Deafness after bacterial meningitis

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SUMMARY Seventeen children with previous bacterial meningitis and 17 sib controls were examined clinically and otoscopically. They were also tested with air-conduction and bone-conduction audiometry and evaluated by tympanometry. There were no major neurological abnormalities and few otoscolical signs of ear disease. 21 % of the ears showed abnormalities on air-conduction audiometry but all were normal on bone-conduction audiometry. 30 % had abnormal middle-ear pressures (more negative than 100 mm water) on tympanometry and 7 % had abnormal compliance of the drum. There were no significant differences on any test between the postmeningitis children and the sib controls. Population studies have confirmed that minor hearing loss due to middle-ear dysfunction is common in children, but is probably temporary in most of them. We have found no excess of middle-ear dysfunction and no sensorineural deafness in these postmeningitis children, but other workers have shown that nerve deafness may occur in association with clinical neurological damage. However, much of the deafness attributed to bacterial meningitis in other studies may well reflect population variability.

Standard paediatric texts (Forfar, 1973; Nelson, 1975) list deafness as a major complication of bacterial meningitis and it is standard practice to test the hearing in the follow-up of children who have had the disease, even though there may be no other signs of residual damage. Significant hearing loss is sometimes found and it is implied that this is the result of an insult to the auditory nerve by the disease process. We can find no series where the hearing following meningitis has been compared with that of controls, so the role of meningitis in causing deafness cannot be considered proven.

The published reports on postmeningitis deafness are inconclusive. Some describe patients treated in the 1940s and 1950s before present regimens of treatment were established (Bergstrand *et al.*, 1957; Teng *et al.*, 1962; Hutchison and Kovacs, 1963). Some separate out sensorineural hearing loss from other forms of deafness, suggesting that nerve deafness occurred mainly in association with other signs of neurological and psychological damage. In later reports (Sproles *et al.*, 1969; Gamstorp and Klockhoff, 1974; Feigin *et al.*, 1976) the methods of testing and the criteria used for hearing loss are not described. Where conduction deafness has been separated from sensorineural hearing loss (Sell *et al.*,

1972; Fitzhardinge *et al.*, 1974) the incidence of sensorineural deafness has been low and usually associated with other signs of neurological damage.

We have tested the auditory function of children who have had bacterial meningitis and sib controls to find whether deafness is a sequel to meningitis and to find whether sensorineural or conduction deafness predominates.

Patients, controls, and methods

Seventeen children were chosen from the records of the Mater Children's Hospital, and the Royal Children's Hospital, Brisbane. The criteria were (1) they had had proven bacterial meningitis after the neonatal period but more than 2 years before this study, (2) they were in the age range 5-10 years at the time of the study, (3) they had a sib in the same age range to use as a control, and (4) the parents agreed to have their children investigated. Bacterial meningitis was diagnosed if the child had at least two of the following: (i) clinical signs of meningitis (neck stiffness, fever), (ii) CSF cell count ≥ 1000 with $> 50\%$ polymorphs, and (iii) a positive culture from the CSF.

The following tests were performed on both patients and sibs. (1) Full neurological examination performed by one of us (H.J.). (2) Wechsler Intelligence Scale for Children, Bender-Gestalt, and

Received 23 November 1976.

Frostig psychological tests (these will be reported elsewhere). (3) Assessment of auditory function. (a) Clinical examination of the ears with an otoscope. (b) Pure tone air-conduction audiometry at 500, 1000, 2000, and 4000 Hz on both ears. All the patients and 15 of the 17 controls also had bone-conduction audiometry. Because sound is transmitted well through the skull, defects cannot be lateralized with bone-conduction studies, and so this was done only on one side in each child. (c) Tympanometric assessment: the techniques were similar to those described by Northern and Downs (1974). Middle-ear pressures, drum compliance, and contralateral reflex thresholds were measured for each ear.

The criteria used to indicate impairment of hearing or middle-ear function were as follows. (1) Pure tone audiometry: a hearing level equal to or greater than 25 db was considered abnormal if it occurred at any frequency in either air or bone conduction. (2) An electroacoustic impedance meter was used to find the pressure within the middle ear and also the mobility of the ear drum. (a) Pressure within the middle ear normally varies between 0 to -100 mm water. A negative pressure >100 mm water was considered abnormal. If the eustachian tube is blocked, air is absorbed in the middle ear and the pressure becomes more negative; the drum becomes deformed and hearing acuity may be significantly decreased. (b) Mobility of the drum can be measured by estimating the change in volume of the external ear with varying applied pressures. The lower limit of normal is taken as 0.3 ml and the maximum as 1.5 ml. A volume change of <0.3 ml was considered abnormal and usually means decreased mobility and is often associated with structural damage or fluid within the middle ear. (c) The stapedius reflex was used as a test of middle-ear function. If a loud noise is heard the stapedius muscle contracts to make the ear drum less responsive and so protect the ear. The movement of the drum can be detected by an impedance meter. A sound up to 110 db is applied to the opposite ear and movement of the drum measured. If the drum moves, the hearing in the opposite ear and the mechanism controlling the stapedius muscle are normal. A response at 100 db at 500, 1000, 2000, and 4000 Hz was taken as normal. Audiometric testing was done by a trained audiologist (J.S.) using an Angus & Coote PR9/C clinical audiometer and a Peters electroacoustic impedance meter.

Results

Clinical findings. 17 postmeningitis children were studied, each with a sib control with no disease

history suggestive of meningitis. The 17 children all met the diagnostic criteria. 13 grew *Haemophilus influenzae*, 2 grew pneumococcus in the CSF; in 2 there was no growth on culture. The lowest cell count in the CSF was 1000 cells/ml, and in all children the majority of the cells were polymorphs. A summary of the clinical course and complications is shown in Table 1, together with the antibiotic

Table 1 Summary of the clinical features of the episode of meningitis in the 17 children

Total sample size	17
Age at time of meningitis	Mean 2.1 years (range 0.75-5.75 yrs)
Duration of symptoms before admission	Mean 2.0 d (range 1-7 d)
No. given antibiotics before admission	6/17
No. with fits before admission	6/17
Time taken for temperature to return to normal	Mean 54 h (range 8 h-9 d)
No. with late fever	4/17
Organisms found in CSF	
<i>Haemophilus influenzae</i>	13
<i>Streptococcus pneumoniae</i>	2
No growth	2
Antibiotics used in treatment	
Chloramphenicol	14
Penicillin	14
Sulphonamides	13
Ampicillin	8
Kanamycin	1
Methicillin	1
Streptomycin	1

treatment given. With one exception (one child was given ampicillin only) the children were given multiple antibiotic therapy intravenously in appropriate dosage. There was no correlation between the antibiotic therapy and the findings in this study.

Further details of symptomatology of these children will be given in a later paper dealing with neurological and psychological testing and their correlation with the severity of disease.

Otoscope findings. The eardrums were well seen in 15 patients and 16 controls. In one pair of children the otoscopy was accidentally omitted and in another there was wax which partially obstructed the drum. In 7 drums in 5 children (2 patients, 3 controls), there was scarring and/or opacity of the drum suggestive of old disease; in 2 drums (1 patient, 1 control) there were retraction pockets resulting from old perforation, in 5 drums (3 patients) there was mild inflammation suggesting minor intercurrent ear disease. In all but one of the ears which had otoscopic changes abnormalities were found on audiometric and/or tympanometric testing. These tests also disclosed abnormalities on many ears which were otoscopically normal.

Table 2 Results of air-conduction audiometry on the 17 children and 17 controls (both ears)

Frequency (Hz)	After meningitis		Control		χ^2	Significance
	Normal <25 db	Abnormal ≥25 db	Normal <25 db	Abnormal ≥25 db		
500	26	8	28	6	0.09	$P \geq 0.1$
1000	28	6	33	1	2.55	$P > 0.1$
2000	29	5	32	2	0.64	$P \geq 0.1$
4000	28	6	29	5	0.00	$P \geq 0.1$

There is no significant difference between subjects and controls at any frequency.
db = decibels.

Pure tone audiometry. Pure tone air-conduction audiometry was performed on all postmeningitis children and on the sib controls. The results are shown in Table 2. Many patients and controls had hearing loss, particularly at 500 Hz. At higher frequencies the losses appeared to be slightly more frequent among the subjects than the controls, but the χ^2 test showed no statistical differences. Abnormal air-conduction audiograms can be due to defects in the external ear (excluded in these children by otoscopy), the middle ear, or the sensorineural pathway. Sensorineural hearing loss typically is more severe at high frequencies, which was not evident here, and is also detected by a loss on bone-conduction audiometry, which bypasses the middle ear.

The results of bone-conduction studies on the 17 patients and 15 of the controls are shown in Table 3. This table shows that bone-conduction is

Table 3 Results of bone-conduction audiometry on 17 children and 15 controls

Frequency (Hz)	After meningitis		Control	
	Normal <25 db	Abnormal >25 db	Normal <25 db	Abnormal >25 db
500	17	0	15	0
1000	17	0	15	0
2000	17	0	15	0
4000	17	0	15	0

Only one test was done on each child. None was abnormal.

Table 4 Results of tympanometry on the children

	After meningitis		Control		χ^2	Significance
	Normal	Abnormal	Normal	Abnormal		
Middle-ear pressures	24	10	23	11	0.0	$\geq P 0.1$
Compliance of ear drum	31	3	32	2	0.0	$\geq P 0.1$
Sound thresholds for stapedius reflex	15	19	13	21	0.06	$\geq P 0.1$

There were no significant differences between subjects and controls.

normal in all children. Though bone-conduction necessarily tests the better of the two ears, the hearing losses found on air-conduction are unlikely to be due to sensorineural changes, but have probably arisen in the middle ear. Because of the frequency of middle-ear dysfunction, we have used tympanometry as an independent measure of middle ear dynamics.

Tympanometry. The methods used in clinical tympanometry have been described. All children had tympanometric assessment immediately after the audiometry. The results of measurement of middle-ear pressure and of compliance of the eardrums are shown in Table 4. Many children in both postmeningitis and control groups had abnormal results on tympanometry; but there were no significant differences between the groups. Middle-ear pressures were abnormal in 31% of ears and compliance of the drum abnormal in 7% of ears. Reflex thresholds were abnormal in 59% of ears. The abnormal middle-ear pressures suggest that the eustachian tubes on these children were not functioning normally. In most children both ears showed similar pressures. Few eardrums showed evidence of decreased mobility.

To confirm that middle-ear dysfunction is the principal cause of decreased air conduction, a cross-correlation was done between tympanometric and audiological results (Table 5). The reflex thresholds have been omitted because they depend on the

Table 5 Cross-correlations between tympanometric and audiometric findings in the children

	Air conduction audiogram group			
	Postmeningitis group		Controls	
	Normal	Abnormal	Normal	Abnormal
Middle-ear pressure normal				
Drum compliance normal	19	2	19	3
Drum compliance abnormal	2	0	1	0
Middle-ear pressure abnormal				
Drum compliance normal	3	7	6	4
Drum compliance abnormal	0	1	0	1

function of both ears and also appear to class an excessive number of children as abnormal.

Of the 43 ears with both normal middle-ear pressure and drum compliance, 38 were normal to air-conduction audiometry, and 5 were abnormal. The 3 ears with normal pressure but abnormal compliance all had normal hearing. This is a known normal variant where the drum appears to be less flexible but hearing remains normal (Northern and Downs, 1974). In the ears with abnormal pressures but normal compliance 9 had normal hearing and 11 were abnormal. In the two ears with both abnormal pressure and compliance the hearing was also abnormal. In these ears there is probably some fluid immobilizing the drum. There is a reasonable, but by no means perfect, correlation between air-conduction audiometry and tympanometry which helps to confirm that the hearing loss is of middle-ear origin.

There are therefore three independent indicators that the hearing loss found in the patients and the control children is due to middle-ear dysfunction: the shape of the air-conduction audiogram, the difference between the bone-conduction and air-conduction audiograms, and the number of abnormal tympanograms.

Discussion

It is widely accepted that bacterial meningitis can lead to deafness, presumably by damaging the cochlea or the 8th nerve, even in the absence of other signs of neurological damage. We can find no published series where the frequency and type of deafness following meningitis has been compared with controls or with the population at large.

In this series we have found no signs of sensorineural deafness either in the 17 postmeningitis children or in the sib controls. The lack of sensorineural deafness in the subjects could not be due to doubtful diagnosis as all had definite bacterial meningitis. Nor could this favourable outcome be due to mild disease as a number had immediate

complications. There was, however, a considerable amount of hearing loss in both patients and controls, shown by audiometry and by tympanometry to be due to middle-ear dysfunction. The use of tympanometry is valuable in confirming the site of the dysfunction (McCurdy *et al.*, 1976). A possible explanation for these findings is that this group of children was particularly prone to middle-ear disease. This hypothesis seems unlikely as McCurdy *et al.* have found high levels of middle-ear abnormality on tympanometry in the USA, and V. Smythe (to be published) has found that 20% of 289 'normal' schoolchildren in Brisbane failed on pure tone air-conduction audiometry. A number showed abnormalities in the tympanograms, particularly in the reflex thresholds. However, only 1% showed signs of sensorineural deafness. In some groups such as Australian Aboriginal children, the amount of hearing loss is much greater (Canty *et al.*, 1975). These findings are at first sight alarming but it is likely that much of the hearing loss is temporary (Lewis *et al.*, 1975) and probably due to intercurrent infection affecting the middle ear.

We found a considerable amount of hearing loss in children who have had meningitis, but this does not exceed the amount found in sib controls and may in fact be the same as the population at large. There is good published evidence that sensorineural deafness can occur after meningitis, but apparently only when there are other signs of neurological damage. If children who have had bacterial meningitis are to have their hearing tested at follow-up, the testing should be designed to separate sensorineural from conductive hearing loss. At present, there is no evidence that conductive hearing loss is related to bacterial meningitis except in the rare instances where there has been an extension of infection in the ear through the meninges. Middle-ear disease is often temporary, so it is important to identify the type of dysfunction by both pure tone audiometry and by tympanometry, and if in doubt to review the child's hearing at a later date before passing a verdict.

We thank the Medical Records Librarians at the Mater Children's Hospital and Royal Children's Hospital, Brisbane, for locating case records, and Mr. A. N. Lewis, Senior Lecturer in Audiology, University of Queensland, for advice and criticism.

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