Clinical Predictors for Hearing Loss in Children With Bacterial Meningitis

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Objectives: To identify clinical risk factors that predict a higher incidence of hearing loss in children with bacterial meningitis, to determine the overall incidence of hearing loss in a large group of children proven by culture findings to have bacterial meningitis, and to compare clinical characteristics among patients with Streptococcus pneumoniae meningitis and Neisseria meningitidis meningitis.

Design: Retrospective review

Setting: Tertiary pediatric hospital.

Patients: A total of 171 children identified with bacterial meningitis who met inclusion criteria over a consecutive 10-year period.

Main Outcome Measure: Presence of sensorineural hearing loss.

Results: Of 134 patients who underwent audiologic testing during their initial hospitalization, 41 (30.6%) were found to have at least a unilateral mild sensorineural hearing loss. The incidence of hearing loss was greater in patients with S pneumoniae meningitis than in patients with N meningitidis meningitis (35.9% and 23.9%, respectively). Length of hospitalization, development of seizures, elevated cerebrospinal fluid protein, and decreased cerebrospinal fluid glucose were significant predictors for hearing loss in children with bacterial meningitis. These factors were not found to be as strong a predictor for hearing loss in patients with N meningitidis meningitis. Stability of hearing was demonstrated with limited follow-up audiometry.

Conclusions: Sensorineural hearing loss is a common sequela in children with bacterial meningitis. Identification of hearing loss in children with bacterial meningitis and early rehabilitation will lessen the long-term educational and social difficulties these children may experience.

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Bacterial meningitis is the most common etiology for acquired hearing loss.1 In addition, 5% to 35% of patients with bacterial meningitis will develop permanent sensorineural hearing loss, and profound bilateral hearing loss will occur in up to 4% of patients.2-4 The resulting social and educational impairments can be devastating to the individual and to society. The exact mechanism of hearing loss in patients with bacterial meningitis is not well understood and is likely due to multiple factors that include direct labyrinth involvement, cochlear neuroepithelial damage, and vascular insult. By identifying children at risk for development of hearing loss, early rehabilitation may lessen long-term adverse outcomes.

The microbiologic characteristics of bacterial meningitis has significantly changed over the past decade, mostly owing to the introduction of the conjugate vaccine against Haemophilus influenzae type b (Hib). Recent studies have shown a dramatic decrease in the incidence of Hib infections, with decreased incidence greater than 90% shortly after the introduction of the vaccine. Currently, Streptococcus pneumoniae and Neisseria meningitidis are by far the most common organisms responsible for bacterial meningitis; however, this will continue to evolve with the recent introduction of the heptavalent pneumococcal conjugate vaccine. This study is a retrospective review to describe the most current incidence of hearing loss in children with bacterial meningitis, to compare presentations...
of patients with *S pneumoniae* and those with *N meningitidis* meningitis, and to identify clinical predictors for hearing loss in children with bacterial meningitis.

### METHODS

Medical records for all children admitted to the Texas Children’s Hospital, Houston, with a diagnosis of bacterial meningitis from January 1992 to November 2002 were reviewed. Exclusion criteria included age younger than 3 months, recurrent meningitis, concurrent serious medical conditions, factors that may increase the risk for the development of meningitis (ventriculoperitoneal shunt, etc), or a history of hearing loss. Most children did not present with previous audiologic testing, so a history of no prior hearing loss was based on the initial history given by the parents. The diagnosis of bacterial meningitis was made with positive cerebrospinal fluid (CSF) cultures. Routine computed tomographic or magnetic resonance imaging scans of patients diagnosed with bacterial meningitis are not performed at our institution, so imaging studies are not included in the data analysis. Audiologic testing was performed by a certified audiologist during the initial hospitalization using age-appropriate testing that included behavioral observational audiometry, auditory brainstem response audiometry, and conventional audiometry. In addition, limited follow-up audiologic testing was available, and findings were analyzed to predict the stability of hearing over time. Risk factors for hearing loss as a result of bacterial meningitis were assessed and identified by univariate analysis using unpaired t test, Mann-Whitney test, χ² test, and Fisher exact test.

### RESULTS

A total of 171 patients (100 males and 71 females) were identified who met the inclusion criteria for this study. Ages ranged from 3 months to 17 years (mean age, 3.8 years). Clinical findings are illustrated in Table 1. *Streptococcus pneumoniae* and *N meningitidis* were isolated in 92 and 65 children, respectively (91.8% of cases). There were distinctly different clinical presentations among children with *S pneumoniae* and *N meningitidis* meningitis. As a whole, children with pneumococcal meningitis were younger, presented with a longer history of symptoms, required longer hospitalization, had a greater incidence of seizures, and were more often found to have concurrent otitis media at presentation than children with meningococcal meningitis. Children with meningococcal meningitis were school-aged, had a greater elevation in CSF white blood cell count, and had less decrease in CSF glucose. Children with pneumococcal meningitis were more likely to have hearing loss (35.9%) than children with meningococcus (23.9%), although this did not reach statistical significance.

### CLINICAL PREDICTORS FOR HEARING LOSS IN ALL CHILDREN WITH BACTERIAL MENINGITIS

Of the 134 children tested, 41 (30.6%) were found to have at least a unilateral mild sensorineural hearing loss during initial audiologic testing. Of the children with hearing loss, 17 (41.4%) had mild or moderate sensorineural hearing loss, and 29 (38.6%) had severe or profound sensorineural hearing loss. Nine (31.0%) of the 29 children with severe or profound sensorineural hearing loss had at least a severe bilateral hearing loss. Findings for all patients tested for hearing loss are found in Table 2. Length of hospitalization, development of seizures, concurrent cranial nerve neuropathy, elevated CSF protein, and decreased CSF glucose were significant predictors for hearing loss. A higher percentage of patients who received preadmission antibiotics did not develop hearing loss, although this did not reach statistical significance.

### CLINICAL PREDICTORS FOR HEARING LOSS IN CHILDREN WITH *S PNEUMONIAE* MENINGITIS

The incidence of sensorineural hearing loss in children with *S pneumoniae* meningitis was 33.9%. Of the
children with hearing loss, 9 (32.1%) had mild or moderate sensorineural hearing loss, and 19 (67.9%) had severe or profound hearing loss. Of the children with severe or profound hearing loss, 8 (42.1%) had bilateral severe to profound hearing loss. One of the 5 children who developed sensorineural hearing loss compared with an incidence of 16.7% in boys; however, this was not found to be significant. The incidence of seizures and concurrent cranial nerve neuropathy were similar among patients who developed hearing loss and patients who maintained normal hearing. Laboratory values were similar in patients who would develop hearing loss, although CSF glucose was lower in the group of patients who developed hearing loss.

### CLINICAL PREDICTORS FOR HEARING LOSS IN CHILDREN WITH N Meningitis

Of children with N meningitidis meningitis, 23.9% developed sensorineural hearing loss. Of the children with hearing loss, 6 (34.6%) had mild or moderate hearing loss and 5 (45.4%) had severe to profound hearing loss. One of the 5 children had severe to profound bilateral hearing loss. Table 4 illustrates clinical characteristics that were predictive for hearing loss. Of the girls, 31.8% developed a sensorineural hearing loss compared with an incidence of 16.7% in boys; however, this was not found to be significant. The incidence of seizures and concurrent cranial nerve neuropathy were similar among patients who developed hearing loss and patients who maintained normal hearing. Laboratory values were similar in patients who would develop hearing loss, although CSF glucose was lower in the group of patients who developed hearing loss.

### STABILITY OF HEARING LOSS

Follow-up data were limited; however, only 12 patients with hearing loss underwent additional outpatient audiologic testing. Seven patients (58.3%) were found...
to have stable hearing when retested as outpatients an average of 9.8 months after initial testing. The hearing of 4 patients (33.3%) was found to have improved during follow-up audiologic testing. All 4 of these patients had had unilateral mild hearing loss that was found to be normal during follow-up audiologic testing. One patient was found to have normal hearing during hospitalization but developed a unilateral moderate sensorineural hearing loss 16 months after hospitalization. Overall, limited follow-up data demonstrated stability of hearing over time.

COMMENT

This retrospective study evaluated a large number of children proven by culture findings to have bacterial meningitis and found a sensorineural hearing loss incidence during the initial hospitalization of 30.6%. The incidence of at least a unilateral severe sensorineural hearing loss was 21.6% among all patients with bacterial meningitis. The incidence of hearing loss in this study is greater than that reported in most previous studies. This is likely due to several factors. The study institution is a tertiary referral center for a major metropolitan area that likely receives a disproportionate number of very sick children. In addition, perhaps current pathogens are more virulent. Also, current audiologic testing, especially auditory brainstem-evoked response, may be more sensitive than previous methods. Finally, most children in this study had not had previous objective audiologic testing, and a negative history for hearing loss was based on history alone. Therefore, a few children in this study may have presented with a previously undiagnosed hearing loss. This could potentially artificially inflate the incidence of hearing loss in this study; however, it is unlikely this would significantly affect the overall incidence.

Previous authors have shown that hearing loss occurs during the first 2 days of meningitis. In addition, the hearing loss may be reversible if treated early, as demonstrated by Bhatt et al, who also demonstrated that rabbits always show signs of hearing loss 12 hours after intrathecal injection with Streptococcus and that the rabbits treated with appropriate antibiotic therapy within 12 hours regained hearing whereas untreated animals remained deaf. In this study, 77.6% of patients who did not develop hearing loss were treated with preadmission antibiotics. In contrast, only 22.4% of patients who developed hearing loss received preadmission antibiotics. Limited follow-up audiologic testing found the initial hearing loss to be stable with time, a finding that is consistent with previous reports.

Streptococcus pneumoniae was the organism most commonly responsible for bacterial meningitis in this series of patients and accounted for 53.8% of all cases whereas N meningitidis accounted for 38.0% of cases. Previous series were dominated by Hib meningitis; however, with the introduction of the covalent vaccine against Hib, its incidence has drastically decreased. In this series of patients, Hib accounted for only 8 cases of bacterial meningitis (4.7%), and the last case was in 1998. In this series of patients, the incidence of hearing loss in children with Hib meningitis was 33.3% (2 children were not evaluated with audiometry). The introduction of the Hib vaccine is the most significant advancement in the prevention of meningitis, and this is reflected by the near eradication of the organism in this series of patients. Similar results may develop with the recent introduction of the heptavalent pneumococcal conjugate vaccine.

Decreased CSF glucose is the most consistent predictor of hearing loss, as illustrated herein and in previous studies. It is unclear why a low CSF glucose level is such a strong predictor of hearing loss. It may be assumed that a low CSF glucose level correlates with the bacterial concentration of the CSF, increasing the likelihood of suppurative labyrinthitis as an etiology of subsequent hearing loss. However, other studies have demonstrated a much weaker association with elevated CSF protein and CSF pleocytosis, 2 factors that are elevated in patients with a high CSF bacterial concentration. In the study described herein, patients with hearing loss infected with S pneumoniae were found to have a significantly higher CSF protein level. Another potential sequela of low CSF glucose is direct damage to the cochlea neuroepithelium. Further studies evaluating the effects of hypoglycemia and the cochlea are needed to better understand this relationship.

Seizures are common in children with bacterial meningitis and may be seen in 20% to 30% of patients. In this series of patients, the development of seizures and cranial nerve neuropathies were more common in children with pneumococcus meningitis than in children with meningococcal meningitis. In addition, both factors predicted an increased incidence of hearing loss in patients with pneumococcal meningitis. Other studies have demonstrated an overall worse prognosis for patients who develop seizures. The development of seizures is multifactorial and may be due to high fevers, metabolic disturbances, or focal cerebral irritation. The presence of a cranial nerve neuropathy is certainly a sign of a severe infection and is highly correlated with the development of hearing loss. In this study, 10 patients (5.8%) developed a cranial nerve neuropathy, and all but 3 were found to have hearing loss. Of the patients with hearing loss and cranial nerve neuropathy, 5 patients (71.4%) had at least a severe sensorineural hearing loss.

In conclusion, this study represents a large series of children with bacterial meningitis at a major tertiary referral center. This patient population more accurately represents the current microbiologic characteristics of bacterial meningitis since the introduction of the conjugate vaccine against Hib. The overall incidence of sensorineural hearing loss in all patients with bacterial meningitis was 30.6%. A higher incidence of hearing loss was seen in children infected with S pneumoniae than N meningitidis (35.9% and 23.9%, respectively). This difference did not reach statistical significance. Preadmission antibiotics are associated with a decreased incidence of hearing loss, although this too did not reach statistical significance. The strongest predictors for the development of hearing loss in chil-
Children with bacterial meningitis are decreased CSF glucose, the presence of concurrent cranial nerve neuropathies, and length of hospitalization.

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REFERENCES