperbaric oxygen therapy. Retained ventilation tubes are associated with a higher risk of persistent TM perforation. Nichols et al. found that 40% of patients with retained tubes longer than 36 months had persistent TM perforations versus 19% of patients with tubes less than 36 months.

The overall rate of spontaneous healing of traumatic TM perforations is approximately 80% (Kristensen, 1992). The type of traumatic injury does affect the rate of spontaneous healing. Thermal injuries have the least likely chance of healing (40%). Other factors which have a negative influence on healing are age greater than 30 years, large kidney bean shaped

central perforations, posterosuperior perforations, infection, malnutrition and immunosuppression.

Preoperative Evaluation

The preoperative assessment includes a complete history and head and neck exam. In the history, key points should be elicited such as hearing loss, time line of otorrhea/infection, previous otologic procedures, tinnitus, otalgia, vertigo, and facial paralysis. Any previous operative reports must be reviewed although they may not reflect the current status of the middle ear. Other medical problems such as diabetes, heart, lung and kidney disease should be documented to determine if the patient will need additional preoperative medical clearance.

The ear exam starts with evaluation of the pinna for any lesions or signs of infection such as cellulitis, perichondritis, or discharge at the meatus. Otomicroscopy is then performed. The external auditory canal (EAC) is evaluated for cerumen impaction, discharge, or canal skin infection or lesions. The tympanic membrane is evaluated after the EAC has been cleaned. Attempts are made to locate the usual landmarks. If a perforation or retraction is present, the extent and location is noted. Presence of cholesteatoma, continuity of the lateral attic wall, presence of tympanosclerosis, status of the annulus and ossicles, and segmental middle ear aeration are all evaluated.

Audiometric evaluation is necessary and includes tuning fork testing by the surgeon, air-bone-speech audiometry, and an index of suspicion for Tullio's phenomenon which may be a subtle sign for labyrinthine fistula. Tullio's phenomenon is said to be present when a loud noise precipitates vertigo. The most accurate audiometric evaluation is achieved when the ear is dry and should be performed after maximal attempts at achieving this goal. This may mean placing the patient on ear drops with or without oral antibiotics for ten to fourteen days or longer. Strict dry ear precautions should be employed. If cholesteatoma is present or if the patient is noncompliant, a dry ear may never be attained.

Objectives of medical and surgical management of the perforated TM should be discussed extensively with the patient. The indications for surgery include conductive hearing loss due to TM perforation or ossicular dysfunction, chronic or recurrent otitis media and recurrent otitis media due to contamination through a perforated TM, progressive hearing loss due to chronic middle ear pathology, perforation or hearing loss persistent for more than three months due to trauma, infection or surgery, and the inability to bathe or participate in water sports safely due to perforation of the TM. The goals of tympanoplasty are (1) to establish an intact tympanic membrane (2) to eradicate middle ear disease and create an air-containing middle ear space and (3) to restore hearing by building a secure connection between the ear drum and the cochlea. Once surgery has been decided upon, the risks, benefits and alternatives to the procedure are discussed. All patients undergoing tympanoplasty are also consented for possible mastoidectomy, particularly in patients with a persistent or recurrently draining ear as some cholesteatomas are not visible on exam or computed tomography.

Techniques

There are two widely accepted techniques for grafting in tympanoplasty: the underlay technique or medial grafting and the overlay technique or lateral grafting. Either technique may be equally successful in experienced hands, however, it is generally accepted that overlay grafting is technically more challenging and has the potential for more complications. Lateral grafting may be more useful in repairing large perforations particularly those that involve the anterior and marginal as it offers exceptional exposure to these lesions. The technique decided upon by the surgeon depends on his or her familiarity with the particular procedure and training experience.

Underlay technique (medial grafting)

Tympanoplasty is usually performed under general endotracheal anesthesia although patients who are reluctant to undergo general anesthesia may be given local anesthesia supplemented with intravenous sedation. Nitrous oxide should be avoided as it can shift the graft position. Muscle relaxants should also be avoided if possible. The postauricular and canal skin are initially injected with 1% lidocaine with 1:100,000 concentration of epinephrine to assist with hemostasis.

Tympanoplasty is typically performed via a postauricular approach although transcanal approaches are also utilized and is equally successful in the appropriate patient. Some authors recommend against the transcanal approach if a 5 mm speculum is unable to fit into the canal and for a tortuous canal. The postauricular incision is made approximately 1 cm behind the postauricular crease, a location that simplifies closure. A large temporalis fascia graft is harvested, cleaned of residual muscle, and placed on a ceramic block to allow drying. A T-shaped incision is made in the periosteum overlying the mastoid. Alternatively, a Palva flap can be made. The periosteum is elevated and moved anteriorly into the ear canal. The canal skin and periosteum is elevated using a duckbill elevator or round knife. A self-retaining retractor is placed to retract the canal skin and the ear forward. The canal incision is designed to create a laterally based canal skin flap or vascular strip. The horizontal incision is cut first approximately 2 to 5 mm lateral to the annulus from the 12 to the 8 o'clock position (right ear). The vertical incisions are made next. The superior limb follows the tympanosquamous suture line and the inferior limb follows the tympanomastoid suture line. The margins of the perforations are débrided. The functions to separate the inner mucosal and outer cutaneous layer and disrupt the fistulous tract.

The undersurface of the TM is then abraded with a round knife to increase adhesion to the graft. A tympanomeatal flap is then elevated anteriorly. The undersurface of the flap should be inspected for any skin that has turned over the edge of the perforation and is subsequently removed. The flap may be incised to create superior and inferior flaps which may give better exposure and may be more easily replaced. The status of the middle ear is then inspected for disease. The ossicles are gently manipulated with a Rosen needle to evaluate for mobility. The round window reflex may be inspected at this time. Some curettage of the scutum may need to be done to inspect the stapes footplate. If cholesteatoma is present, the decision is made at this time to perform a mastoidectomy which is then carried out. If the ossicles are eroded or involved with cholesteatoma or immobile, the decision as to what type of ossicular reconstruction must be

made (refer to types of tympanoplasty)

The eustachian tube and middle ear are then packed with Gelfoam. The fascia graft is shaped to the proper size needed for the perforation. It is then carefully tucked into position under the anterior tympanic membrane remnant and onto the posterior canal wall. Care is taken to obtain the maximum amount of circumferential overlap of the graft with the TM. Rizer (1997) recommends at least 5 mm of overlap if possible. The annulus is placed back into position posteriorly and the vascular strip is carefully moved into its anatomic place. Gelfoam is placed over the drum remnant, graft, and vascular strip and the external canal is filled with a bacitracin ointment impregnated cotton ball. The postauricular incision is closed subcutaneously with absorbable suture and steri-strips or staples are applied to the skin. A mastoid dressing is placed to provide light pressure and protection. The patient is then carefully awoken from anesthesia attempting to avoid unnecessary coughing or straining which could increase eustachian tube and middle ear pressure.

Advantages of medial grafting include: (1) ideal grafting for small and easily visualized perforations, (2) technically less demanding and less time consuming than lateral grafting, (3) avoids complications of TM lateralization and blunting. Disadvantages include (1) less visualization of the anterior meatal recess as compared to lateral grafting, (2) reduction in volume of the middle ear space particularly in cases with severely diseased middle ear mucosa, and (3) increased failure when the bed size of the graft is limited secondary to large anterior marginal perforations

Overlay technique (lateral grafting)

The initial steps in exposing the TM through postauricular incision for the overlay or lateral grafting technique are similar to that of medial grafting. Once the vascular strip has been elevated the remainder of the bony canal skin and periosteum is elevated medially towards the annulus. Once the annulus is reached, dissection is continued onto the TM between the squamous and fibrous layer. Getting into this plain is more easily accomplished starting anterosuperiorly using cup forceps. A duck bill can then be used to bluntly dissect the rest of the squamous layer off of the TM. Sheehy then recommends drilling down the anterior bulge of the bony canal and enlarging the anterior angle created by the canal and the TM. This is thought to prevent postoperative blunting. The fascia graft is then placed over the TM remnant. A slit is made in the graft to allow it to be placed medial to the handle of the malleus. It is thought that the squame left on the malleus will then grow outward over the graft. The canal skin is then replaced and the vascular strip is laid back down. The closure is the same as for the medial grafting technique

Advantages of lateral grafting include excellent exposure of the anterior meatal recess, high success rate because the drum is essentially replaced intact at the end of the procedure, and no resulting reduction in the middle ear space. Disadvantages are as follows: (1) technically more demanding (2) complications including lateralization and blunting of the TM and development of epithelial cysts or cholesteatomas on the TM, and (3) delayed healing up to 4 to 8 weeks.

Classification of tympanoplasty

Wullstein created a classification scheme in 1956 identifying five basic types of tympanoplasty. This classification was established to predict outcomes. Many authors criticize this system because it does not incorporate the status of the middle ear other than characteristics of the ossicular chain. Wullstein's classification of tympanoplasty is as follows:

Tympanoplasty type I:

Type I tympanoplasty is performed when all three ossicles are present and mobile and involves repair of a TM perforation or retraction without ossicular chain reconstruction.

Tympanoplasty type II

Type II tympanoplasty is utilized when the malleus is eroded and involves grafting the tympanic membrane to an intact incus and stapes or remnant of the malleus

Tympanoplasty type III

A type III tympanoplasty is indicated when the lateral ossicles are eroded. The stapes must be intact and mobile. The tympanic membrane/graft or if a partial ossicular chain reconstruction prosthesis is used is placed in contact with the stapes superstructure.

Tympanoplasty type IV

Type IV describes an absent or eroded suprastructure with the graft or tympanic membrane overlying a mobile stapes footplate. The resulting middle ear consists of the hypotympanum and the Eustachian tub orifice only.

Tympanoplasty type V

Type V tympanoplasty is used when the stapes footplate is fixed. Type Va involves grafting over a fenestration created in the horizontal semicircular canal. This technique has largely been abandoned in favor of the type Vb which involves a stapedectomy

Postoperative care

Hospital discharge occurs the same day of surgery, unless the patient is nauseated or vertiginous. The mastoid dressing is removed the following day by the patient or a family member. The incisions can be cleaned twice daily with hydrogen peroxide and topical antibiotic drops are applied twice daily. The steri-strips or staples are removed in one week. Patients are instructed to follow dry ear precautions and limit activity initially to avoid Valsalva maneuvers.

Patients are seen at three weeks to remove and suction the packing from the external auditory canal and to ensure that adequate healing has begun. They are seen again at six weeks to evaluate complete healing. An audiogram may be obtained at this time or 2 to 3 months postop.

Grafting materials

Multiple substances have been used for grafting the TM since the inception of tympanoplasty. The original use of full thickness and split thickness skin grafts has been replaced by other graft substances because of the high rate of delayed re-perforation secondary to desquamation and subsequent infection. House and Sheehy started using canal skin and initially had excellent results (97%) however subsequent desquamation occurred with these grafts as well, resulting in infection and delayed failure (77% of cases were ultimately successful). Vein grafts were first used by Shea and then replicated by Tabb (1960). Initial results were excellent however the graft tended to atrophy after a few months and occasionally re-perforate. Hermann (1960) was the first to describe the use of temporalis fascia as a graft material. Storrs (1960) was the first to use temporalis fascia in the United States. It now is the most common source of graft material used in tympanoplasty today. It has the benefit of providing a large quantity of graft material, it is more sturdy than loose areolar tissue, more resilient than vein, and is easily harvested without need for a separate incisions. Homograft tympanic membrane has been used to replace severely damaged TMs and has similar success rates as temporalis fascia (Hicks, 1988), however, the risk of transmission of infections prions and HIV has limited the use of this material

Cartilage tympanoplasty

Cartilage was first used in middle ear surgery for ossicular chain reconstruction in 1958 by Jansen. In 1963, Salen and Jansen first reported the use of cartilage composite grafts for tympanic membrane reconstruction. Over the past twenty years autologous cartilage-perichondrium grafts have come into use to prevent recurrence retraction pockets and cholesteatomas in patients with Eustachian tube dysfunction. Cartilage is also thought to reduce the rate of extrusion of prostheses used for ossicular chain reconstruction. Vrabec (2002) showed that patients with postoperative atelectasis had a higher rate of extrusion of their prosthesis and recommends cartilage tympanoplasty to prevent this. Cartilage grafts are usually used in combination with temporalis fascia grafts and are most successful when placed posterosuperiorly and in the area of the posterior pars flaccida (Poe and Gadre, 1993). Cartilage has also been used to graft the entire TM (Dornhoffer, 1997). Hearing results after cartilage tympanoplasty have been shown to be comparable to temporalis fascia and perichondrium (Gerber et al., 2000 and Dornhoffer, 1997 respectively).

Tympanoplasty in children

Otologic surgery in children is considered to be less successful than in adult patients. Success rates for pediatric tympanoplasties are reported to range from 35 to 93%. Most consider the higher incidence of otitis media and eustachian tube dysfunction in the pediatric population as the reason for poorer results. Most consider cholesteatoma or the chronically draining ear that is resistant to medical therapy as indications for surgery. The management of patients with persistent perforation of the tympanic membrane, with or without intermittent otorrhea, is cause of considerable controversy. Numerous factors to predict success or failure in elective cases have been studied including: age, surgical technique, status of the contralateral ear, presence of

adenoids, presence of active infection, size of the perforation, and eustachian tube function. There is no consensus of opinion despite extensive literature on the topic.

The different views concerning the right time for closing a dry perforation in children can be summarized as follows: 1) A perforation should not be closed before the child has attained school age. 2) A perforation should not be closed before the child has reached the age of 10 to 14 years; and in cases of bilateral perforations in which tubal function is considered to be more seriously affected, the child should be at least 12 years of age. 3) The indications for surgery in noncholesteatomatous chronic otitis media and its sequelae should be very strict. 4) In older children the ear must be dry for a period of at least one year, and in younger children for two years, before the perforation is closed. (Podoshin *et al.*). These views are certainly not universally accepted especially concerning the age at which repair is most appropriate. Ages ranging from 3 to the teen years have been recommended in the literature.

In discussing the need and timing for tympanoplasty in children, the following points must be considered. 1) Frequent upper respiratory tract infections and frequent episodes of acute OM may be contraindications, 2) narrow external auditory canals and technical difficulties are more frequent in children than in adults, 3) tubal function is poorer in children than in adults, 4) poorer long-term results occur in children than in adults including high re-perforation rates, and 5) closure of the perforation may result in secretory otitis with fluid accumulation or retraction and adhesive otitis; there is no immediate need for closing a small unilateral perforation associated with only a minor hearing impairment, particularly in view of the associated difficulties and complications. A small perforation may even function as a useful ventilation tube. 9

Despite all of this concern, Tos and Lau (1989) found high take rates and found that the age of the child is not a decisive factor in the success rate of tympanoplasty which, “when performed for the right indications, is a more rewarding procedure in children than in adults.” They found that tympanoplasty at an early age helps to lessen progression of ossicular pathology and recommended early closure because of this concern. They quote a graft-take rate of 92% with only four late perforations (6 of 10 re-perforations were closed with repeat procedures) at an observation time up to 15 years. They report closure of the air-bone gap to within 20 dB in 88% and only a 5% rate of subsequent insertion of grommets secondary to middle ear effusions. They do not mention rates of atelectatic pocket formation. Podoshin *et al.* studied older children aged 9 to 14 trying to define the “magic age” of closure and report a “success rate” of 92% but do not comment on rates of residual disease or re-perforation.

Many authors dispute this high success rate although they concede that initial healing rates can be as high as in the adult population. They contend that delayed failure and recurrence of middle ear disease prohibit long term success in the majority of patients. A study by Manning *et al.* found successful closure of the tympanic membrane in 78% of tympanoplasties initially but only 52% had a healed graft with good postoperative middle ear function. Gianoli *et al.* had a 92% rate of successful graft healing but when using the strictest reporting criteria at two years of followup only had a 38% success rate. They also found that patients with previous adenoidectomy and more impressively adenotonsillectomy had statistically higher success rates of tympanoplasty.

Vrabec and Deskin (1999) recently performed a meta-analysis of all the variables commonly questioned in the literature and found that advancing age is the only parameter that reached statistical significance when judging for success of the procedure. No other factor could be definitively associated with success.

It is obvious from all the dispute on tympanoplasty success, especially in the pediatric age-group, that outcome measures need to be standardized. The ability to use published literature in guiding your management of pediatric patients has been compromised by variable reporting methods. There are many different definitions of success and many authors use different criteria to gauge this. The ultimate objectives of the surgery are repair of an anatomic deformity and improved function, but a lower incidence of recurrent disease is critical for long-term success. This incidence of recurrent disease needs to be uniformly presented in future studies along with longer followup data in order to come to a more scientific conclusion.

Complications

The complications associated with tympanoplasty are usually the result of two factors: First, the extent of destruction caused by the disease process, exposing vital structures to injury, and second, surgical accidents.

Postoperative infections are considered a complication and can be due to poor aseptic technique or to the presence of bacteria in the ear at the time of surgery. Graft failure is a complication that is often associated with postoperative infection. Graft failure can also occur because of inadequate packing of the anterior mesotympanum with gelfoam. This allows the anterior graft to fall away from the anterior drum remnant. Faulty undersurface grafting technique will often result in graft failure.

Chondritis is rare but can be a significant problem requiring antibiotics. This can occur if the vertical incision is carried too far laterally into the conchal cartilage. Small epithelial pearls or “drum cholesteatomas” occasionally develop postoperatively and are more common with the lateral grafting technique. These can be removed in the clinic with the cooperative patient by uncapping the dome and removing the pearl. Leaving remnants of epithelium on the tympanic membrane or anterior inferior sulcus when elevating the external canal skin from the medial canal can result in residual drum or canal cholesteatomas.

Injury to the chorda tympani nerve results in disturbances of sensation of the tongue and the sense of taste usually described as metallic. This typically results when the chorda is stretched, desiccated, or divided. Patients may remain symptomatic for 4 to 6 months or occasionally have permanent dysfunction.

Sensorineural hearing loss and vertigo are rare. Excessive manipulation or trauma to the ossicular chain may be transmitted to the inner ear. A greater conductive hearing loss may develop despite successful repair of a tympanic membrane perforation. Explanations for an unexpected result include an unrecognized eroded incudostapedial joint, significant blunting of the anterior sulcus, or lateralization of the tympanic membrane from the malleus handle and

umbo.

Some complications have to do with the type of technique employed. For instance, lateralization and anterior blunting of the graft occur most commonly with the overlay technique, as does stenosis of the external auditory canal. A graft that is too thick, placed beyond the fibrous annulus, and extended onto the anterior inferior canal wall may result in blunting. This can be avoided by trimming the graft to the appropriate size and shape. The ear canal skin may attempt to heal with cicatricial mid canal soft tissue stenosis. If left unattended, this appears to be a lateralized drum. In the immediate postoperative period most patients have relatively insensate canals, allowing office debridement and stenting with Merocele stents or wicks.

Results

Closure of the perforation

Ideally, all tympanoplasty efforts result in an intact tympanic membrane. Tympanic membrane grafting in a clean, dry ear with normal eustachian tube function should be successful routinely. Residual perforations do occur and frustrate the surgeon and the patient. One must attempt to determine whether failure of the graft was due to technical error, infectious complications, or poor tubal function. Failure due to the first two reasons are often amenable to revision surgery. Patients with poor tubal function and recurrent otorrhea may require a revision tympanomastoidectomy. 1

Smyth in his 1992 Toynbee Memorial Lecture stated that most publications that discuss the results obtained with tympanoplasty report a success rate of around 90 percent. Such a statistic can be seen as justifying modern techniques of tympanic membrane repair and engendering patient's confidence. However, reliance on the available data must be diminished if the frequently short durations of follow-up and the usual methods of calculating success rates are taken into account. Observation times in the majority of operated ears are less than one year. Most data analyses are confined to numbers of ears with maintained healing of the tympanic membrane and do not include the formation of atelectatic pockets. 6

Halik and Smyth found a success rate of 89% with regard to maintained healing of the tympanic membrane and 95% with regard to atelectatic pocket formation. When corrected with survival life-table analysis they found their rate dropped to 81% for successful closure and 91% for avoidance of atelectatic pocket formation at 11 years. They found that re-perforation and atelectatic pocket formation occurred with relentless frequency to at least 11 years. They also noted a poorer rate of subsequent success in these patients who redeveloped perforations and quoted a rate of approximately 60%. They feel that long-term results of 90% success or better are difficult to achieve even by experienced otologic surgeons. They found that the type of middle ear secretion present at surgery had no effect on result. Homograft dura and autologous temporalis fascia had no significant difference in take rates. They did report a trend for better results when using fascia and operating on dry ears. Many authors have reported less success with closure of anterior perforations. Recent work has shown the anterior portion of the tympanic membrane to be the least vascular. They recommend autologous temporalis fascia in this area as it is less antigenic, has a low metabolic rate, and is better able to withstand prolonged anoxia.

Hearing

Albu *et al* found many anatomic and technical factors responsible for postoperative hearing results. The mucosal status of the middle ear was the most important predictive factor. The presence of the manubrium mallei was the second most important predictive factor as it allows for the proper adaptation of the myringoplasty graft and optimizes the stability of the reconstructed ossicular chain. In cases with perforated TM, perforations <50% of the drum surface performed significantly better than larger ones.

Halik and Smyth contradict this and found that secretion type, site of perforation, and graft material had no adverse effect on hearing. They report their success rates as being comparable to other quoted literature. They had approximately an 80% success rate of closure of the air-bone gap to within 10 dB at five years but could not comment on results beyond this period as many of their patients were discharged from followup. They recommended aiming for a final air-conduction threshold less than 30 dB or within 15 dB of the other ear for the patient to benefit from binaural hearing and sound localization.

Underlay versus Overlay

Few studies have compared the results of overlay tympanoplasty versus underlay. Doyle *et al.* (1972) compared 52 ears reconstructed with the overlay technique to 79 ears reconstructed with the underlay technique. All were performed in a training program. His results showed an overall re-perforation rate of 36% for the overlay technique versus 14% for the underlay technique. Hearing was also better in the underlay group with improvement (air level within 15 dB of the preoperative bone level) in 62% versus 27% for the overlay group. Complications were also less for the underlay group. Doyle concluded that in experienced hands, the either technique can be equally successful, however in the hands of residents and otolaryngologists of limited experience, the medial grafting of the TM gives better healing and fewer complications. One thing to note is that all the tympanoplasties performed in Doyle's study were done through an endaural approach. It is very difficult to visualize the annulus and anterior sulcus in this way. The majority of tympanoplasties today are performed through a postauricular approach, which gives way to a much better angle of vision particularly for the overlay technique. Therefore, some argue that the conclusions from this study are outdated and no longer apply.

Sheehy and Anderson reviewed 472 cases of overlay tympanoplasty. 97% graft take was seen in cases using fascia grafts versus 84% for those cases in which canal skin was used. 1.3% of cases were complicated by anterior blunting and lateralization. 80% had air-bone gaps within 10 dB. Important conclusions from this study were that fascia is better than canal skin and that higher complication rates were seen in patients who had undergone surgery via a transcanal approach.

The largest study to date comparing overlay to underlay grafting was performed by Rizer (1997). He retrospectively reviewed 551 cases in which the underlay technique was used and 158 cases using the overlay technique. Successful healing was seen in 88.8% of the underlay group compared to 95.6% of the overlay group. Improvement in hearing (closure of air-bone gap to within 10 dB) was seen in 84.9% of the underlay group compared to 80.4% of the overlay

group. Complications were seen in 7.8% of the underlay group which included infection and worsened hearing. In the overlay group 8.9% experienced complications which included infection, worsened hearing, and lateralization of the TM (one case). In both groups, no relationship was found between the incidence of re-perforation and the following variables: age of the patient, perforation size, perforation location, middle ear status, presence of cholesteatoma, and the cause of disease.

Conclusion

Tympanoplasty has a rich history which resulted in the establishment a large portion of the subspecialty of otologic surgery as we know it. The development of antibiotics, use of the operating microscope and the creativity and work of numerous surgeons has made tympanoplasty a successful and rewarding operation. Still, further research in the era has yet to be done particularly in the area of pediatric tympanoplasty. Establishment of a more uniform method of describing preoperative disease and reporting postoperative outcomes is also needed.

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