Effects of Central Nervous System Residua on Cochlear Implant Results in Children Deafened by Meningitis

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**Background:** This study explored factors associated with speech recognition outcomes in postmeningitic deafness (PMD). The results of cochlear implantation may vary in children with PMD because of sequelae that extend beyond the auditory periphery.

**Objective:** To determine which factors might be most determinative of outcome of cochlear implantation in children with PMD.

**Design:** Retrospective chart review.

**Setting:** A referral center for pediatric cochlear implantation and rehabilitation.

**Subjects:** Thirty children with cochlear implants who were deafened by meningitis were matched with subjects who were deafened by other causes based on the age at diagnosis, age at cochlear implantation, age at which hearing aids were first used, and method of communication used at home or in the classroom.

**Main Outcome Measure:** Speech perception performance within the first 2 years after cochlear implantation and its relationship with presurgical cognitive measures and medical history.

**Results:** There was no difference in the overall cognitive or postoperative speech perception performance between the children with PMD and those deafened by other causes. The presence of postmeningitic hydrocephalus, however, posed greater challenges to the rehabilitation process, as indicated by significantly smaller gains in speech perception and a predilection for behavioral problems. By comparison, cochlear scarring and incomplete electrode insertion had no impact on speech perception results.

**Conclusions:** Although the results demonstrated no significant delay in cognitive or speech perception performance in the PMD group, central nervous system residua, when present, can impede the acquisition of speech perception with a cochlear implant. Central effects associated with PMD may thus impact language learning potential; cognitive and behavioral therapy should be considered in rehabilitative planning and in establishing expectations of outcome.

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Hearing impairment is one of the most frequent complications of meningitis and is reported to occur in 6% to 16% of cases. Postmeningitic deafness (PMD) threatens the normal development of verbal communication and carries implications for literacy and educational achievement. Even in the absence of hearing impairment, delayed language development, and neurologic deficits, subsequent educational difficulties are recognized complications of childhood meningitis.

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Cochlear implantation in children who fail to reach communication milestones because of the severity of their sensorineural hearing loss has generally been demonstrated as an efficacious intervention for childhood hearing impairment, yielding verbal language growth curves that approach those of hearing children. The resulting impact on quality of life and educational placement suggests that this is a cost-effective intervention with durable generic benefits. The task of communication rehabilitation in children deafened by meningitis, however, may be complicated by language and cognitive deficits that result from liquefactive and inflammatory brain insults.

Neurologic complications of bacterial meningitis result predominantly from immune response to the invading pathogen, with less injury resulting from direct effects of the offending organism. Cytotoxic injury of neurons that induces cerebral edema and hydrocephalus can provoke further increased intracranial
pressure and secondary cerebral ischemia with further neuronal injury.

Central neuropathologic correlates of acute bacterial meningitis imply that expectations of benefit from a cochlear implant may differ in children with PMD compared with children with an isolated auditory disorder. Although cochlear implantation has yielded levels of speech perception in children with PMD that vary compared with those of children deafened by other causes,12-15 strict comparisons of the effect of pathogen-

pressures and secondary cerebral ischemia with further neuronal injury.

Central neuropathologic correlates of acute bacterial meningitis imply that expectations of benefit from a cochlear implant may differ in children with PMD compared with children with an isolated auditory disorder. Although cochlear implantation has yielded levels of speech perception in children with PMD that vary compared with those of children deafened by other causes,12-15 strict comparisons of the effect of pathogenesis on outcome are difficult to make owing to a number of intervening variables and confounders. There has been no systematic examination of how clinical features of the acute illness and its neurologic sequelae affect performance.

Deafness and cognitive delay are complications of meningitis that correlate with the severity of illness.5,16 Illness severity is linked to delayed diagnosis and treatment9 and is marked by the presence of central nervous system (CNS) deficits and low levels of cerebrospinal fluid (CSF) glucose.4,5,17 The severity of auditory pathway injury and neurocognitive deficits within the PMD childhood population has implications for language outcome. The identification of clinical predictors of cochlear implant outcome in children with PMD may help direct appropriate rehabilitation plans and expectations by the implant team, school, and family. This study tests the hypothesis that children with PMD experience slower rates of speech perception gain after implantation thanagematched children deafened by other causes, because of neurocognitive residua of the illness.

### METHODS

**SUBJECTS**

Our study included 30 children with PMD and 30 children deafened by other, predominantly congenital causes (the comparison group), all of whom received multiple-channel cochlear implants at The Johns Hopkins Hospital, Baltimore, Md, between 1991 and 2002. All candidates had severe-to-profound levels of sensorineural hearing loss based on the average of preimplantation unaided pure-tone thresholds at 500, 1000, and 2000 Hz of 75- to 90-dB hearing level (HL) (severe) and over 90-dB HL (profound). All subjects failed to experience speech perception benefit from appropriately fit power hearing aids. Each subject with PMD was matched with a child deafened by other causes based on age at diagnosis, age at which hearing aids were first used, age at cochlear implantation, and method of communication used at home or in the classroom (Table 1).

### PROCEDURES

All subjects at The Listening Center, The Johns Hopkins Hospital, received audiological, speech perception, and psychological evaluations immediately before cochlear implantation. Speech perception testing was conducted using age-appropriate instruments (see below) in the best-aided condition both before and after surgery, using live voice presentation at conversational levels. All subjects received audiological evaluations at 6, 12, and 24 months after activation. Information about the acute meningitis illness and its medical sequelae were obtained from medical records requested with permission from outside hospitals and from Hopkins records. This study was approved by the institutional review board at The Johns Hopkins University School of Medicine, Baltimore.

### SPEECH PERCEPTION MEASURES

The speech perception tests used in the study included the Early Speech Perception Test, Northwestern University–Children’s Perception of Speech, Word Intelligibility by Picture Identification (WIPI), Glendonald Auditory Screening Procedure, Lexical Neighborhood Test, and Phonetically Balanced Word Lists-Kindergarten. The Early Speech Perception Test is a 4-level, closed-set instrument that examines pattern perception, spon-
dantic word identification, and monosyllabic word identification using toy objects or pictures to represent the stimulus item. It is most appropriately used with children 2 years of age and older. The Northwestern University–Children’s Perception of Speech is a 4-choice, closed-set picture test that is adminis-
terred to children 3 years of age and older. The WIPI is a 6-choice, closed-set picture test with phonemically similar words for children aged 6 years and older. The Glendonald Auditory Screening Procedure is an open-set task consisting of 10 common (3- to 7-word) questions and 12 common words administered to children aged 6 to 13 years. The Lexical Neighborhood Test is an open-set list of 25 phonetically balanced words and is most appropriate for children 3 years of age and older. The Phoneti-

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**Table 1. Comparison of Cochlear Implantation (CI) Results in Children Deafened by Meningitis and a Matched Group of Children Deafened by Congenital Causes**

<table>
<thead>
<tr>
<th></th>
<th>Meningitis Group (n = 30)</th>
<th>Congenital Group (n = 30)</th>
<th>Statistics†</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communication method, No.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oral</td>
<td>14</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>Total communication</td>
<td>10</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Sign</td>
<td>6</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Age at diagnosis, y</td>
<td>1.4 (1.2)</td>
<td>1.4 (1.0)</td>
<td>t = 0.03</td>
</tr>
<tr>
<td>Age at amplification, y</td>
<td>1.8 (1.1)</td>
<td>1.6 (0.8)</td>
<td>t = 0.62</td>
</tr>
<tr>
<td>Age at CI, y</td>
<td>4.3 (4.1)</td>
<td>4.2 (3.3)</td>
<td>t = 1.3</td>
</tr>
<tr>
<td>Interval between diagnosis and CI, y</td>
<td>2.9 (3.9)</td>
<td>2.8 (3.1)</td>
<td></td>
</tr>
<tr>
<td>No. with open-set speech discrimination</td>
<td>2</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Preoperatively</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Postoperatively</td>
<td>14</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>Interval to postoperative speech discrimination testing, mo</td>
<td>20.8 (5.4)</td>
<td>22.4 (3.8)</td>
<td></td>
</tr>
</tbody>
</table>

*Data are mean (SD) unless otherwise indicated. †P > .05 for all.

subjects younger than 2 years, a subset of the
of performance (categorized on a common ordinal scale consisting of 6 levels
ception measured using a variety of different instruments was
passed levels 1 to 4 inclusively, whereas open-set speech per-
incorporates several measures. Closed-set speech perception,
responds to levels 5 and 6.

ESP Pattern 50%–100%

ESP Mono 33% — 50% — 100%

NU-CHIPS 36% — 50% — 100%

PBK-W 4% — 8% — 100%

GASP-W 16% — 25% — 100%

WIPI 28% — 30% — 100%

PBK-S 4% — 8% — 100%

GASP-S 16% — 25% — 100%

The use of this scale in a meta-
assesses an individual's capabilities in 4 domains: communication, daily living skills, socialization, and motor. The combi-
ment of these 4 domains forms the Adaptive Behavior Composite. All 4 domains and the Adaptive Behavior Com-
comparing the emergence of open-set speech perception across a wide age range. The scale incorporates several measures. Closed-set speech perception,
in which visual cues accompany auditory information, encompass
level at which the child displays mastery). The present study used
opmental age, which is based on the highest developmental age
of performance across a wide age range. The scale incorporates several measures. Closed-set speech perception,
which responds solely on auditory information, corresponds
level at which the child displays mastery). The present study used

Bayley Scales yields 3 factor scores (expressed as a develop-
mental age, which is based on the highest developmental age
level at which the child displays mastery). The present study used

Figure 1. Speech perception categories.16 ESP indicates Early Speech Perception Test; NU-CHIPS, Northwestern University–Children's Perception of Speech; WIPI, Word Intelligibility by Picture Identification; GASP, Glendonald Auditory Screening Procedure (W, word; S, sentences); and PBK, Phonetically Balanced Word Lists-Kindergarten.

The Bayley Scales yield 4 facet scores (expressed as a develop-
amals in infancy (Figure 2), only 7 were affected in the postlingual period (>24 months of age). The bacterium
cultured from the CSF was known in 15 cases. Twelve children were infected by Streptococcus pneumoniae,
and 1 each by Haemophilus influenzae, Neisseria men-

<table>
<thead>
<tr>
<th>Detection</th>
<th>Pattern</th>
<th>Closed-Set Words</th>
<th>Open-Set Recognition</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESP Mono</td>
<td>33% — 50% — 100%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NU-CHIPS</td>
<td>36% — 50% — 100%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PBK-W</td>
<td>4% — 8% — 100%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GASP-W</td>
<td>16% — 25% — 100%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WIPI</td>
<td>28% — 30% — 100%</td>
<td></td>
<td></td>
</tr>
<tr>
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<td></td>
</tr>
<tr>
<td>GASP-S</td>
<td>16% — 25% — 100%</td>
<td></td>
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</tr>
</tbody>
</table>

Approximately 30 (8.7%) of 343 children who underwent implantation at our center over an 11-year period
between January 1992 and January 2003 were deafened by meningitis. Most children acquired postmeningitic
deafness in infancy (Figure 2), only 7 were affected in the postlingual period (>24 months of age). The bacterium
cultured from the CSF was known in 15 cases. Twelve children were infected by Streptococcus pneumoniae,
and 1 each by Haemophilus influenzae, Neisseria men-

Figure 2. Distribution of ages at which meningitis illness and resulting deafness occurred (n=30). Postmeningitic deafness was more prevalent within the first 18 months of life; only 7 children developed postmeningitic deafness in the postlingual period (after 2 years of age).

Bayley Scales yield 4 facet scores (expressed as a develop-
mental age, which is based on the highest developmental age
level at which the child displays mastery). The present study used

The appropriate score is identified in the data analysis as the SB/BSID Nonver-
bal IQ.

The Stanford-Binet yields 3 factor scores (each with a mean
[SD] of 100 [16]). The present study used only the Nonverbal Reasoning/Visualization factor score, which reflects the ability
to interpret and organize visually perceived material, to per-
form basic mathematical operations using visual cues, and to demonstrate visual-motor skills.12

The Bayley Scales yield 4 facet scores (expressed as a develop-
mental age, which is based on the highest developmental age
level at which the child displays mastery). The present study used
only the Cognitive facet score, which assesses nonverbal problem-
solving skills. A developmental quotient (DQ) was calculated by
dividing the estimated developmental age by the chronological age and multiplying by 100 (DQ = [developmental age/chronological age] × 100).

Adaptive Functioning

The Vineland Adaptive Behavior Scales (Survey Form) assess
adaptive skills and social competence in individuals from birth
through the age of 19 years.23 The Vineland is completed through
a structured interview with a parent or other respondent who
is familiar with the individual’s daily living activities. It as-

Psychological Measures

Nonverbal Cognitive Functioning

Nonverbal cognitive functioning was assessed using a subset of
the Stanford-Binet Intelligence Scale: Fourth Edition20 or, in
subjects younger than 2 years, a subset of the Bayley Scales of

Emotional/Behavioral Functioning

The Child Behavior Checklist is a written parent-report mea-
sure that was designed to assess behavioral and emotional problems in children aged 2 to 18 years,24,25 or as young as 18 months,
for serial assessments. It yields normalized scores (mean
[SD] = 50 [10]) in several specific areas as well as a total score. Higher scores indicate greater behavior problems, with scores
higher than 60 denoting clinically significant problems.

Statistical Methods

To compare characteristics before and after implantation be-
tween the postmeningitic and comparison groups, 1-way analy-

STATISTICAL METHODS

To compare characteristics before and after implantation be-
tween the postmeningitic and comparison groups, 1-way analy-
sis of variance or the unpaired t test was conducted. One-way
analysis of variance was used to compare preimplantation scores
between groups in nonverbal cognition, adaptive functioning,
and emotional/behavioral functioning. The PMD and compari-
sion groups were compared for the incidence of categorical out-
comes such as open-set speech perception and the incidence
of neurologic complications using chi-square analysis. All statistical
analyses were performed using Statview (Version 5.0.1; SAS In-
stitute Inc, Cary, NC) and SPSS (Version 10.0; SPSS Inc, Chi-
ago, Ill) software. All P values less than .05 were considered significant. All data are presented as mean (SD).

RESULTS

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ingitides, and group B streptococci. A similar distribution of preoperative speech perception performance was observed for both the children with PMD and the comparison group (Figure 3A). Closed-set speech perception was demonstrated by 27 and 28 children in the PMD and the comparison groups, respectively, the majority of whom performed at the lowest level of function. Detailed information was available regarding the cochleostomy and array insertion in 27 of 30 children with PMD, 9 of whom required an extended cochlear drill-out or trough. Of 28 cases in which the extent of electrode insertion was known, 26 had full insertion.

Detailed behavioral and cognitive testing, which has been routinely performed during the candidacy process since 1995, was available for 18 children with PMD and their matched counterparts. There were no significant differences between the 2 groups in age at diagnosis, at first hearing aid use, at implant surgery, or at evaluation. As shown in Table 2, subjects generally demonstrated average nonverbal cognitive functioning (SB/BSID Nonverbal IQ) before cochlear implantation. Overall adaptive abilities before implantation (Vineland) were in the low-average range, with significant delays noted in the communication and socialization domains. There were no overall emotional/behavioral problems reported before implantation. The unpaired t test revealed no significant group differences in preimplantation nonverbal intelligence, adaptive abilities, or emotional/behavioral functioning.

At an average of 21.5 (5.0) months after cochlear implantation, there was a significant shift in the distribution of speech perception performance toward open-set hearing (categories 5 or 6, Figure 3) in both the PMD group ($\chi^2=34.3; P<.001$) and the comparison group ($\chi^2=40.1; P<.001$). There was no difference in the distribution of speech perception levels between the PMD and comparison groups at this postsurgical interval ($\chi^2=3.1; P>.05$). As a test of intermediate difficulty, the WIPI test provided longitudinal data for the largest number of children over the longest duration. The applicability of other speech recognition testing was limited to the highest or lowest performers over shorter periods. The WIPI scores over time suggested greater variability in the rate of acquisition of speech perception among children with PMD compared with children in the comparison group (Figure 4).

We assessed the incidence of clinical features of meningitis to determine their impact on speech perception after cochlear implantation. We compared children with PMD and open-set hearing with those with only closed-set hearing for clinical features of the acute illness (Table 3). There was, on average, a 4-month difference in the postimplantation interval at which speech perception data were available for subjects in the open- and closed-set groups. The only clinical feature found to be significantly different between open-set and closed-set listeners was the significantly higher incidence of hydrocephalus as a complication of meningitis in the closed-set group ($\chi^2=6.8; P<.01$). Longitudinal WIPI scores suggest that children with PMD who sustained neurologic complications, including stroke syndrome, brain abscess, cranial nerve deficits (other than deafness), and hydrocephalus, were delayed in the acquisition of speech perception abilities compared with other children with PMD and the comparison group (compare Figure 4A and B). These data also suggest that functional gains were not rapid enough for 4 months of additional implant experience to explain the superior performance of the open-set group.

We observed a trend toward lower CSF cell counts in the closed-set group ($t=2.3; P=.06$) (cell counts $<100/\text{mm}^3$: 5 of 6 in the closed-set group; 2 of 6 in the open-set group). Communication method, age at illness, age at cochlear implantation, and presurgical cognitive measures were not significantly different between open-set and closed-set groups. Also, there were no differences in the severity of cochlear obstruction or rate of full electrode insertions between children with open-set (5 of 13 subjects and 1 of 14 subjects, respectively) and closed-set (4 of 14 subjects and 1 of 14 subjects, respectively) speech perception abilities. There was no significant difference in the distribution of cochlear implant devices used by children with open- vs closed-set hearing ($\chi^2=0.95; P>.05$).

A comparison of all 6 subjects with postmeningitic hydrocephalus with 18 subjects with PMD without this complication confirmed that there was a significantly lower speech perception performance in the hydrocephalus group despite a mean postsurgical testing interval that was comparable to that of the nonhydrocephalus group.
The results of our study suggest that neurologic sequelae of meningitis impede the development of speech perception after cochlear implantation in children with PMD. Cochlear implantation increases auditory sensitivity by direct electrical activation of auditory nerve fibers, enabling phonemic awareness, discrimination, and identification and ultimately yielding speech understanding. These data indicate, however, that central auditory stations must be capable of processing implant-encoded information to generate the physiologic substrate of speech comprehension. The presence of clinically evident meningitic residua within the CNS appeared to hold sway over cochlear ossification and associated degeneration of the auditory nerve as a predictor of attenuated growth rates of speech perception skills after implantation. When the burden of early auditory deprivation is combined with the increased risk of cognitive and behavioral deficits associated with meningitis, children with PMD can face significant challenges in acquiring spoken language skills after implantation. Nonetheless, auditory benefit manifests even in this high-risk group.

Despite an average of 1.4 years of postnatal auditory experience before the onset of PMD, children with implants who were prelingually deafened by meningitis acquired levels of open-set speech discrimination similar to those of the comparison group, most of whom were deaf at birth. Variability in the growth of WIPI scores in children with PMD (Figure 4), however, suggests that meningitis poses an additional burden on the acquisition of speech perception by these children, even though many of them eventually achieved the same level of performance as their congenitally deafened peers, albeit after delays of as much as 5 years. As previously reported in prelingually deafened children with cochlear im-

Table 2. Comparison of Preoperative Cognitive Function in Children Deafened by Meningitis and Matched Children With Congenital Deafness*  

|                                      | Meningitis Group (n = 18) | Congenital Group (n = 18) | t Statistic | f |
|--------------------------------------|---------------------------|---------------------------|-------------|
| Age at preoperative evaluation, mo   | 41.7 (40.3)                | 45.1 (36.9)               | 0.26        |   |
| Nonverbal intelligence               |                           |                           |             |   |
| Stanford-Binet/Bayley IQ/DQ          | 90.3 (13.4)               | 92.8 (11.8)               | 0.6         |   |
| Adaptive abilities                   | 82.2 (11.8)               | 79.8 (22.2)               | 0.4         |   |
| Emotional/behavior                   |                           |                           |             |   |
| Child Behavior Checklist Total T-score | 47.0 (6.9)            | 48.9 (5.5)                | 0.9         |   |

Abbreviations: DQ, developmental quotient; SS, standard score.
*Data are mean (SD). Cognitive data only available for children who received cochlear implants after 1996.
†P > .05 for all.

Comment

(Table 4). Also, there was no significant difference in age at diagnosis of illness (t = 0.8; P > .05), age at implantation (t = 1.1; P > .05), or prevalence of other causes (open circles). In both figures, each child with postmeningitic deafness (PMD) is assigned a unique symbol. A, Despite some variability in the increase of WIPI scores among children with PMD without neurologic complications, the progression of open-set speech perception skills is similar to that of children in the comparison group (open circles), most of whom approach maximum scores within the first 12 to 24 months. B, Compared with children who are not deafened by meningitis (open circles), neurologically involved children with PMD are more likely to experience a gain in speech perception scores that is delayed in onset and more gradual.

Figure 4. Word Intelligibility by Picture Identification (WIPI) scores of children deafened by meningitis at different times after cochlear implantation (CI) in comparison to children deafened by other causes (open circles). In both figures, each child with postmeningitic deafness (PMD) is assigned a unique symbol. A, Despite some variability in the increase of WIPI scores among children with PMD without neurologic complications, the progression of open-set speech perception skills is similar to that of children in the comparison group (open circles), most of whom approach maximum scores within the first 12 to 24 months. B, Compared with children who are not deafened by meningitis (open circles), neurologically involved children with PMD are more likely to experience a gain in speech perception scores that is delayed in onset and more gradual.
A central question concerns whether PMD effects manifest peripherally (cochlear scalae and auditory nerve) or centrally (auditory nerve structure and conductivity of central pathways) to produce lower-than-expected gains in auditory perception after implantation. Constraints on auditory rehabilitative benefit may also represent a continuum of injuries that includes central auditory stations that are responsible for the development of linguistic function. The similar incidence of cochlear scarring and ossification and incomplete electrode insertions between children with PMD who have open-set and those who have closed-set hearing suggests that peripheral effects of meningitis may have relatively little influence on ultimate speech recognition results. One caveat is that a minimal number of electrode channels must be available for auditory nerve activation. The peripheral effects of meningitis on the parameters of electrical stimulation that are required for optimal speech perception were not addressed in the present study and require further evaluation.

Even in the absence of postmeningitic deafness and clinically obvious neurologic compromise, language deficits, lower IQs, and increased behavioral problems occur as a result of CNS changes after meningitis. Since neurologic complications due to meningitis are more prevalent in children with hearing deficits than in normal-hearing children, our results reassert that children with PMD have the added burden of CNS injury and its effects on central processing of auditory inputs.

The present study also extends observations that children with PMD suffer from neurologic complications that can pose particular rehabilitation challenges after cochlear implantation. Children with PMD and CNS residua exhibited a slower acquisition of speech...
Table 4. Comparison of Children Deafened by Meningitis With and Without Hydrocephalus Complication

<table>
<thead>
<tr>
<th></th>
<th>Hydrocephalus Present (n = 6)</th>
<th>Hydrocephalus Absent (n = 18)</th>
<th>Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oral communication, No.‡</td>
<td>1/6</td>
<td>9/18</td>
<td>$\chi^2 = 2.1, P &gt; 0.05$</td>
</tr>
<tr>
<td>Age at PMD, y</td>
<td>0.9 (0.6)</td>
<td>1.2 (0.8)</td>
<td>$t = 0.8, P &gt; 0.05$</td>
</tr>
<tr>
<td>Age at CI, y</td>
<td>2.1 (0.9)</td>
<td>4.1 (4.4)</td>
<td>$t = 1.1, P &gt; 0.05$</td>
</tr>
<tr>
<td>Interval without CI, y</td>
<td>1.2 (1.1)</td>
<td>2.9 (4.2)</td>
<td>$t = 1.0, P &gt; 0.05$</td>
</tr>
<tr>
<td>Preoperative open-set discrimination, No.</td>
<td>0/6</td>
<td>2/18</td>
<td>$\chi^2 = 0.7, P &gt; 0.03$</td>
</tr>
<tr>
<td>Postoperative open-set discrimination, No.</td>
<td>0/6</td>
<td>11/18</td>
<td>$\chi^2 = 6.8, P &lt; 0.01$</td>
</tr>
<tr>
<td>Interval to postoperative speech discrimination test, mo</td>
<td>24.0 (0)</td>
<td>21.3 (5.1)</td>
<td>$t = 1.3, P &lt; 0.05$</td>
</tr>
<tr>
<td>Cognitive measures</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PreIQ</td>
<td>87 (26.9); n = 3</td>
<td>89.9 (11.7); n = 3</td>
<td>$t = 0.4, P &gt; 0.05$</td>
</tr>
<tr>
<td>Vineiland</td>
<td>78.6 (10.9); n = 3</td>
<td>81.6 (13.2); n = 11</td>
<td>$t = 0.4, P &gt; 0.05$</td>
</tr>
<tr>
<td>CBCL total</td>
<td>54.0 (3.7); n = 3</td>
<td>44.6 (6.8); n = 12</td>
<td>$t = 2.3, P &lt; 0.05$</td>
</tr>
<tr>
<td>Coincidence with other complication, No.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seizure</td>
<td>4/5</td>
<td>7/17</td>
<td>$\chi^2 = 2.3, P &gt; 0.05$</td>
</tr>
<tr>
<td>Stroke syndrome</td>
<td>4/5</td>
<td>4/18</td>
<td>$\chi^2 = 5.8, P &lt; 0.03$</td>
</tr>
<tr>
<td>Brain abscess</td>
<td>2/5</td>
<td>2/18</td>
<td>$\chi^2 = 2.3, P &gt; 0.05$</td>
</tr>
<tr>
<td>CSF studies</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glucose, mg/dL</td>
<td>12.0 (8.7)</td>
<td>10.0 (12.6)</td>
<td>$t = 0.3, P &gt; 0.05$</td>
</tr>
<tr>
<td>Protein, mg/dL</td>
<td>394.3 (311.4)</td>
<td>228.4 (72.7)</td>
<td>$t = 1.5, P &gt; 0.05$</td>
</tr>
<tr>
<td>Cell count, /mm$^3$</td>
<td>58.8 (54.2)</td>
<td>211.8 (228.5)</td>
<td>$t = 1.3, P &gt; 0.05$</td>
</tr>
<tr>
<td>Cochlear patency, No.‡</td>
<td>1/5</td>
<td>7/16</td>
<td>$\chi^2 = 0.9, P &gt; 0.05$</td>
</tr>
<tr>
<td>Obliterative scar‡</td>
<td>1/5</td>
<td>0/5</td>
<td></td>
</tr>
<tr>
<td>Incomplete insertion</td>
<td>0/5</td>
<td>1/17</td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations: See Table 3.
SI conversion factor: See Table 3.
*Data are mean (SD) unless otherwise specified.
‡Of 6 children with hydrocephalus, sign, total communication, and oral methods of communication were used in 3, 2, and 1 children, respectively, whereas 3, 6, and 9 children without hydrocephalus used these methods.
§Requiring drill-out to at least the first turn.

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