Chapter 11: Reconstruction of the ear

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In this chapter the evolution of surgical techniques of tympanoplasty with and without mastoidectomy in chronic suppurative otitis media is outlined, the terminology defined and the biological and synthetic materials used to reconstruct the middle ear transformer mechanism are described.

Definitions of operative terms currently used in middle ear and mastoid surgery

Skin incisions

These are named according to the anatomical site in which they are made, that is *meatal, endaural* and *postaural* and can be combined and fashioned in a variety of ways to provide the access, exposure and other requirements (for example meatal skin flaps and meatoplasty) of the operation to be performed.

Myringoplasty

An operation performed to repair or reconstruct the tympanic membrane, often incorrectly referred to as type I tympanoplasty (because myringoplasty does not imply removal of disease from the middle ear).

Tympanoplasty

An operation performed to 'eradicate disease in the middle ear and to reconstruct the hearing mechanism, without mastoid surgery, with or without tympanic membrane grafting' (Committee on Conservation of Hearing, of the American Academy of Ophthalmology and Otolaryngology, 1965).

Ossiculoplasty

An operation performed to repair or reconstruct the ossicular chain.

Mastoidectomy

Open or canal wall-down procedures

Atticotomy

An operation performed to remove all or part of the outer attic wall (scutum) and adjacent deep posterior meatal wall, to expose the attic (epitympanum) and when necessary the aditus ad antrum in order to gain access to these sites and their contents and/or remove disease limited to these sites.

Radical mastoidectomy

An operation performed to eradicate all middle ear and mastoid disease in which the mastoid antrum and air cell system (when present), aditus ad antrum, attic and middle ear (mesotympanum and hypotympanum) are converted into a common cavity exteriorized to the external auditory meatus. During the course of removal of all diseased tissues the tympanic membrane, malleus and incus are removed, leaving only the stapes *in situ* (footplate only plus/minus superstructure, if intact and healthy).

Modified radical mastoidectomy

This operation differs from the radical mastoidectomy in that the tympanic membrane or remnants thereof and ossicular remnants (usually the malleus handle and stapes) are retained (synonym: *attico-antrostomy* if the operation is performed by the anterior-posterior technique, that is by exposing the attic first and then proceeding backwards into the aditus ad antrum and mastoid antrum).

Closed or canal wall-up procedures

Cortical mastoidectomy

This is an operation performed to remove disease from the mastoid antrum and air cell system (when present) and the aditus ad antrum, with preservation of an intact posterior bony external auditory canal wall, without disturbing the existing middle ear contents.

Combined approach tympanoplasty

(Synonym: intact canal wall tympanoplasty with mastoidectomy.) This is an operation performed to remove disease from the middle ear and mastoid by way of (a) the mastoid, (b) a posterior tympanotomy, and (c) the transcanal route, followed by reconstruction of the middle ear transformer mechanism.

Tympanoplasty with mastoidectomy

This is an operation performed to eradicate disease in the middle ear and mastoid and to reconstruct the hearing mechanism with or without tympanic membrane grafting: for example, combined approach tympanoplasty or cortical mastoidectomy with tympanoplasty (closed or canal wall-up techniques); muscle or other obliteration of an open mastoid cavity with tympanoplasty (obliteration techniques); reconstruction of the outer attic and posterior canal wall of an open mastoid cavity with tympanoplasty (canal wall reconstruction techniques); open or canal wall-down mastoidectomy with tympanoplasty (cavity techniques).

Cavity obliteration and canal wall reconstruction techniques convert an open cavity into a closed cavity.

The evolution of surgical techniques of tympanoplasty with and without mastoidectomy

The fundamental techniques and concepts of modern reconstructive middle ear surgery in chronic suppurative otitis media with and without cholesteatoma, came into being when Moritz (1952), Zöllner (1953, 1955) and Wullstein (1953, 1956) in Germany, introduced the tympanoplasty operations. These operations were designed to restore or conserve hearing and promote healing, after the excision of disease from the middle ear and mastoid. Skin grafts were used to repair the tympanic membrane and close the tympanum and were positioned as free 'onlay' grafts over the tympanic membrane remnant and whatever elements of the ossicular chain remained after the surgical excision of disease. If only a mobile stapes footplate remained, this was left exteriorized and the skin graft was positioned so as to create a round window baffle (an air containing tunnel, in continuity with the eustachian tube and incorporating the round window). If the stapes was fixed by tympanosclerosis or otosclerosis, a fenestration operation was performed.

Prior to this pioneering work, the surgery of chronic suppurative otitis media had been wholly orientated to the eradication of chronic infection and cholesteatoma and the prevention of intracranial infection. The radical mastoid operation (Stacke, 1893), the modified radical mastoid operation (Bondy, 1910) and the more conservative modifications of the Bondy operation, such as the atticotomy (Tumarkin, 1948) were all operations designed to *expose, excise* and *exteriorize* disease to the external auditory meatus. Although attempts had been made by a few surgeons to obliterate open mastoid cavities with muscle, and thus promote healing (Kisch, 1928; Meurman and Ojala, 1949), no attempt had been made by these surgeons to close the tympanum and repair the ossicular chain after the excision of disease.

The concepts and final execution of the classical tympanoplasty operations by Moritz, Zöllner and Wullstein had not come about by chance, but were influenced by other events. Berthold (1876) in Germany had successully repaired the tympanic membrane with full thickness skin and called the operation 'myringoplastik'. In 1921, Nylen working in the Stockholm University Ear Clinic introduced a monocular operating microscope and a year later Holmgren, Nylen's teacher, was first to introduce the binocular operating microscope and magnifying ocular loop. There had also been a re-orientation of otological surgery from operations for infection towards reconstruction, when Lempert (1938) in America, successfully carried out the one-stage fenestration operation. Rosen (1953) revived the stapes mobilization procedure for otosclerosis and Juers (1953) had noted that in some patients with cholesteatoma and erosion of the long process of the incus, pathological approximation of the pars tensa with an intact mobile stapes, produced excellent hearing. He created a similar conduction mechanism surgically, using a meatal skin flap and called the operation 'myringodermostapediopexy'. The dental drill rapidly replaced the hammer and gouge previously used for mastoid exenteration, sulphonamides and antibiotics in the form of penicillin were now available and there had been significant improvements in general and local anaesthetic techniques. Leading otologists such as Simson Hall in Edinburgh, Cawthorne in London and Shambaugh in America had operating microscopes which incorporated light sources and were developing new otological techniques, but were largely ignorant of developments in Germany at that time. In 1948, Wullstein had his own binocular microscope built by Leitz and from 1948 to 1953 performed over 1000 ear operations (Wullstein, 1981).

In 1953, the Zeiss operating microscope became available commercially and, in the same year, Wullstein and Zöllner launched their tympanoplasty methods at the Fifth International Congress of Otorhinolaryngology in Amsterdam.

These methods were soon adopted vigorously by otologists all over the world, but many experienced difficulty and disappointment with skin grafts used to repair the tympanic membrane and line open mastoid cavities and with the hearing results obtained from the classic tympanoplasties. Full thickness skin fared badly in the ear. The grafts were bulky, continued to secrete sebum and became infected and necrotic (Wright, 1960). Eleven per cent of the grafts perforated; epithelial cysts and graft cholesteatomata complicated 3% of cases (Guilford, 1962; Wright, 1963) and the formation of fibrous adhesions between the undersurface of the graft and the promontory resulted in obliteration of the middle ear space (Thorburn, 1960; Palva, 1963). Similar problems were encountered with split skin grafts, 30% of which perforated, and surgeons were encouraged to find alternative grafting materials for tympanic membrane repair.

In 1956, Zöllner (Zöllner, 1963) successfully used autologous fascia lata. Hall (1956) introduced autologous cheek mucosa and Claros-Domenech (1959) introduced autologous periosteum. Shea (1960a) accidentally tore the tympanic membrane during a stapedectomy procedure and repaired the tear suffessfully with a free autologous vein graft placed medial to the tympanic membrane, thus introducing the 'underlay' technique of myringoplasty. Heermann (1960) reported successful myringoplasty results using autologous temporalis fascia 'onlay' grafts and successful results were also reporting using tragal perichondrium (Goodhill, Harris and Brockman, 1964) and free autologous fat grafts (Ringenberg, 1962). These grafts were stable and easy to handle, only a small percentage perforated and they could be positioned lateral to the tympanic membrane remnant (onlay) or medial to it (underlay). Chalat (1964) was the first to use tympanic membrane allografts and 2 years later Albrite and Leigh (1966) published their preliminary report on allograft dura mater myringoplasty.

The surgery of otosclerosis was yet again to have a profound effect on tympanoplasty techniques. In 1956, Shea performed the first stapedectomy, covered the oval window with subcutaneous connective tissue and replaced the stapes with a Teflon replica (Shea, 1956). He later introduced the vein graft-polyethylene tube method of stapes replacement. Soon other implant materials including tantalum, platinum and stainless steel wire were used as stapes replacement prostheses and, as such, were well tolerated in the middle ear. These materials were, therefore, applied to ossicular chain reconstruction in tympanoplasty but early enthusiasm for these techniques soon waned when it became apparent that many prosthetic assemblies were unstable and became displaced in the middle ear. If the prosthesis came into contact with the undersurface of the tympanic membrane, extrusion was common, despite the ingenuity of design, such as that shown by the polyethylene-tube umbrella (Oppenheimer and Harrison, 1963), the polyethylene tube-wire mesh 'sunflower' columella (House and Sheehy, 1963) and the Teflon 'umbrella' (Austin, 1963), and these prostheses were, therefore, abandoned.

From this catalogue of disasters, enormous experience was gained with microsurgical techniques, together with a more comprehensive understanding of the reparative processes in the middle ear and mastoid and the realization that successful ossicular chain reconstruction could only be achieved in a closed, air-containing ear cavity (Rambo, 1961; Tabb, 1963). To promote growth of new, healthy middle ear mucosa, to maintain a middle ear free of adhesions and to support the neotympanic membrane, absorbable and non-absorbable materials were placed in the middle ear. Wullstein (1960a) advocated the use of absorbable gelatin sponge known today as Gel-foam or Gel-film. Non-absorbable plastic sheeting made of polyethylene (House, 1960), Teflon, Silastic (see Shea, 1981) and paraffin wax (Rambo, 1961; Tabb, 1963) were introduced for use in ears where the excision of disease included removal of most of the middle ear mucoperiosteum. These materials needed to be removed from the ear 3-6 months postoperatively and the concept of 'staged tympanoplasty' was born, that is in these 'severely damaged' ears, no attempt was made to reconstruct the sound conducting mechanism until a healthy, ventilated middle ear cavity and an intact, healthy tympanic membrane existed (Tabb, 1963; Farrior, 1966; Austin, 1969; Sheehy and Crabtree, 1973).

Leading otologists had also come to realize that no single operation was pertinent to the surgical treatment of chronic suppurative otitis media. The two opposing demands of tympanoplasty, namely radical and complete removal of disease and reconstruction of the sound conducting mechanism posed a major problem. Every case needed to be evaluated on the basis of whether disease excision required a purely transcanal operation, or whether, in addition, some form of mastoidectomy was needed together with a tympanoplasty.

When a mastoidectomy is necessary, two basic surgical techniques have evolved, namely, the canal wall-down and the canal wall-up procedures.

In the canal wall-down procedures, the posterior bony meatal wall and the outer attic wall are removed and the attic, aditus ad antrum together with the mastoid antrum and air cell system are exteriorized to the external auditory meatus. Small 'open cavities' thus created usually epithelialize rapidly and are healthy and stable postoperatively. Large cavities, however, are often prone to recurrent infection due to incomplete epithelialization (despite complete excision of disease, a low facial ridge and the presence of a wide meatus) and this, in turn, prejudices the reconstruction of the middle ear sound conducting mechanism. To avoid this, cavity obliteration techniques and posterior canal wall reconstruction techniques were introduced.

Obliteration techniques to reduce the size of the mastoid cavity, or obliterate it completely, have been successfully achieved using autologous cancellous iliac crest bone grafts (Schiller and Singer, 1960) and allogeneic femoral cortical bone chips (Shea, Gardner and Simpson, 1972). More popular, however, are the muscle obliteration techniques using pedicled muscle-periosteal transposition and rotation flaps of sternomastoid muscle (Meurman and Ojala, 1949), temporalis muscle (Rambo, 1958), postauricular muscle-periosteal flaps based on the sternomastoid muscle (Hilger and Hohmann, 1963) and the anteriorly based postauricular muscle-periosteal transposition flap (Palva, 1963, 1982).

Posterior canal wall and outer attic wall reconstruction techniques using autologous or allogeneic cartilage grafts (Jansen, 1972; Smyth, 1972a; Wehrs, 1972, 1982a), allogeneic external auditory meatus bone (Smith, 1970) or autologous mastoid bone (Marquet, 1976a) and mastoid bone paté (Pulec, 1976) have been introduced as an alternative to cavity obliteration.

The canal wall-up techniques of tympanoplasty with mastoidectomy preserve the posterior bony external auditory canal wall and the tympanic sulcus, avoid a postoperative mastoid cavity and allow for reconstruction of the tympanic membrane in its normal anatomical position.

With the passage of time, increasing evidence has accumulated indicating that many surgeons fail to eradicate cholesteatoma (residual disease) in about 25% of all 'closed' operations at primary surgery (Smyth and Hassard, 1981) and in all forms of combined approach tympanoplasty there is a high incidence of retraction pocket formation (recurrent disease) (Austin, 1977; Smyth, 1982a). Of necessity therefore, all 'closed' operations must be staged and 'second look' revision procedures need to be continued until the surgeon is confident that the tubotympanic cleft is free of cholesteatoma. Alternatively, the ear with recurrent or residual disease must be converted into an 'open cavity'.

Enormous controversy surrounds the merits and demerits of 'open cavity' and 'closed cavity' (cavity obliteration, posterior canal wall reconstruction and intact canal wall techniques) (Kohut, 1980; Sheehy, 1980; Smyth, 1982a). Despite this, these operations produce two distinctly different types of middle ear space, namely, 'shallow' and 'deep', depending on whether the tympanic membrane is reconstructed in its normal anatomical position or at the level of the facial ridge. Consequent upon this different techniques of ossicular reconstruction needed to be found.

Grafts used in tympanoplasty and mastoidectomy

Otologists using tissue transplants to reconstruct the middle ear have, like other transplant surgeons, needed to add a number of new words to their vocabulary in order to describe the types of graft they use. This jargon has been called 'transplantese' and there has been much debate over the terminology that will prove to be most appropriate, informative and etymologically accurate. Nonetheless, a new terminology has evolved and this can and should be applied to tympanoplasty and mastoidectomy (Frootko, 1985a).

Four types of graft can be defined according to the genetic relationship between donor and host *(Table 11.1).*

Reconstruction of the ossicular chain

Ossicular bone autografts

Reticent to use metal and plastic prostheses in the middle ear, Hall and Rytzner (1957) performed the first ossicular chain reconstruction using autologous ossicular bone. Having accidentally fractured the stapes superstructure performing a stapes mobilization for otosclerosis, they successfully *interposed* the patient's own sculptured inus between the tympanic membrane and the mobilized stapes footplate. The immediate postoperative air-bone gap closure was short-lived because the incus slipped off the footplate. To prevent this complication in subsequent cases of otosclerosis, a small fenestration was made in the footplate or the stapes was removed, and the short process of the autologous incus placed directly into the oval window. In cases of chronic suppurative otitis media with erosion of the long process of incus, Hall and Rytzner removed the incus, malleus and stapes superstructure.

The autologous malleus was then sculptured and interposed between the neotympanic membrane and stapes footplate. They reported no serious cochlear damage but, in some cases, the interposed ossicle became displaced, or bony fixation occurred in the oval window niche. Three interposed ossicles removed at revision surgery showed histological evidence of vascularization of marrow spaces, some viable osteocytes in the lacunae, but no obvious new bone formation or bone resorption apart from minor reduction of calcified matrix on the surface (Hall and Rytzner, 1960, 1961). This work led directly to the application of ossicular bone grafting for reconstruction of the ossicular chain in tympanoplasty.

Table 11.1 Terminology

Old terminology		*New Terminology*		
Noun	*Adjective*	*Noun*	*Adjective*	*Definition*
Autograft	Autogenous	Autograft	Autologous or autogeneic	Tissue transplanted from one part of the body to another in the same individual, eg, a temporalis fascia or tragal perichondrial graft used to repair the tympanic membrane
Isograft	Isologous or isogenic	Isograft	Isogeneic or syngeneic	Tissue transplanted between genetically identical individuals, eg, an incus graft between rats of the same inbred strain
Homograft	Homologous	Allograft	Allogeneic	Tisue transplanted between genetically non-identical members of the same species, eg, a preserved human cadaver acquired tympanomeatal graft used to reconstruct the tympanic membrane, or a preserved human cadaver acquired incus used to repair an ossicular chain defect
Heterograft	Heterologous	Xenograft	Xenogeneic	Tissue transplanted between members of different species, eg, a preserved bovine vein graft used to repair a human tympanic membrane.

Autologous ossicles were also repositioned using *transposition* techniques. In these operations the incus remnant and/or malleus were partially mobilized from their normal anatomical positions and transposed onto the stapes head or footplate. When the long process of the incus was missing Bell (1958) removed the incus and transposed the malleus attached to the tympanic membrane by its umbo, onto the stapes head (tympanomalleostapediopexy). Similar malleus transpositions were described by Hall and Rytzner (1957), Farrior (1960) and Portmann (1963). Other transposition techniques used when the long process of the incus was missing involved mobilizing the incus out of the fossa incudis, dislocating the incudo-malleolar joint and transposing the necrosed long process onto the stapes head. In such cases

Farrior (1960) mobilized the incus/malleus complex leaving the incudomalleal joint intact and transposed either the short process of the incus or its eroded long process onto the stapes head. Long-term hearing results achieved with these transposition procedures were not published, but Farrior (1969) reported that many transpositions had failed because of ankylosis of the transposed ossicles to the bony walls of the tympanum.

Throughout the 1960s, therefore, most surgeons focused their attentions on the more successful *interposition* techniques using a sculptured autologous incus or malleus (Farrior, 1960, 1966; Portmann, 1963; Chandler, 1965; Guilford, 1965; Sheehy, 1965; Szpunar, 1967; Wright, 1967).

The usefulness of autologous ossicular bone grafts in tympanoplasty was challenged by Jongkees (1957) when he stressed that failure to control infection in chronic suppurative otitis media might be due to occult osteitis in the ossicles retained in the middle ear after the surgical removal of mucosal disease and/or cholesteatoma. These suspicions were confirmed when Grippaudo (1958) reported histological evidence of infection in 92% of incudes and mallei removed from 42 cases of chronic suppurative otitis media. Grippaudo emphasized that the use of these diseased autologous ossicles in tympanoplasty may prejudice the results of reconstruction. Similar evidence of osteitis in ossicles removed from cases of chronic suppurative otitis media was reported by Bellucci and Wolff (1966), and Steinbach and Hildmann (1972). Austin (1971) warned about the use of autologous ossicles that showed any evidence of erosion macroscopically and advised that any such ossicles with adherent squamous epithelium or cholesteatoma should never be used in reconstruction.

Ossicular bone allografts

Realizing the need to find a new material to reconstruct the ossicular chain in patients without a malleus, and/or incus, and/or stapes superstructure, or with severe infection or cholesteatoma involving the ossicles, House, Patterson and Linthicum (1966) introduced the incus allograft. These incus allografts, acquired from the healthy middle ears of patients undergoing surgery for the removal of an acoustic neuroma were preserved in 70% ethyl alcohol prior to use. Twenty-eight ossiculoplasties were performed using an alcohol-preserved allograft incus interposition technique, but only 10 were followed up. Of five tympanic membrane-to-stapes head interpositions, only two achieved a postoperative air-bone gap of less than 20 dB and, in five tympanic membrane-to-footplate interpositions, only one was successful. One incus extruded 9 months postoperatively and was examined histologically. No inflammatory response was found in or around the graft, the marrow spaces were vascularized but there was no new bone formation. House's (1969) impression was that these grafts remain in the middle ear as dead bone and he recommended that ossicles could be acquired post-mortem provided the donor did not have malignant disease, hepatitis, syphilis or chronic suppurative otitis media. Pulec (1966) found no evidence of resorption or change in shape of three alcohol-preserved incus allografts removed at revision surgery 3-21 months postoperatively.

Histologically, these grafts were found to be covered by mucous membrane and there were no signs of an inflammatory response. In the bony matrix 'no evidence of any living cell was discerned'. Linthicum (1966) compared the histological findings in nine autograft incudes and two alcohol-preserved allograft incudes used in tympanic membrane-to-stapes interpositions removed 9-12 months after surgery, because of lateral displacement of the graft off the stapes head. He found no evidence of inflammation in the middle ears of these cases at the time of revision surgery. In all specimens, host vascularization and connective tissue infiltration of marrow spaces was seen. New endosteal bone formation was found at a single site in only one specimen; in all the others, no new bone formation was found and most lacuane were empty. There was no difference in the macroscopic or histological appearance between the autografts and allografts. Austin (1971) found histological evidence of limited osteoblastic activity with new bone formation in one alcohol-preserved incus removed one year postoperatively; in another, 'massive absorptive erosion' was seen and Austin question whether or not this represented a rejection phenomenon. Kerr and Smyth (1971a) examined 19 incudes (nine autografts and 10 alcohol-preserved allografts) and four mallei (one autograft and three alcohol-preserved allografts) removed at revision surgery 3-39 months postoperatively; no macroscopic evidence of erosion was found. Histologically, bot the allografts and autografts were similar, with vascularization and plasma cell infiltration of marrow spaces together with small areas of new bone formation. It was noted that most new bone was formed in those grafts which had been longest in the middle ear. The authors concluded that there was no evidence of allograft ossicular bone rejection in the middle ear and that in time the grafts would be incorporated into the ossicular chain as vital structures. In a later report, however, Smyth, Kerr and Hassard (1977) concluded that new bone formation in alcohol-preserved ossicular bone allografts was not directly proportional to the time in the middle ear and that complete replacement of these grafts by new bone would be rare.

Preservation of cadaver acquired ossicular bone by autoclaving was introduced by Hildyard (1967). Having observed no adverse reactions and no morphological changes in autoclaved allogeneic incudes placed in the hypotympanum of six patients with central tympanic membrane perforations, Hildyard used an autoclaved incus allograft as a tympanic membrane-to-footplate interposition in one case. Ten months postoperatively, the incus was removed because of poor hearing gain; histologically the graft was found to be acellular with no evidence of revascularization, new bone formation or inflammatory response.

Encouraged by the apparent lack of immune or inflammatory response and the ability of these ossicular bone allografts to remain in the middle ear without resorption many surgeons started using allograft ossicular bone preserved in alcohol (Pulec, 1966; Wehrs, 1967; Smyth and Kerr, 1967) or by autoclaving (Hildyard, 1967; English et al, 1971) for ossiculoplasty when healthy ossicular autografts were not available.

Otologists now began to concentrate on designing stable ossicular interpositions. The popular 'loose' interposition techniques, that is tympanic membrane-to-stapes head interposition or tympanic membrane-to-footplate interposition did not produce consistently good results (Guilford, 1966; Hildyard, 1967; Armstron, 1969; Szpunar, 1969; Hough, 1970). The problems encountered included displacement of the graft, lateral retraction of the stapes head or footplate, consequent on lateral retraction of the neotympanic membrane during healing, and fibrous and bony ankylosis between graft and posterior bony annulus, facial canal or promontory (Hough, 1970; Austin, 1971). The grafts were also often too bulky (Goodhill, Westerbergh and Davis, 1974) and filled the space between the facial canal and the annulus blocking the epitympanic isthmus and therefore obstructing air flow into the aditus ad antrum with resulting mucus accumulation and continued inflammation (Austin, 1971).

By surgical trial and error, coupled with careful postoperative observation Guilford (1966) found that interpositions between the malleus handle and stapes head, that is malleus-stapes interposition or malleus-footplate interposition were more stable and produced better postoperative hearing gains than tympanic membrane-to-stapes head or tympanic membrane-to-footplate interposition. These sentiments were strongly supported by the experiences of Hildyard (1967), Armstrong (1969), Szpunar (1969), Hough (1970) and confirmed by Elbrond and Elpern (1965) in an experimental study of the stability and acoustic properties of various incus interposition techniques in cadaver temporal bone models.

In 1971, Austin presented his classification of the anatomical defects found in the ossicular chain in 1151 consecutive ears with chronic suppurative otitis media at the Abraham Lincoln School of Medicine in Chicago. Isolated loss of the malleus handle (2% of ossicular defects) and isolated loss of the stapes superstructure (1.7% of ossicular defects) were not classified because of their rarity. In all other cases, the incus was deficient either wholly or in part and four types of ossicular defect were therefore described depending on the presence or absence of the malleus handle and the presence or absence of the stapes superstructure (Austin, 1971).

When the malleus handle and stapes superstructure were present, Austin sculptured an autologous or allogeneic malleus head or incus body to fit between the malleus handle and stapes head. A cup-shaped depression was drilled into the graft to receive the stapes head and a concave depression carved to fit snugly against the malleus handle. This interposition technique was called the 'malleus/stapes assembly' and was more stable, less bulky, and less affected by lateral movement of the tympanic membrane during healing than was tympanic membrane-to-stapes head interposition.

When the malleus handle was present/stapes superstructure absent, Austin sculptured an autologous or allogeneic incus and interposed the graft precisely between the malleus handle and a small connective tissue pad placed on the stapes footplate. As with malleus/stapes assembly, the malleus handle was used as an energy coupler and lateral fixing point, and the small connective tissue pad on the stapes footplate helped centre the graft in the oval window niche and prevent slipping. This interposition technique was called the 'malleus/footplate assembly' and was more stable than tympanic membrane-to-footplate interposition and produced better hearing results. Similar techniques were described by Hildyard (1967) and Hough (1970).

Pennington (1973) improved the design of the Austin malleus/stapes assembly to deal with the two basic anatomical malleus/stapes relationships encountered in tympanoplasty. He designated the vertical malleus/stapes head relationship 'type 1a' and 'type 1b' and the horizontal malleus/stapes head relationship 'type 2'. In type 1a and 1b the incudomalleal joint surface of the incus was grooved to a deep yoke or 'mortice' to receive the malleus neck or handle, the incus short process was amputated and the long process dowelled or cupped to fit over the stapes head. In the type 2 case, the double dowel technique over the stapes head. Using these malleus/stapes assembly techniques, Pennington reported closure of the air-bone gap to less than 16 dB in 69% of 216 ears followed up for 2-5 years.

Wehrs (19740 introduced the notched incus autograft or allograft technique. For malleus/stapes assembly, the incus long process was amputated, a notch was drilled into the short process to accommodate the malleus neck or handle and the incus body was dowelled to fit the stapes head ('notched incus with short process'). For malleus/footplate assembly, the incus short process was drilled in a similar fashion and the long process placed directly onto the stapes footplate ('notched incus with long process'). To deal with the varying spatial relationships between the malleus handle and the stapes head or footplate, appropriate sculpturing of the notch and dowel was found to be applicable to most anatomical situations encountered.

These basic sculpturing techniques for malleus/stapes and malleus/footplate assemblies using allograft or autograft *incudes* or *mallei* with minor modifications are used by most surgeons today (Smyth, 1972b; Goodhill, Westerbergh and Davis, 1974; Marquet, 1976a; Ironside, 1979; Smith, 1980a, b; Hough, 1982; Smith and McElveen, 1982).

The least common of the ossicular defects encountered, namely the absent malleus handle but with stapes superstructure present and the absent malleus handle with absent stapes superstructure, pose the most difficult reconstructive problems. The number of solutions proposed testify to this fact, but fundamentally the problem has been tackled in two ways.

The first was to establish a link between the neotympanic membrane and the stapes using a sculptured allograft malleus or incus, that is tympanic membrane-to-stapes head or tympanic membrane-to-footplate interposition (Austin, 1971, 1982; McGee, 1979; Smyth, 1980). In a shallow middle ear space, myringostapediopexy has been recommended by Lee and Schuknecht (1971), Goodman (1980) and Smyth (1980) if the stapes superstructure is absent, Smith and Dobie (1976) and Marquet (1976a), recommended myringostapeidopexy using an allograft stapes positioned onto the footplate. Gotay-Rodrigues and Schuknecht (1977) were able to achieve a 30-dB postoperative air-bone gap in 59% of 72 ears treated by open mastoidectomy and the use of autologous temporalis fascia to create a round window baffle and small split-skin grafts to cover the exteriorized mobile footplate (type IV tympanomastoidectomy).

The second method was to reconstruct a neomalleus in the neotympanic membrane to form the main building block upon which a link could be established with the stapes head or footplate. Early attempts by Guilford (1966) to suture a rod-shaped autologous cortical bone graft to the undersurface of the neotympanic membrane were unsuccessful. Schiller (1979) was able to achieve a postoperative air-bone gap of less than 15 dB in only 30% of 33 cases using his two-stage malleomyringoplasty procedure. Hough (1982) has reported successful results using autologous cortical bone, shaped like the malleus handle or an allogeneic malleus placed on the undersurface of the neotympanic membrane and held in place by a sculptured allograft ossicle interposed between the neomalleus and the stapes head or footplate. Using a two-ossicle (allograft stapes - incus) assembly in ears without a tympanic membrane, malleus, incus and stapes superstructure, Tos (1978) has reported early postoperative closure of the air-bone gap to 18 dB or less in 67% of 23 cases.

Tympanomeatal and tympano-ossicular allografts

A major contribution to the problem of reconstruction of the malleus handle in the neotympanic membrane, developed as an evolution of the pioneering work with orthotopic cadaver acquired allograft tympanic membrane transplantation by Chalat, Betow and Marquet in the early 1960s.

Chalat (1964) used fresh, unpreserved tympanic membrane allografts to repair central perforations in three patients; two of these grafts perforated early and the procedure was abandoned. In 1959, Betow (1982) used an unpreserved tympanic membrane allograft to repair a perforation and noted graft resorption and necrosis on the twenty-eighth day postoperatively. In the same year, Brandow (1973) had observed similar necrosis and perforation of unpreserved tympanic membrane allografts in 11 patients. Both Betow and Brandow recognized that this graft necrosis was probably an immunological rejection phenomenon. Betow (1982) subsequently preserved tympanic allografts preoperatively in an antibiotic solution at -24°C, but the majority of these grafts perforated. Smyth and Kerr (1969) using tympanic membrane allografts which included a 6-mm cuff of meatal skin (tympanomeatal grafts), preserved in 5% chlorhexidine and 10% framycetin solution at -20°C preoperatively, reported necrosis and perforation in 65% of cases and Glasscock and colleagues (Glasscock and House, 1968; Glasscock, House and Graham, 1972) reported a similar high incidence of necrosis in tympanic membrane grafts preserved preoperatively in propriolactone or benzalkonium chloride or by freeze-drying techniques. Preservation in 70% ethyl alcohol, however, increased the graft take rate to 70%. House, Glasscock and Sheehy (1969) then conceived the idea of alcohol preserved composite allografts, consisting of *en-bloc* tympanic membrane with ossicles attached (tympano-ossicular monoblock grafts) for use in ears without a tympanic membrane, malleus and incus, with or without a stapes superstructure. Sixteen tympano-ossicular transplants were performed but hearing results were poor.

Working independently in Antwerp, Marquet had noted that bone and tendon allografts preserved in the organomercuric compound Cialit (sodium 2-ethyl mercurithiobenzoxazole-5-carboxylate, Hoechst Pharmaceuticals) had been used successfully in orthopaedic procedures. Inspired by the reported lack of an immune response to these grafts, Marquet used Cialit to preserve cadaver acquired de-epithelialized tympanic membranes to repair perforations and reported successful myringoplasties using this technique in 15 out of 17 cases (Marquet, 1966). Other surgeons (Brandow, 1969; Morrison, 1970; Smyth, Kerr and Goodey, 1971; Smyth, 1976) were less successfl with Cialit-preserved tympanic membrane grafts. Marquet's excellent results coupled with the experiences of House, Glasscock and Sheehy (1969) with tympano-ossicular grafts offered a potentially reliable method for reconstruction of the middle ear transformer, in those ears where radical excision of disease was necessary. With the recent introduction of combined approach tympanoplasty (Jansen, 1963), Marquet was not able to transplant and accurately position tympanomeatal allografts with attached ossicles via a posterior tympanotomy (Marquet, 1968, 1969, 1976a).

Perkins (1970a, b) reported successful myringoplasty in 23 out of 24 subtotal perforations repaired with allogeneic tympanic membranes preserved preoperatively in buffered formaldehyde solutions. Glasscock, House and Graham (1972) reported a 90% graft take rate and Lesinski (1982) has reported an 85% graft take rate in 100 consecutive tympanomeatal allografts with and without attached ossicles using the formaldehyde preservation technique.

Marquet then combined his method of preservation with that of Perkins by fixing tympano-ossicular grafts in 4% buffered formaldehyde for 2-3 weeks and then preserving the grafts in aqueous Cialit 1/2000 at 2°C prior to use. His immediate postoperative graft take rate in 1912 ears improved progressively from 73% in 1964 to 97% in 1976 (Marquet, 1977). This improvement has been attributed to refinements in surgical technique (Marquet, 1976a) and to the introduction of the Marquet/Perkins method of preservation (Marquet, 1977; Plester and Steinbach, 1977).

Wehrs froze cadaver temporal bone cores prior to preservation of the 'dissected out' tympanic membranes and tympano-ossicular grafts in 70% ethyl alcohol. Using 'de-epithelialized' tympanic membranes preserved in this manner (with or without an attached malleus) as onlay grafts, covered by autologous temporalis fascia or pedicled meatal skin, Wehrs (1982b) has reported successful closure of perforations in over 90% of 920 cases operated on between 1968 and 1980.

In 1976, Smith introduced the technique of freeze-drying and ethylene oxide gas sterilization for the preoperative preservation of otologic allografts (Smith, 1980a, b). Tympanomeatal, tympano-ossicular and ossicular bone allografts prepared by this technique appear to be successful in the short term, but long-term results have not been published (Smith, 1982; Smith and McElveen, 1982).

In those ears without a tympanic membrane, malleus or incus, with or without an intact stapes superstructure, composite tympano-ossicular allografts have been used by some surgeons as the main building block for middle ear reconstruction. In combined approach tympanoplasty procedures, tympano-ossicular allografts (comprising tympanic membrane and meatal skin cuff, malleus and incus) have been transplanted successfully into ears where only an intact mobile stapes remains (Marquet, 1977). Tympano-ossicular allografts (comprising tympanic membrane and meatal skin cuff, malleus, incus and stapes crura) have been less successful in those ears where only a mobile stapes footplate remains. This is primarily because of problems inherent in making adequate and lasting contact between the donor stapes crura and the recipient stapes footplate (Marquet, 1982, personal communication). Another major problem encountered with these types of reconstruction is fibrous and bony ankylosis of the short process of the transplanted incus to the lateral semicircular canal (Ironside, 1979) or to the bony margins of the posterior tympanotomy.

In order to adapt these tympano-ossicular grafts to both the shallow and deep middle ear and to try to avoid postoperative discontinuity and fixation of the reconstructed ossicular chain, a two-stage tympanoplasty method has been advocated by Ironside (1979), Lesinski (1982), Smith (1982) and Wehrs (1982b). In stage I, a composite tympanic membrane and meatal skin cuff with incorporated malleus is transplanted to act as the main building block for the middle ear reconstruction. At the second stage, 6 months later, a sculptured preserved ossicular bone allograft can be used as a malleus-to-stapes assembly or malleus-to-footplate assembly according to whether or not the stapes superstructure is intact.

Autologous and allogeneic cortical bone grafts

Sculptured columellae and autologous cortical bone from the outer mastoid cortex, bony external auditory meatus and spine of Henle have been used in tympanic membrane-to-stapes head and tympanic membrane-to-footplate interpositions, malleus-to-stapes and malleus-to-footplate assemblies by Hough (1958), Zöllner (1960, 1969), Farrior (1960, 1966), Kley and Draf (1965), Bauer (1966), Guilford (1966), Wright (1967) and Tos (1974), but long-term hearing results have not been reported by these authors. Pulec and Sheehy (1973) reported resorption of autologous cortical bone columellae in the middle ear but Robin, Bennett and Gregory (1976) were unable to comment on surface resorption of cortical bone grafts removed at revision surgery 12-48 months postoperatively, because such features were masked by preoperative sculpturing of the grafts. Berkovits et al (1978) have performed 200 ossiculoplasties using autologous cortical bone, precisely modelled on a Micro-fraize machine for malleus-to-stapes and malleus-to-footplate assemblies. Eight grafts removed because of recurrent cholesteatoma, showed histological evidence of vascularization of marrow spaces with some viable osteocytes in the lacunae, but there was 'rounding off' of the edges of these grafts due to surface resorption of bone. Graft resorption was also seen in those ears in which chronic infection persisted postoperatively (Berkovits, 1982, personal communication).

Ojala et al (1983) compared the hearing results in 51 ears in which autologous mastoid bone struts were used, and 113 ears in which autologous or preserved allogeneic ossicular bone had been used to reconstruct the ossicular chain. He concluded that the early (one year postoperative) and late (5-12 years postoperative) hearing results were the same for ossicular and cortical bone grafts in tympanic membrane-to-stapes head interposition and malleus-to-stapes assembly.

In animal experiments, Beck and Franz (1961) have demonstrated resorption of fresh allogeneic cortical bone grafts in the middle ear of guinea-pigs and Müsebeck and Falck (1963) reported similar results in rabbits. Fresh cortical bone allografts used to reconstruct the ossicular chain in dogs (Guilford, Shortreed and Halpert, 1966) and in cats (Benitez, Behar and McIntire, 1971) showed new bone formation, good vascularization of marrow spaces and no histological evidence of resorption. Cialit-preserved cortical bone allografts induced an inflammatory response associated with osteoclastic resorption of the grafts in the middle ear of non-inbred rabbits (Hildmann, Steinbach and Koburg, 1974; Steinbach, 1982, personal communication). As a result of these experiments preserved cortical bone allografts have not been used extensively in tympanoplasty.

Autologous and allogeneic cartilage grafts

Utech (1960) introduced sculptured auricular cartilage autografts for tympanic membrane-to-stapes head and tympanic membrane-to-footplate interpositions and Jansen (1963) found autologous tragal cartilage and autologous or preserved allogeneic nasal septal cartilage suitable for tympanic membrane-to-stapes head interposition (short columella) and tympanic membrane-to-footplate interposition (long columella) reconstructions in combined approach tympanoplasty procedures. Jansen (1972) soon found the long cartilage columellae too flimsy and reinforced them with stainless steel wire, a procedure also adopted by Smyth (1969) in his 'boomerang' strut. To increase the stability of tympanic membrane-to-footplate interposition, Brockman (1965) designed a cmposite autologous tragal cartilage-perichondrial columella. Using this technique, he reported postoperative closure of the air-bone gap to less than 16 dB in 30 cases. Encouraging hearing reslts were also achieved by Portmann (1963) and Shea and Glasscock (1967) using similar techniques with autologous cartilage perichondrial grafts.

Altenau and Sheehy (1978) found that the most common cause of failure of autologous and alcohol-preserved allogeneic cartilage struts assessed at revision surgery was that they were 'too short' and became displaced. No obvious resorption of cartilage was found in these grafts or in the cartilage grafts removed from the middle ear and studied histologically by Don and Linthicum (1975). Goodhill et al (1979) noted postoperative softening of autologous tragal cartilage used in tympanic membrane-to-footplate interpositions and Smyth (1980) reported displacement of 'boomerang' struts in 22 revision operations, with erosion of the medial limb of the strut in three cases. Notching of the medial limb of the strut was also noted in some ears where the strut had come into contact with Silastic sheeting placed over the promontory and oval window niche.

Seventy-six alcohol-preserved nasal septal cartilage allografts that had been in the middle ear for up to 9 years were studied histologically by Kerr, Byrne and Smith (1973). In most cases the morphology of the grafts was retained. Variable amounts of fibrous tissue replacement of cartilage together with erosion and thinning of the medial limb were seen particularly in those grafts longest in the middle ear. Kuijpers and van den Broek (1975) have also reported resorption of alcohol-preserved cartilage columellae and Smyth (1980) found resorption of the medial limb of 3% of 'boomerang' struts removed at revision surgery. Other causes of failure were lateral displacement of the columella off the stapes footplate and immobilization of the columella by middle ear adhesions.

A most significant histological study of the fate of cartilage in ossicular reconstruction was undertaken by Steinbach and Pusalkar (1981). Fifty-two cartilage struts (39 tragal cartilage autografts and 13 Cialit-preserved nasal septal cartilage allografts) were removed 1-15 years postoperatively. Forty-four of these grafts were removed because of failure of hearing improvement and eight because of recurrent disease. In the vast majority of cases, deterioration in hearing occurred between the third and seventh year postoperatively. There were no obvious differences in the macroscopic or histological appearance in the removed allografts and autografts. Thirty-eight grafts had become soft and spongy, 25 grafts had decreased in size and, in seven, the medial limb had been resorbed completely. In three ears revised because of recurrent cholesteatoma, the grafts had disappeared.

Total or partial resorption of alcohol-preserved cartilage columellae with or without stainless steel reinforcement has been a common finding at revision surgery by the author (unpublished data) and Austin (1982) has used the term 'creeping resorption' to describe the behaviour of cartilage columellae in the middle ear.

Glues and adhesives

To aid in stabilizing ossicular bone assemblies and tympano-ossicular allografts, stainless steel microscrews and wire have been employed by Marquet (1969) and Jako (1972) and the properties of different glues have also been evaluated. Mecrylate (COAPT-1), Bucrylate (COAPT) and Eubucrylate (Histo-Acryl) cause inflammatory responses including foreign body reactions and osteitis in the middle ear (Kerr and Smyth, 1971b; Heumann and Steinbach, 1980) and have therefore been abandoned by most otologists. The two component fibrin-sealant, Tissucol/Tisseel (Seelich, 1982), forms a stable adhesive by combining concentrated human fibrinogen and factor XIII with a thrombin calcium chloride/aprotinin solution. The resulting adhesive retains its properties in a moist field and does not induce an inflammatory response (Katzke, Pusalkar and Steinbach, 1983). Marquet (1982) and Portmann (1982) have used this adhesive successfully in tympanoplasty over the last few years and there are indications that its use will become widespread.

Otological tissue banks

Many surgeons using allografts in tympanoplasty secure their own cadaver donor material from the hospitals in which they work and the 'dissecting out' and preservation of these allografts is performed by themselves or their staff. In the USA, the passing of the Universal Donor Act in 1969, made it possible to obtain donor material easily and, in 1970, Perkins created the first ear bank under the sponsorship of Project Hear (Palo Alto, California). Other ear banks have subsequently been established in the USA and elsewhere. Most function as non-profit-making organizations to provide high quality, preserved, sterile otological allografts. These banks are currently preserving otological allografts in chemical agents, that is formaldehyde, glutaraldehyde, Cialit, alcohol or by freeze-drying and ethylene oxide sterilization *(Table 11.2).* Grafts are distributed on demand, nationally and internationally, to surgeons who do not have the time or facilities to acquire their own donor tissues or cannot do so because of the medicolegal or religious restrictions of the countries in which they work (Chiossone, 1977; Lesinski, 1977, 1982; Smith, 1980b).

Acquired immunodeficiency syndrome (AIDS): the virus is inactivated by tissue preservation in glutaraldehyde, formaldehyde or alcohol, but not by freeze-drying alone.

Table 11.2 Preservation techniques for otological allografts

(1) 70% ethyl alcohol
(2) 0.02% aqueous Cialit, (sodium 2-ethylmercurithiobenzoxazole-5-carboxylate)
(3) 4% buffered formaldehyde fixation and 0.5% buffered formaldehyde preservation
(4) 4% buffered formaldehyde fixation and 0.05% aqueous Cialit preservation
(5) 0.5% buffered glutaraldehyde fixaton and 0.02% aqueous Cialit preservation
(6) Freeze-drying and ethylene oxide gas sterilization.

Biomaterials

In recent years, collaborative efforts between biomaterial scientists and surgeons have led to the manufacture of new materials specifically designed for implantation. As a result of these efforts, three porous plastic materials, namely Proplast, Plastipore and Polycel, together with a vast range of ceramic materials have been developed for use in tympanoplasty and mastoidectomy *(Table 11.3).*

Proplast 1 prepared by the combination of two polymer families, namely polytetrafluoroethylene and vitreous carbon was first used by Janeke and Shea (1975) as a total ossicular replacement prosthesis in 23 cases in whom the malleus, incus and stapes superstructure were missing. Proplast prostheses subsequently became available for tympanic membrane-to-stapes head and tympanic membrane-to-footplate interpositions, and malleus-to-stapes, and malleus-to-footplate assemblies, but foreign body reactions to the prosthesis and extrusion of these prostheses through the tympanic membrane have occurred (Kerr, 1981; Palva and Makinen, 1983).

The second plastic implant material, Plastipore (porous polyethylene) reported to have non-reactive properties and sufficient porosity to encourage host tissue ingrowth to stabilize the implant in the middle ear, was first used successfully by Shea (1976) for tympanic membrane-to-footplate interposition and malleus-to-footplate assembly and was called the total ossicular replacement prosthesis (TORP). For tympanic membrane-to-stapes head interposition and malleus-to-stapes assembly, a Plastipore partial ossicular replacement prosthesis (PORP) was introduced (Richards Technical Publication, 1980).

Shea, Emmett and Smyth (1977) and Hicks, Wright and Wright (1978) reported encouraging short-term hearing results and only a small percentage of extrusions using partial and total ossicular replacement prostheses. Smyth (1982b), however, has reported a 5-year follow-up of 28 ears in which partial ossicular replacement prostheses were used and 116 ears in which total ossicular replacement prostheses were used. Fifty-seven per cent of the partial and 78% of the total prostheses failed to maintain closure of the air-bone gap (preoperative bone conduction and postoperative air conduction) to 10 dB or less at 0.5-2 kHz. Using the same criteria, Frootko (1983) reported a 3-5 year follow-up of 78 ears in which partial ossicular replacement prostheses and 41 ears in which total ossicular replacement prostheses were used; the failure rates were 72% and 83% respectively. Extrusion of the prosthesis through the tympanic membrane was the major cause of failure (40% partial, 32% total). This was not prevented by the interposition of connective tissue between the prosthesis head and the undersurface of the tympanic membrane, nor was extrusion prevented by placing the prosthesis under the malleus handle or chorda tympani nerve, when present. At the present time, it appears that cartilage interposed between the prosthesis head and the tympanic membrane is the best method of protection against extrusion, reducing this complication to less than 5% of cases (Brackmann, 1986). Other causes of failure include postoperative migration and displacement of prosthesis. With partial ossicular replacement prostheses, necrosis and fracture of the stapes superstructure has been observed (Belal and Odnert, 1982; Frootko, 1983) and with total ossicular replacement prostheses single cases of foreign body granuloma on the stapes footplate (Palva and Makinen, 1983) and perforation of the stapes footplate with resultant perilymph fistula (Myer and Cotton, 1982) have occurred. There is also conclusive light and electron microscopic evidence that biodegradation of Plastipore occurs in the middle ear, albeit at microscopic level (Kerr, 1981; Belal and Odnert, 1982) and the prostheses evoked a local but sustained foreign body reaction (Kerr, 1981; Frootko, 1983; Palva and Makinen, 1983).

The third plastic implant material, Polycel (thermofusion formed ultra-high-molecular-weight porous polyethylene; Treace Medical Inc) offers design advantages over other porous plastic implants. The prostheses for both tympanic membrane-to-stapes head and tympanic membrane-to-footplate interpositions offer a centred and offset peg-top platform onto which the cartilage interposition can be secured. In addition, the tympanic membrane-to-footplate interposition prostheses have a stainless steel core and slim shaft, enabling the shaft and head to be bent to the desired configuration and the stainless steel core acts as a 'tack' fixing the prosthesis to the stapes footplate. Using these prostheses, Chüden (1985), Brackmann (1986) and Moretz et al (1986) have reported encouraging hearing results, low extrusion rates and minimal foreign body reaction in the middle ear, but longer-term follow-up results of cases in which these prostheses have been used are awaited.

The most recent materials available for ossiculoplasty, posterior canal wall and outer attic wall reconstruction and mastoid obliteration, are the ceramics (Grote, 1984) *(see Table 11.3)*. The almost totally *bio-inert* and very hard *aluminium hydroxide ceramic* (Frialit) has been used successfully in ossiculoplasty by Jahnke and Plester (1981). The prostheses become encapsulated in the middle ear and produce no interface reactions. The *bioactive calcium silicate glass ceramics* undergo chemical changes at their surface, resulting in interface bonding with adjacent structures, that is the adjacent ossicle or undersurface of the tympanic membrane, and very encouraging ossiculoplasty results using the bioactive calcium silicate glass ceramic 'Ceravital' have been reported by Reck (1980, 1985). *Biodegradable hydroxyapatite-tricalcium phosphate ceramics* of the porous variety have been used in posterior canal wall reconstruction and mastoid obliteration and have been shown to be replaced in part by host connective tissue elements and osteogenic cells (see Grote, 1984).

Table 11.3 Implants used in middle ear and mastoid reconstructive surgery

1. *Metallic*
   - Stainless steel
   - Tantalum
   - Platinum
   - Titanium

2. *Non-metallic*

   2.a. Plastics

   2.a.1. Solid
   - Polyethylene
   - Polytetrafluoroethylene (Teflon)
   - Polydimethylsiloxane (Silastic)

   2.a.2. Porous
   - Polytetrafluoroethylene-carbon fibre composite (Proplast 1)
   - Polytetrafluoroethylene-aluminium oxide composite (Proplast 2)
   - High density polyethylene (Plastipore)
   - Ultra-high molecular weight polyethylene (Polycel)

   2.b. Ceramics

   2.b.1. Bio-inert
   - Aluminium oxide ceramics (Frialit)

   2.b.2. Bioactive
   - Calcium silicate glass ceramics (Ceravital, Bioglass)

   2.b.3. Biodegradable or bioresorbable
   - Hydroxyapatite - tricalcium phosphate ceramics (dense and porous varieties).

Conclusions

The ear surgeons of today, have at their disposal, a wide range of surgical procedures for the treatment of chronic suppurative otitis media, both with and without cholesteatoma. The fundamental prerequisite for this type of surgery is the meticulous and complete removal of disease from the middle ear and/or mastoid.

Ideally, every ear surgeon should be accomplished and competent enough to perform all of the surgical procedures that have evolved and should have a thorough knowledge of temporal bone anatomy and physiology, but this ideal has and probably never will be achieved. The surgery of chronic suppurative otitis media must, therefore, not only be tailored to the patient's presenting pathology and requirements, but also to the level of competence of the surgeon and the surgical and follow-up facilities available. It is, to take the extreme example, quite wrong for an unaccomplished ear surgeon to perform a combined approach tympanoplasty on a patient who will be lost to follow-up postoperatively.

The debate as to whether the open techniques of mastoidectomy with tympanoplasty are better or worse than the closed techniques will continue. There is no short cut to successful excision of disease and the operation of choice must be that in which all the disease can be excised. Once this is achieved, the surgeon can decide on the type of middle ear and/or mastoid reconstruction procedure to be used, whether this should be staged or not and what the reconstruction should ultimately achieve.

There is one situation that permits special mention in this chapter: the patient who has lost all useful hearing in one ear, and requires surgical removal of cholesteatoma in the other ear. In this situation, the surgeon must be aware that any surgical technique or manoeuvre that may endanger the cochlea must be avoided. The best method of management is by open mastoidectomy. No attempt should be made to reconstruct the ossicular chain. The stapes superstructure and/or footplate must not be manipulated and cholesteatoma or diseased mucosa on these structures should not be removed. Tympanic membrane reconstruction should only be considered if ossicular discontinuity already exists, thus protecting the stapes, and the middle ear must be free of disease.

Many graft and implant materials are available for middle ear reconstruction. Most ear surgeons prefer to use healthy, fresh, autologous tissues whenever possible and, in the main, these have proved most successful. Their second choice has been preserved allogeneic tissues and their use has only been possible, because the deep external auditory meatus and middle ear are sites where immune rejection responses to a tissue allograft across major histocompatibility barriers are somewhat muted (Frootko, 1985b). These sites may therefore be regarded as sites favourable to graft acceptance, that is immunologically privileged sites (van den Broek, 1968; Frootko, 1984). Current preoperative otological allograft preservation techniques *(see Table 11.2)* also appear to make these tissues less susceptible to rejection after grafting across major histocompatibility barriers, by alternating, to a greater or lesser extent, the molecular configuration of antigenic determinants of transplantation antigens. This appears to diminish the graft's ability to immunize the recipient, but does not alter their specificity (Frootko, 1985b). It is presumably for similar reasons that successful tympanic membrane reconstruction has been achieved using preserved bovine connective tissue xenografts.

The solid and porous plastic implants have not gained universal acceptance by the otological fraternity for reasons outlined in this chapter, and the ceramics have yet to prove their superiority over autografts and preserved allografts in middle ear reconstruction.