THE "CLOSED" FENESTRATION OPERATION

LONG TERM RESULTS AND ACOUSTICS

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THE open fenestration cavity, which is an integral part of the classical fenestration operation according to the method of Sourdille or Lempert, is prone to infection. Once infected the cavity requires prolonged post-operative toilet and may even result in a permanently discharging ear, resisting every known form of treatment. The "closed" fenestration method was devised with the aim of eliminating a cavity open to external air, thus preventing infection and permanent discharge. It was practised by Holmgren (1949), who used post-auricular incision, did not remove the endosteum of the lateral canal and applied the periosteum of the vestibular dome as covering for the fenestra. The method was introduced into this country by Garson (1952) who used conjunctival graft and operated in two stages. Simplification by a one stage operation was suggested by Bauer (1953). Suggitt (1955) adopted the one stage method using skin instead of conjunctiva for covering of the fenestra. The same technique was used by Simson Hall (1957). In Germany Moser (1956) applied buccal mucosa as covering for the fenestra, preserved the ossicular chain, packed the cavity with gelatine sponge and sutured the post-auricular incision completely. A similar technique was used by Tobeck (1958). Fenestration by the neurosurgical approach ("Transtegmentary technique") of Bartual and Bordés (1949) and primary fenestration of the *superior* semicircular canal (Wullstein, 1951) can also be considered as examples of closed fenestration. Rosen's fenestration of the stapedial footplate in cases of failed mobilization of the stapes has many acoustic problems in common with the closed fenestration of the semicircular canal.

Philip Garson's premature death has prevented him from publishing long term results of his operation. It is the purpose of this paper to review the functional results of his closed fenestration operation, to compare them with the results of the classical, open fenestration method and to discuss the differences.

Fifty cases operated on by P. Garson personally between 1947 and 1955 have been studied. The results of 39 of these are suitable for evaluation, as adequate audiograms are available. The post-operative course may be summarized as follows: In 26 cases there has been an immediate post-operative improvement of hearing with considerable narrowing of the

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air–bone conduction gap, the initial gain amounting to 10–30 dbs. for speech frequencies. After the first 3 days the hearing deteriorates but remains better than before the operation for just under 3 months. After this period there is another deterioration, often sudden and the air–bone conduction gap increases again. Seven cases retained improvement of hearing amounting to 10–15 dbs. for speech frequencies. In 11 cases there was no appreciable initial gain and in 2 cases there was some deterioration. No patient reached permanently the 30 db. line for speech frequencies so that in no case has "socially adequate hearing" been permanently attained. Fifteen of the patients were eventually supplied with a hearing aid. There were no eye complications from taking the conjunctival graft.

Thus the functional results of the closed fenestration operation are definitely inferior to those of the classical methods with an open cavity.

Moser (1956) has come to the same conclusion. Of his 20 patients only 5 retained the improvement achieved and this did not reach beyond the 25 db. line. Moser makes the interesting observation that in cases with central perforation of the tympanic membrane or in patients where the perforation was made on purpose the results equalled those with an open cavity. Simson Hall's experience (1957) was that "the hearing gain is possibly not so great as with the open fenestration method". Suggitt (1958) published a series of 13 cases in which an open cavity fenestration was performed in one ear and a closed fenestration in the other. In 5 of the patients the result was better in the open cavity fenestration, in 2 the closed fenestration gave better results and in the remaining cases there was no material difference. It is not clear from the published table how soon after the operation the hearing was tested. Tobeck (1958) has reported the result of his 6 cases. He found marked fluctuation of hearing in all of them and in 3 patients the good initial gain had receded considerably within 7 months. In his opinion the final results were inferior to those obtained in similar cases with the conventional open fenestration. Mündnich (1959) using amniotic membrane or conjunctiva found good hearing improvement for the first days which deteriorated again the following months and years and was retained in one case only.

In order to explain the difference in the functional results of the two types of fenestration it is necessary to consider the mechanics of the sound conduction in each type of operation.

Shambaugh and Juers (1946) held the view that vibrations of the tympanic membrane are carried to the new window *by the tympano-meatal flap*. They gave two reasons for this opinion: It was noticed that (1) patients with an unusually good post-operative hearing also had a strongly positive fistula test, when pressure was applied to the lower edge of the pars tensa of the tympanic membrane, (2) perforation of the tympanic membrane during or after fenestration caused deterioration of hearing. I do not think that this view is correct because equally good hearing may be

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achieved with a free skin graft over the fenestra (Wullstein's method), where there is no continuity between the graft and the tympanic membrane. Barajas (1958) suggests however that with Wullstein's technique transmission occurs from the tympanic membrane through the ossicular chain to the short process of the incus, thence to its posterior ligament to which the graft adheres and through the graft to the fenestra. The reason for deterioration of hearing following perforation of the tympanic membrane will be discussed later.

v. Békésy (1947) by direct measurement of sound pressure over the windows came to the conclusion that hearing depends on the pressure difference between the two windows. Van Eyck (1951) produced experimental evidence from electrophysiological studies on a pigeon with a

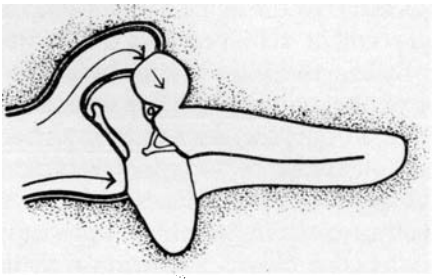


FIG. 1.

In the open fenestration cavity the fenestra nov-ovalis is directly exposed to the sound wave and becomes the receiving window. The round window is separated from the new window by the tympanomeatal flap and is protected from the direct impact of the sound wave by the tympanic membrane and the air cushion in the middle ear. The difference in pressure and phase over the two functioning windows is considerable. Hearing adequate.

congenital ankylosis of the columella, that after fenestration it is the *round* window which transmits the sound to the cochlea and that the new window only allows for compensatory movements of the cochlear fluids, as a round window does in a normal ear. Skoog (1951) shared v. Békésy's view, namely that in a fenestrated ear the sound may reach the organ of Corti both through the round window and through the new window in the lateral canal. He noticed that by covering the tympanic membrane with cotton wool soaked in paraffin hearing could be improved in a number of cases. This is interpreted as follows:

The sound reaching the cochlear fluid from the two sides, from the vestibular and from the tympanal side, will push on the basilar membrane in opposite direction (Wever, 1954). The intensity of the stimulation of the basilar membrane will depend on the phase relation of the entering sound, i.e. the more out of phase the stronger will be the stimulation and the better the hearing. Perforation of the tympanic membrane has the opposite effect: access of sound to the round window is facilitated, the

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difference in pressure and phase between the two windows becomes smaller and hearing deteriorates.

Fig. 1 represents the situation in the *open* fenestration: The ossicular chain is not functioning behind an intact tympanic membrane because of the fixation of the stapes by the otosclerotic process and because the incus and the head of the malleus have been removed (Lempert's method). There is therefore no pressure transformation by the tympanic membrane through the ossicular chain to the oval window. The tympanic membrane in the absence of a functioning ossicular chain, and only then, acts as a sound protection for the round window (A. Meyer, 1958, Wullstein, 1957–8). The tympanomeatal flap seals off the air space in the middle ear from the fenestration cavity and thus separates the round window, which

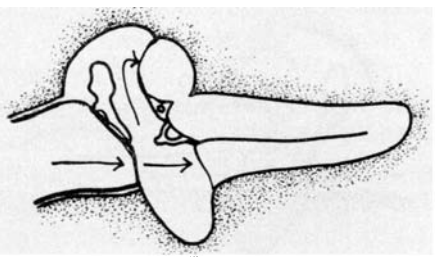


FIG. 2.

In the closed fenestration the new window and the round window are both behind the tympanic membrane. The round window is the receiving window. As both functioning windows are in the same cavity the difference in sound pressure and phase at the two windows is small. Hearing poor.

is inside the enclosed space of the middle ear, from the new window, which is outside it. The sound pressure in the auditory meatus reaches the tympanic membrane and the covering of the new window at the same time and with equal intensity, but as the flap over the new window is in direct contact with the perilymph and possibly adherent to the endolymphatic tube, whilst the round window is separated from the direct impact of the sound wave by the tympanic membrane and the air cushion of the middle ear, the displacement of the cochlear fluid will be greater in the scala vestibuli than in the scala tympani. In this case *the fenestra novovalis will be the receiving window*. (Lempert, 1955.)

Let us now consider the situation in a closed fenestration (Fig. 2): In the absence of an open cavity the new window cannot be directly exposed to the sound pressure in the auditory meatus and therefore cannot possibly be the receiving window. Under these conditions the sound wave reaches the tympanic membrane first and has to overcome its resistance (reflection and absorption); with diminished intensity it has to traverse the air cushion enclosed in the middle ear before arriving at the *round window*,

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which now becomes the receiving window. Both the round and the new window are in the same air-filled cavity, the middle ear communicating with the closed fenestration cavity through the narrow attic and aditus ad antrum. The difference in pressure at the two windows is therefore less than in the open fenestration and conditions for stimulation of the basilar membrane are less favourable.

The distance between the round window and the new window is important. According to v. Békésy the difference in phase increases with the distance of the two functioning windows, especially for high frequencies. It is obvious from the functional results of the closed fenestration operation that increase in the distance alone is not an adequate compensation for the lack of separation of the two windows. In fenestration of the

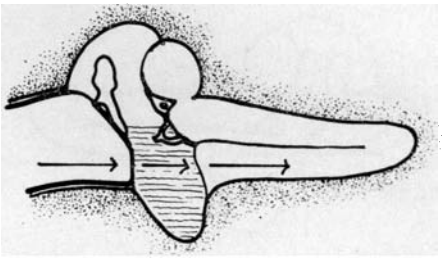


FIG. 3.

The presence of fluid in the hypotympanum acts as a "columella" from the tympanic membrane to the round window. Sound pressure transformation takes place from the tympanic membrane to the round window through the fluid. Difference in pressure and phase over the functioning windows is great. Hearing very good.

superior semicircular canal the distance of the newly created window from the round window is less than the distance between a fenestra nov-ovalis in the lateral canal and round window, the difference in phase will therefore be less and the acoustic results ought to be even worse than in closed fenestration of the lateral canal. Similarly, a fenestra in the stapedial footplate being closer still to the round window, can be expected to give even less difference in phase and therefore even worse hearing. It will be discussed later.

And yet, the *immediate* post-operative functional results of the closed fenestration operation are excellent. What is the explanation?

The only factor which is different immediately after the closed fenestration operation as compared with the situation 3 months later, when sudden deterioration of hearing takes place, is the presence of fluid, namely serum and possibly blood, in the middle ear. The presence of fluid in the hypotympanum affects the sound conduction considerably. The sound wave reaching the tympanic membrane is now transmitted through the fluid in the hypotympanum directly to the round window (Fig. 3). The

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difference in size of the tympanic membrane and the round window membrane accounts for the increase in sound pressure by transformation on the round window, the fluid in the hypotympanum acting as a "columella" from the tympanic membrane to the round window. There is no barrier of the air cushion in the middle ear to overcome. The sound wave reaches the round window with greater energy and stimulates the basilar membrane *viâ* the scala tympani. This action is limited to the round window only because the oval window is immobilized by the otosclerotic process. These conditions last as long as there is fluid in the middle ear. Serum forms in the closed fenestration cavity until its walls become epithelized. When epithelization is complete and the last fluid has emptied itself through the Eustachian tube, the direct conduction of sound to the round window ceases, air fills the hypotympanum and hearing deteriorates. Thus it is the accidental presence of fluid in the hypotympanum, acting as a temporary round window "columella", which explains the initial excellent hearing improvement.

Kobrak (1959) on stroboscopic observation of his tympanal prosthesis could actually see acoustic vibration of the fluid,with which the prosthesis was moistened, and came to the conclusion that it is the moisture which is acoustically active, whilst the cotton pellet only holds the drop of moisture in place but does not oscillate itself. Dry cotton pellets were ineffective. I consider this observation as a confirmation of the proposition discussed above, that the fluid in the middle ear transmits acoustic vibrations to the round window.

Wullstein (1955) in discussion of Moser's paper criticized the closed fenestration operation on the ground that both, the new and the round window, lie "in the sound protection of the middle ear", so that although the dynamics of the inner ear have improved as the result of the fenestration, there is no difference in the sound pressure on the two windows. He attributes permanent hearing improvement in closed fenestration to an accidental adhesion-formation between the short process of the incus and the covering of the new fenestra. In cases where the incus has been removed this adhesion cannot of course occur.

A number of modifications of the *open* fenestration method were devised in order to increase the difference in pressure and time (phase) at the two functioning windows: Thus Shambaugh applies a thick layer of ointment onto the tympanic membrane in order to obstruct the propagation of sound to the round window.

Bozzi (1955) performs a funnel-shaped plastic on the auditory meatus, directing the sound waves towards the fenestra nov-ovalis, placed at the apex of the funnel and at the same time forming a space between the flap and the tympanic membrane to act as an obstacle to the progress of sound waves towards the tympanic cavity and thus to the fenestra rotunda. Moritz (1957) in a modification of Wullstein's tympanoplasty combined

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with fenestration of the lateral canal uses a *thick* pedicled flap (3–4 mm. thick) over the middle ear and a *thin* Thiersch graft over the fenestra in order to increase the difference in impedance and phase.

Can the functional results of a *closed* fenestration method be improved by some similar modification?

Wever *et al.* (1948) have found by animal experiments that if the ossicular chain is interrupted at the incudostapedial joint, the tympanic membrane and the outer ossicles are not only useless but detrimental and that their removal aids the transmission by 10–15 dbs. for tones in the middle range.

Moritz (1952) suggested removal of the tympanic membrane in the case of the patient whose *superior* semicircular canal was fenestrated by Wullstein (already mentioned), in order further to improve hearing, as in this case the tympanic membrane could only act as an obstacle to sound reaching the round window. As already stated, Moser found that artificially made central perforation in the tympanic membrane in cases of his closed fenestration improved hearing to a degree comparable with that of fenestration with an open cavity. However, with a perforation of the tympanic membrane the operation no longer qualifies as a "closed" method and loses its raison d'être, although a perforation of the tympanic membrane is preferable to a fenestration cavity.

Not all authors are equally impressed by the conception of "phase relationship" and Suggitt (1958) doubts that separation of the new window from the tympanic cavity and round window is necessary.

As already mentioned, as long as there is pressure transformation by a functioning ossicular chain or a "columella" to one of the windows, sound protection achieved by separation of the two functioning windows is unimportant. According to H. G. Schmitt (1957) with normal pressure transformation reduced by half, as e.g. by a perforation of the tympanic membrane or scarring, the hearing loss amounts to 5 dbs. only. Until pressure transformation is reduced to $\frac{1}{5}$ of normal, sound protection does not matter. On the other hand, when pressure transformation is completely absent and sound protection at a maximum, the loss of hearing amounts to some 26 dbs. From these figures it follows that in a closed fenestration operation, as long as there is fluid in the hypotympanum making sound pressure transformation possible, separation of the functioning windows is unnecessary. When the fluid has disappeared separation of the two windows in order to achieve sound protection of one of them, does begin to matter. It is certainly true that other factors influence the functional result. The middle ear acts as a resonator with a certain frequency and in order to achieve maximal improvement in hearing its effective frequency must coincide with the speech frequencies. The properties of the middle ear as a resonator depend on the size of the tympanic cavity, size of the fenestration cavity, pneumatization of the mastoid, mass of the ossicles,

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thickness of the covering of the two active windows, the presence and amount of fluid in the middle ear etc. It is very likely that there exists an optimal ratio of all these factors, but at present clinicians have little control over them. It would be possible e.g. to influence the size of the air-cushion in the middle ear and mastoid in a closed fenestration operation by plugging the aditus ad antrum. This would increase the pressure on the round window, because during compression of the tympanic membrane air would not escape through the attic and aditus towards the fenestration cavity, but there might be an undesirable side effect: Cutting off the mastoid cells from ventilation *viâ* the Eustachian tube would predispose to chronic infection in the remaining mastoid cells (Wullstein, 1951). It is of interest that the presence or absence of incus does not have any appreciable effect on the final acoustic result in a closed fenestration (Garson, 1952). Two decades ago and before the principles of the pressure difference at the two windows were appreciated, Hughson (1940) tried to improve hearing by plugging the round window with fascia, muscle or periosteum. If however, *fluid* is the acoustically active medium (Kobrak), the problem of keeping fluid in the hypotympanum indefinitely, on the presence of which in my opinion adequate hearing depends, seems at present insoluble. If this could be achieved, it would have important bearing on the functional results of Rosen's fenestration of the stapedial footplate in cases of failed mobilization of the stapes. At present the reported results of this procedure are far from uniform. After the initial enthusiasm disappointing results are reported (Mündnich, 1959; Scheer, 1959). This author found that "in every instance the initial improvement in hearing was lost in 3 to 8 days after surgery". It is very likely that as long as there is perilymph and serum and blood in the middle ear, the fluid acts as a good sound transmitter with some differential pressure at the two windows especially if only the round window and not the fenestrated stapes is covered by the fluid and there will be a transitory hearing improvement. As in fenestration of the stapedial footplate by Rosen's method there is less trauma than in fenestration of the lateral canal, the secretion of serum will be of shorter duration and the hearing improvement may be expected to be even less lasting than after a closed fenestration. This appears to be the case. The acoustic situation following stapedial fenestration is comparable to that resulting from an interrupted ossicular chain behind an intact tympanic membrane in the presence of two mobile windows, as e.g. in cases of traumatic dislocation of the incus. Patients with this condition suffer from a profound middle-ear type of deafness, their hearing is far below the social adequacy line (Bauer, 1958). Rosen himself believes that in fenestration of the stapedial footplate the difference in size between the tiny opening into the oval window and the larger round window, which becomes the receiving window, causes an impedance difference sufficient to mobilize the endolymphatic fluid (Rosen and Bergman, 1960). If this were the

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correct explanation one would expect lasting favourable results to occur with greater regularity than is in fact the case.

The following conclusions seem therefore justified: A closed fenestration of any type is at present inferior to a fenestration with an open cavity because in a closed fenestration the pressure difference at the two functioning windows is insufficient to provide adequate stimulation of the basilar membrane. The temporary improvement of hearing is due to the presence of fluid in the middle ear which transmits movements of the tympanic membrane directly to the round window. When the fluid disappears hearing deteriorates below a socially adequate level. Until some method is devised which, in addition to closed fenestration, will provide a permanent pressure transmission system from the tympanic membrane to one of the windows or at least an effective separation of the two functioning windows, so as to ensure sound protection for one of them, the closed fenestration method cannot be recommended.

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