



Recommendations for audiometric follow up post paediatric bacterial meningitis based on an Australian experience: a retrospective cross-sectional study

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Background: Bacterial meningitis remains a significant public health burden in both the developed and developing world. Antibiotics have reduced mortality, however, significant morbidity including permanent sensorineural hearing loss (SNHL) remain of concern. Cochlear implantation allows early intervention and improved quality of life for those whom experience severe SNHL. The aim of this study was to review the current referral and audiological follow up time of children suffering bacterial meningitis including identifying the incidence of SNHL. We aimed to offer a standardised referral guideline to be implemented across Queensland hospitals which also contributes to the available published literature on the topic.

Methods: A cross-sectional retrospective review was conducted of treatment and outcomes of all children from birth to 18 years diagnosed with bacterial meningitis at Queensland Children's Hospital (QCH) between November 2014 and December 2021 (7 years). Descriptive data including patient demographics, causative organism, length of hospital stay, audiological referral times and outcomes were collected. A review of recent literature was also conducted using PubMed with search terms including "meningitis", "hearing loss", "audiology", "guidelines", and "paediatric" to identify other published series on the topic and published guidelines from other health services. A review of our results plus published literature was then utilised to develop a post diagnosis audiology referral guideline for these children.

Results: Fifty-seven children were identified to have been diagnosed and treated for bacterial meningitis. Fifty-two (91.2%) were aged less than 1 year and the most commonly isolated pathogen was *E. coli*. 80.7% of children were reviewed by audiology post treatment with wide variance in both referral time (0 to 97 days) and time to audiology review (8 to 304 days, median 36 days). Three children were diagnosed with SNHL post meningitis and all cultured *Streptococcus sp.* on cerebrospinal fluid (CSF) culture. One patient underwent successful cochlear implantation for their hearing loss. The wide variability in time to audiology review highlighted a lack of awareness and standardised pathway for audiology referral post bacterial meningitis. On review of the above and available local and international guidelines, the authors suggest audiology review within 2–4 weeks of meningitis diagnosis and if abnormal, either immediate referral to a cochlear implant team (if severe-profound SNHL) or repeat testing within 2 weeks plus otolaryngology referral if abnormal result but not severe.

Conclusions: The incidence of SNHL post bacterial meningitis was 5.3%, comparable to that of other developed countries such as the United Kingdom (UK) and New Zealand. The review highlighted wide variation in time to audiology referral and review. This variation suggested a lack of awareness among non-otolaryngology specialist medical professionals regarding risk of SNHL and the urgency of assessment. Development and promotion of an evidence-based guideline aims to address this variation and improve patient outcomes for the future.

Keywords: Meningitis, bacterial; cochlear implantation; audiology; child; hearing loss, sensorineural

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Introduction

Prior to the wide availability and implementation of antibiotics, bacterial meningitis was thought to account for 20% of sensorineural hearing loss (SNHL) in children (1). Almost 50 years ago, Nadol published a review of 547 cases of paediatric meningitis of which 236 were bacterial in nature. Twenty-six (11.0%) children suffering bacterial meningitis died and of those whom survived, 28 (11.9%) were diagnosed with SNHL (2). Fortunately, in the last four decades our understanding of meningitis has progressed and death rates in developed countries are now below 5% (3,4).

A Cochrane review (5) of corticosteroid use in bacterial meningitis demonstrated that in high income countries, the incidence of SNHL was reduced in children treated with corticosteroid just prior to, or at commencement of antibiotic therapy. Regarding causative organism, corticosteroids were associated with a lower incidence of SNHL in meningitis associated with *H. influenzae* but not with *S. pneumoniae*. In Australia, the high vaccination rate against *H. influenzae* has significantly reduced the prevalence of associated meningitis, however *S. pneumoniae* meningitis remains of concern (6-8).

Despite high rates of childhood vaccination and improved hospital care, meningitis related hearing loss is still reported in approximately 5% of cases overall, with *S. pneumoniae* meningitis recording rates of hearing loss up to 32% (7). Hearing loss is theorised to occur due to direct extension of bacterial pathogens, or as a result of the associated inflammatory response. In the cochlea, this may lead to labyrinthitis ossificans which can occur in up to 80% of post *S. pneumoniae* meningitis induced SNHL. The timing of onset of labyrinthitis ossificans is poorly defined in humans but has been demonstrated to occur within 3 weeks of meningitis (9,10). In the setting of ossificans, the new bone formation within the cochlear can make cochlear implantation challenging or even impossible. As cochlear implantation is the gold standard of care for severe to profound SNHL, early implantation in this setting becomes critical. Currently, there is a lack of Australian data on audiology follow up and hearing outcomes of children diagnosed with bacterial meningitis by non-Otolaryngology

specialists. Thus the aim of the study was to review the current referral and audiological follow up time of these children, including their hearing outcomes and offer a standardised referral guideline for audiological surveillance post bacterial meningitis. We present this article in accordance with the STROBE reporting checklist (available at <https://www.theajo.com/article/view/10.21037/ajo-23-45/rc>).

Methods

A retrospective cross-sectional study of all children from birth to 18 years of age treated for bacterial meningitis at Queensland Children's Hospital (QCH) between November 2014 and December 2021 (7 years). QCH, Brisbane, Queensland (opened in Nov 2014) is the major tertiary referral centre for the state which has a population of over 5 million.

Initially, a hospital database search was conducted to identify patients with a diagnosis of bacterial meningitis. Electronic medical records allowed this data to be obtained regardless of whether diagnosis and initial treatment occurred at QCH or at another Queensland Health facility within the state.

Once identified, medical records were reviewed and information collected on patient demographics, age at diagnosis, causative organism, length of hospital stay, audiological referral timeline and outcomes were recorded. Patients with a diagnosis of viral meningitis were excluded as were those with cerebrospinal fluid (CSF) features not in keeping with bacterial meningitis (white cell count, glucose and protein levels) despite the growth of an organism (deemed likely a contaminant). Descriptive analysis of data was undertaken.

PubMed database searches were conducted using the terms "meningitis", "hearing loss", "audiology", "guidelines", and "paediatric" in varying combinations of some and all terms. Articles not published in English language were excluded. A search of each Australian state health service website and of the New Zealand Health website was conducted to identify locally available referral

Table 1 Study population demographics

Variables	Age bracket			
	0–30 days	31 days–<1 year	1–5 years	>5 years
Total (n=57)	27	25	1	4
Male	18 (66.7%)	16 (64.0%)	0	4 (100%)
Median age (range)	15 days (2–30 days)	76 days (32–205 days)	2 years	11 years (10–17 years)
Immunised*	19 (70.4%) (unknown 1)	21 (84.0%) (unknown 0)	1 (100%)	4 (100%)
Passed NBHS	22 (81.5%) (unknown 2)	21 (84.0%) (unknown 4)	1 (100%)	3 (75%) (unknown 1)
<i>Streptococcus sp.</i>	1	2 (8.0%)	0	2
<i>E. coli</i>	17 (63.0%)	13 (52%)	0	1
Unknown organism	5	5	2	0
PICU admission	8	2	1	3
Mean duration of IV antibiotic therapy (range)	21.7 days (5–44 days)	21.1 days (10–42 days)	7 days (no range)	20.8 days (14–34 days)
Mean duration of hospital admission (range)	37.4 days (4–386 days)	13.5 days (3–52 days)	9 days (no range)	23.3 days (4–48 days)

*, as per the Australian National Immunisation Program Schedule. NBHS, newborn hearing screen; PICU, paediatric intensive care unit; IV, intravenous.

guidelines.

The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). Ethics approval was gained from Children’s Health Queensland Human Research Ethics Committee (project number 87811). Because of the retrospective nature of the research, the requirement for informed consent was waived.

Results

A hospital database search identified 75 patients with a recorded diagnosis of bacterial meningitis. Review of medical records resulted in exclusion of 18 patients due to incorrect recording of the diagnosis, the most common reason for exclusion was admission due to viral meningitis. Of 57 patients identified, 38 were male (66.7%). Mean age at admission was 378 days (median 33 days, range, 2 days to 17 years) and 45 patients (78.9%) were fully immunised as per the Australian National Immunisation Program Schedule (8) (Table 1).

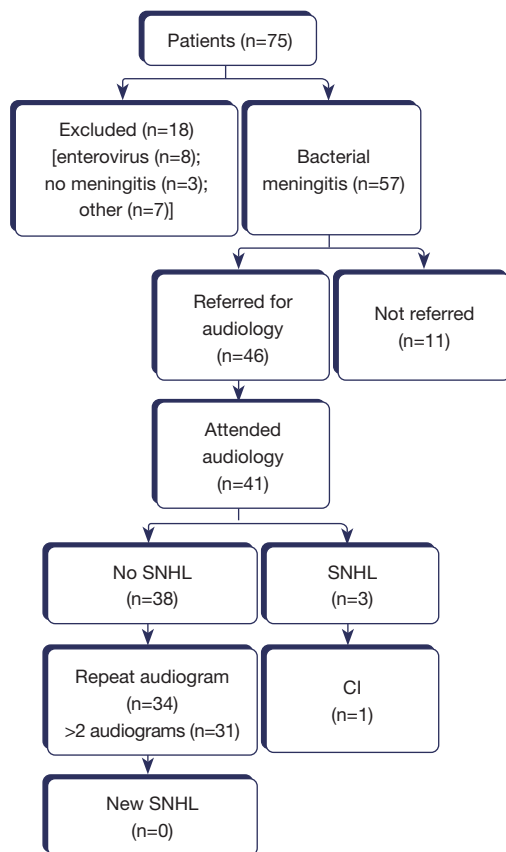
E. coli and *Streptococcus* species were positive in 31 (54.4%) and 5 (8.8%) of these patients respectively. Twelve patients (21.1%) failed to identify an organism on CSF culture but were deemed likely to have bacterial meningitis based on clinical features and other laboratory findings.

Other bacteria identified included *Klebsiella*, *Serratia* and *Pasteurella*. Mean duration of intravenous (IV) antibiotic therapy was 20.7 days (range, 5–42 days) with cefotaxime being the most common primary antibiotic used and mean duration of hospital stay was 25.2 days. Fourteen of 57 children (24.6%) were treated in paediatric intensive care.

In regards to audiological surveillance, 47 patients (82.5%) had a documented pass on their newborn hearing screen with 2 patients receiving a “refer” and another 8 patients (14.0%) unknown. Audiology referral was identified for 33 patients (58.6%) and an additional 13 (22.4%) attended audiology follow up but initial referral could not be located, thus 46 patients (80.7%) were reviewed by audiology post diagnosis. Eleven patients (19.3%) received no referral or audiological follow up post treatment. Forty-one of the 46 patients attended post treatment audiology review. Mean duration from date of hospital admission to audiological testing was 63.4 days (median 36.0 days, range, 8–304 days). Number of days between diagnosis and referral being made varied from 0 to 97 days (median 8.5 days) (Table 2). Of those with normal sensorineural hearing thresholds at first audiological review (n=38), 34 patients (89.5%) underwent repeat testing (mean time between tests, 165 days) and 31 patients (81.6%) had audiology performed on more than 2 occasions. There

Table 2 Time to audiology referral and review

Variables	Number (% of total)	Median time (days)	Range (days)
Referred to audiology	46 (80.7)	8.5	0–97
Attended audiology	41 (71.9)	36	8–304

**Figure 1** Patients referred for audiology. SNHL, sensorineural hearing loss; CI, cochlear implantation.

were no additional cases of SNHL identified on subsequent audiograms (Figure 1).

Only 3 children (5.3%) were identified to have SNHL post meningitis, each cultured *Streptococcus sp.* from CSF (Table 3). Of these three patients, one proceeded to successful surgical bilateral cochlear implantation 93 days post presentation with meningitis. This patient experienced relative delay to audiological assessment at 59 days post admission but rapid escalation with Ear, Nose Throat (ENT) Specialist referral (seen 1 day after audiology) followed by radiological assessment to ensure absence of ossification and subsequent bilateral implantation. The

remaining two patients suffering SNHL post meningitis did not proceed to cochlear implantation due to significant additional comorbidities acquired from the episode of meningitis.

Publicly available guidelines were identified from Royal Children's Hospital, Melbourne (11), New Zealand Department of Health (12), and the United Kingdom (UK) (13).

Discussion

Over a 7-year period, QCH identified and treated 57 children with bacterial meningitis. Similar to current literature, this was most prevalent in those less than 1 year of age, with the median age in this subgroup being 30 days (7). Interestingly, *E. coli* was the most common cultured organism in those under 1 year. In neonates, *E. coli* accounted for 63.0% of cases. Group B *Streptococcus* (GBS) is regularly cited as the most common cause of meningitis in neonates and the lack of cases in this study may be attributed to high rates of prophylactic intrapartum antibiotics administered in Australia (6,14). Some of these neonates may have not been treated at QCH and instead treated in their local neonatal intensive care unit (NICU), hence not being captured in this study. Reducing rates of *Haemophilus influenzae* type B (Hib) have been seen worldwide due to widespread and effective immunisation programs (15,16). In keeping with Australia's high rate of immunisation (8), no children were diagnosed with meningitis secondary to Hib. The incidence of SNHL was 5.3%, similar to that recently reported in New Zealand and the UK (17,18).

When considering whether all children received audiology follow up, 80.7% were known to audiology with 71.9% attending and completing formal audiology assessment. This does not account for those that chose to pursue audiology outside of the public health sector, thus the follow up rate was likely marginally higher than known. The wide-ranging time for referral (0 to 97 days) and varied time to review (8 to 304 days) demonstrates the lack of standardised referral guideline in Queensland for

Table 3 *Streptococcus sp. meningitis*

Patient No.	Age	Organism	Immunised*	PICU duration (days)	Length of admission (days)	Hearing status post event	CI candidate	Implant outcome
Patient 1	2 days	<i>S. pyogenes</i>	N/A	8	386	Severe SNHL; ANSD	No	N/A
Patient 2	107 days	<i>S. agalactiae</i>	Y	0	20	Profound SNHL	Yes	Successful bilateral CI
Patient 3	150 days	<i>S. pneumoniae</i>	N	0	13	Normal hearing	No	N/A
Patient 4	10 years, 5 months	<i>S. pneumoniae</i>	Y	0	48	Normal hearing	No	N/A
Patient 5	17 years, 1 month	<i>S. pneumoniae</i>	Y	1	4	Profound SNHL	Yes	Declined CI

*, as per the Australian National Immunisation Program Schedule. PICU, paediatric intensive care unit; CI, cochlear implantation; N/A, not applicable; SNHL, sensorineural hearing loss; ANSD, auditory neuropathy spectrum disorder; N, no; Y, yes.

these children. Those children waiting such extended time for audiology assessment had increased risk of missing the cochlear implant window should they have had SNHL and subsequent early development of labyrinthitis ossificans.

On review of local and international guidelines for audiology assessment post bacterial meningitis, the UK National Institute for Health and Care Excellence (NICE) guidelines (13) provide a simple evidence-based guide to review. The guidelines recommend firstly offering formal audiological testing, as soon as possible (prior to discharge or within 4 weeks of being “fit to test”). Secondly, all children should be reviewed by a paediatrician, including their hearing test result, within 4–6 weeks of discharge. And finally, if severe or profound hearing loss is identified, urgent assessment for cochlear implant candidacy should occur (13). The New Zealand health service guidelines suggest more timely review, recommending audiology prior to discharge or within 7–10 days of discharge. Again “urgent” assessment for cochlear implantation in those with severe or profound hearing loss is recommended (12). More locally, the Royal Children’s Hospital in Melbourne recommends formal audiology assessment 6–8 weeks after discharge or earlier if concerns for hearing loss are raised (11).

The frequency and duration of repeat testing varies among guidelines with inconsistent evidence to support their development. Repeat testing is not addressed in the NICE Guidelines, whereas New Zealand specifically cites the lack of evidence and recommends repeat testing as optional if hearing is normal at the first assessment. Consistent with our findings, a review of over 200 adult and paediatric patients in the Netherlands found that only those with hearing loss evident on the first post-meningitis audiogram showed any deterioration in status with time (19). Richardson reported similar findings 20 years earlier (20).

This does however conflict with other studies suggesting a rare risk of decline in sensorineural thresholds over time (21–23).

As a result of the above data and review of local and international surveillance guidelines, QCH has recommended that all children with a diagnosis or high clinical suspicion of bacterial meningitis should undergo formal audiology testing within 2–4 weeks of diagnosis and any referral be triaged to be seen within 30 days. Acknowledging the potentially life-threatening complications of meningitis and difficulties in conducting an auditory brainstem response (ABR) testing within an intensive care environment, this 2–4 week window must also consider that the child is “fit to test”. Importantly, audiology referral and review should not be delayed until after discharge or on first paediatric outpatient review. Inclusion of audiology review as part of an Allied Health discharge checklist should be considered to reduce the risk of potential failure to test complex patients. Whilst no children in this study were found to have new SNHL on subsequent audiology if their first test was normal, we have recommended repeat audiology at 6 and 12 months. The rationale for this is multifactorial. A small number of studies have identified new progressive SNHL after meningitis in children with initial normal audiology and these children are also considered at risk for developmental delays and cognitive impairment (7,21,23,24). Should hearing loss of any degree be confirmed on initial testing, urgent referral should be made to an ENT surgeon and repeat audiology should occur at 2 weeks to qualify the loss and identify any rapidly progressive change. Importantly, if the initial audiogram suggests severe or profound SNHL, the audiologist should make immediate contact with the cochlear implant coordinator to expedite the child’s care

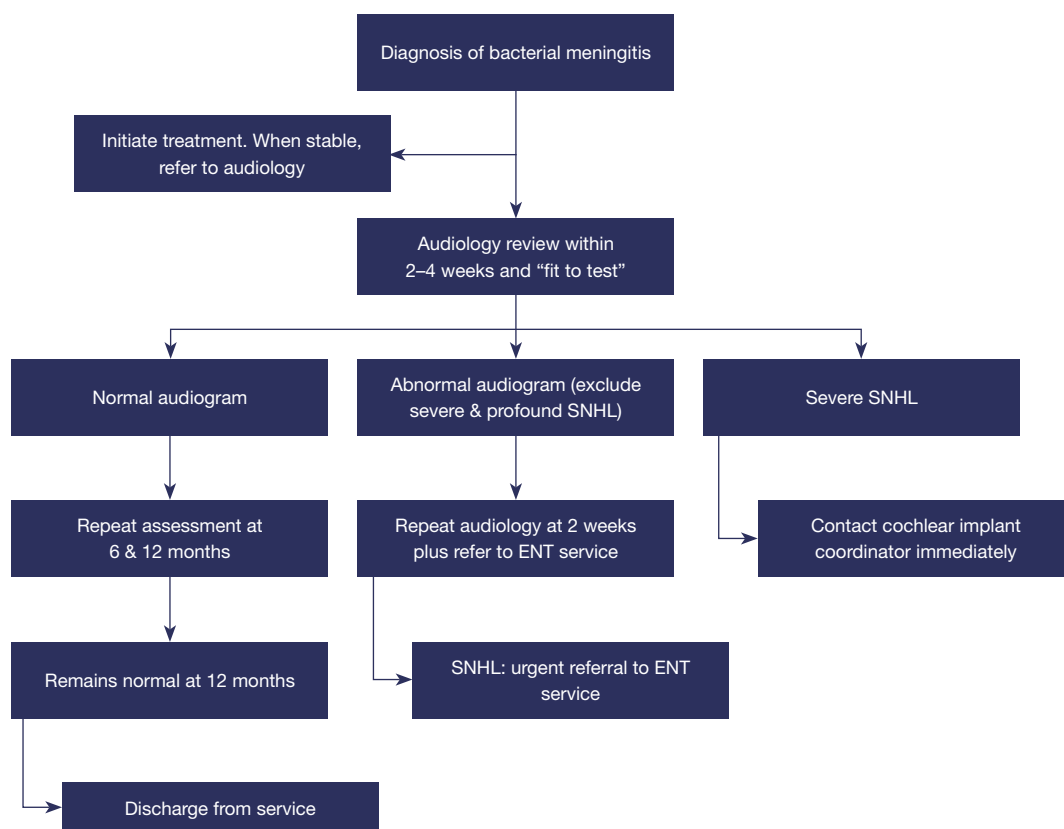


Figure 2 New referral and review guideline for bacterial meningitis at QCH. SNHL, sensorineural hearing loss; ENT, Ear, Nose, Throat; QCH, Queensland Children's Hospital.

(Figure 2).

One limitation of this study is the failure to capture use of dexamethasone early in the treatment paradigm. The use of systemic corticosteroids in bacterial meningitis has been well established to reduce hearing loss in bacterial meningitis (5,25). The use of dexamethasone is considered standard of care in Queensland and thus it can be assumed that the majority of non-neonatal cases were treated accordingly. Other limitations include the lack of data on patients solely treated in NICUs and the relatively small sample size, attributable to the small population of Queensland and thus the limited number of patients experiencing hearing loss. It is not powered to assess the rate and severity of hearing loss linked to *Streptococcal* infection nor the subsequent outcomes of cochlear implantation. A multicentre study would be required to address this limitation. With the implementation of new referral and surveillance guidelines at QCH, a prospective study to examine compliance, effectiveness and accessibility would further add to the literature in this area.

Conclusions

The findings of this study support those published in recent literature from developed countries, with *Streptococcus sp.* being associated with SNHL. It demonstrates wide variation in time to referral and review for audiology, highlighting a lack of awareness of the urgency for assessment and the implications of possible cochlear implantation. A larger, multicentre study would need to be conducted to draw conclusions on rate and success of cochlear implantation post bacterial meningitis.

On review of the current literature, local and international guidelines, we have developed a relevant and achievable referral pathway for clinicians to follow for children with bacterial meningitis. Re-review will be required in the future to determine if this guideline has been implemented and resulted in improved patient outcomes. We acknowledge that guidelines exist in other states of Australia and internationally. The authors would support a comprehensive Australia wide review with a view

to producing a national referral guideline for Australia and New Zealand.

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Footnote

Reporting Checklist: The authors have completed the STROBE reporting checklist. Available at <https://www.theajo.com/article/view/10.21037/10.21037/ajo-23-45/rc>

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Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). Ethics approval was gained from Children's Health Queensland Human Research Ethics Committee (project number 87811). Because of the retrospective nature of the research, the requirement for informed consent was waived.

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