Assessment of Vocabulary Development in Children After Cochlear Implantation

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Objectives: To assess vocabulary development in children following cochlear implantation and to evaluate the effect of age at implantation on performance.

Design: Retrospective study (mean follow-up, 3½ years).

Setting: Tertiary center.

Patients: Children with prelingual deafness provided with a cochlear implant between 1988 and 1999, who serially performed the Peabody Picture Vocabulary Test–Revised (60 patients) and the Expressive One-Word Picture Vocabulary Test–Revised (52 patients). The children were subgrouped into those receiving implants at younger than 5 years and at 5 years or older.

Outcome Measures: Age-equivalent vocabulary test score and gap index (chronological age minus the age-equivalent score, divided by the chronological age at the time of testing) were calculated. For each test, the following were performed: calculation of rate of change for age-equivalent score; comparison of earliest and latest gap indices means (the cohort and intergroup and intragroup comparison); and multiple regression analysis demonstrating the effect of age at implantation, sex, communication mode, etiology of deafness, and residual hearing on the rate of vocabulary development.

Results: Expressive and receptive vocabulary development rates were 0.93 and 0.71 (age-equivalent scores per year), respectively. Subgrouped by age at implantation, the children’s rates (for both vocabularies) were not statistically different (Peabody Picture Vocabulary Test–Revised, \( P = .90 \); Expressive One-Word Picture Vocabulary Test–Revised, \( P = .23 \)). The global latest gap indices were significantly less than the earliest (Peabody Picture Vocabulary Test–Revised, \( P = .048 \); Expressive One-Word Picture Vocabulary Test–Revised, \( P < .001 \)), indicating an improvement in age-appropriate vocabulary development over time. The age subgroups demonstrated similar results, except for the younger group’s receptive gap index. On multiple regression analysis, the significant predictive variables were residual hearing (Expressive One-Word Picture Vocabulary Test–Revised) and male sex and oral communication mode (Peabody Picture Vocabulary Test–Revised).

Conclusions: Children with cochlear implants developed their vocabularies at rates that were sufficient to prevent an increase in their gap indices as related to ideal scores at testing. A late age at implantation does not singularly preclude beneficial development of vocabulary.


During the past decade, investigations have attempted to assess the effect of cochlear implantation on oral communication in children with severe to profound deafness. These studies have generally demonstrated that, in children with prelingual deafness, the age-equivalent scores (on norm-referenced tests of expressive and receptive language or vocabulary) increased significantly over time. However, the subjects maintained a considerable linguistic delay after cochlear implantation. To our knowledge, this delay, or gap between the children’s performance and the ideal performance for their chronological age, has not been quantified in any investigation. In some studies, inferences have been made about how the rates of language development in children with implants compare with those of children without hearing abnormalities, or children with deafness without implants. These investigations did not include similarly assessed and concurrent control subjects, and some results were drawn from cross-sectional data. Also, the type of habilitation of these children after implantation may not have been necessarily equivalent to that of the other groups. Moreover, the follow-up time in the reported studies is generally short, not allowing for the fact that language growth in children may fluctuate over time.

Dawson and Robbins and their colleagues tried to identify factors that may...
MATERIALS AND METHODS

PATIENTS

The database of the Cochlear Implant Program at The Hospital for Sick Children contains information on 133 children who underwent implantation between 1988 and 1999. Only children with prelingual deafness who performed the 2 vocabulary tests detailed in the next subsection, “Language Tests,” were considered for this retrospective study. Of these, the patients whose performance could be quantified by the tests were included. Because the scores before implantation were not available for all patients and represented variable time points before implantation, none of these scores were included in the analysis. Consequently, only patients with scores on at least 2 occasions after implantation were included (Peabody Picture Vocabulary Test–Revised [PPVT], 60 patients; Expressive One-Word Picture Vocabulary Test–Revised [EOWPVT], 52 patients).

LANGUAGE TESTS

The PPVT is an individually administered, norm-referenced test to estimate receptive (hearing) vocabulary for standard American English. The test format contains 5 training items, followed by 175 test items arranged in order of increasing difficulty. Each item has 4 simple black-and-white illustrations arranged in a multiple-choice format. The subject’s task is to select the picture considered to illustrate the best meaning of a stimulus word presented orally by the examiner. The raw scores are converted to age-referenced norms (age-equivalent scores). This test was designed for subjects aged 2 to 12 years who can see and hear reasonably well and understand standard English to some degree.

The EOWPVT is an individually administered, norm-referenced test to estimate a child’s expressive vocabulary in standard scores. It is composed of 143 items, and the child is required to perform a naming task. Again, the raw scores are converted to age-referenced norms (age-equivalent scores). This test was designed for children aged 2 to 12 years (maximum score achievable at 11.9 years equivalent age).

In both tests, the stimulus was only presented orally (the stimulus word was not presented with signed support for children whose primary mode of communication was signing). For the expressive vocabulary test, only spoken answers were considered to determine the child’s score. During testing, all children were using amplification (cochlear implants with or without hearing aids).

OUTCOME MEASURES

An age-equivalent score was calculated for each patient after every assessment. For the purpose of this investigation, an additional value was derived, the gap index. This was calculated by subtracting the age-equivalent score from the chronological age of the child and then dividing by the chronological age (at the time of the test). This index provides a measure of the linguistic gap in relation to age at the time of testing (or to ideal score at the time of testing). If language develops favorably, the gap index should approach zero.

We concur with Robbins and colleagues that a comprehensive analysis of serially measured age-equivalent scores should include measures of the performance of the children over time and the language skills achieved by the end of the follow-up period. In addition, the method should relate the actual performance to that ideally expected, so that one can compare the relative performance of individuals at different time points.

We retrospectively reviewed our database of patients with prelingual deafness who received implants over a 12-year period in The Hospital for Sick Children,

significant variables that were studied to be significant. Recently, Nikolopoulos et al. noted the absence of robust statistical evidence supporting claims that age at implantation is a significant predictor of speech perception and intelligibility after pediatric cochlear implantation. After searching the literature, we similarly found no evidence in relation to oral language development outcomes. Therefore, we aimed to address the effect of age at implantation as a predictive factor of vocabulary development.
Toronto, Ontario, and documented the rates of acquisition of vocabulary (receptive and expressive). We used a novel method to judge the change in vocabulary age gap from the earliest to the latest assessment. Furthermore, we evaluated the effect of age at implantation on these outcomes and explored the predictive value of residual hearing, communication mode, sex, and etiology of deafness on rates of vocabulary acquisition.

RESULTS

As part of the Cochlear Implant Program protocol, all patients undertake vocabulary tests preoperatively for baseline assessment, then postoperatively every 6 months for the first 2 years and once yearly thereafter. Therefore, at a given time after implantation, every patient should have performed both language tests an equal number of times. As this was not achieved because of several constraints (mainly missed appointments and relocated families), 2 patient populations are described.

Satisfying the inclusion criteria were 60 children (28 boys and 32 girls) for the PPVT and 52 children (27 boys and 25 girls) for the EOWPVT (Table 1).

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>PPVT (n = 37)</th>
<th>EOWPVT (n = 37)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. (boys:girls)</td>
<td>60 (28:32)</td>
<td>52 (27:25)</td>
</tr>
<tr>
<td>Age at implantation, y, mean (SD) [range]</td>
<td>5.1 (2.2) [1.9-11.6]</td>
<td>5.3 (2.3) [1.9-11.6]</td>
</tr>
<tr>
<td>Mode of communication</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(oral:total communication: American Sign Language), No.</td>
<td>51:8:1</td>
<td>44:7:1</td>
</tr>
<tr>
<td>Follow-up, y, mean (SD) [range]</td>
<td>3.4 (2.2) [1-9]</td>
<td>3.5 (2.1) [1-9]</td>
</tr>
</tbody>
</table>

*PPVT indicates Peabody Picture Vocabulary Test–Revised; EOWPVT, Expressive One-Word Picture Vocabulary Test–Revised.

Table 2. Comparison of Characteristics of Subgroups by Age of Implantation in the Studied Populations*

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>PPVT &lt;5 y (n = 37)</th>
<th>PPVT ≥5 y (n = 23)</th>
<th>P Value</th>
<th>EOWPVT &lt;5 y (n = 30)</th>
<th>EOWPVT ≥5 y (n = 22)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mode of communication</td>
<td>32:5:0</td>
<td>19:3:1</td>
<td>.72</td>
<td>26:4:0</td>
<td>18:3:1</td>
<td>.48</td>
</tr>
<tr>
<td>(oral:total communication: American Sign Language), No.‡</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Etiology of deafness†</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Usher syndrome</td>
<td>1</td>
<td>1</td>
<td>.42</td>
<td>1</td>
<td>1</td>
<td>.31</td>
</tr>
<tr>
<td>Cytomegalovirus</td>
<td>2</td>
<td>0</td>
<td></td>
<td>2</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Genetic</td>
<td>6</td>
<td>4</td>
<td></td>
<td>6</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Meningitis</td>
<td>2</td>
<td>0</td>
<td></td>
<td>2</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Mondini</td>
<td>2</td>
<td>0</td>
<td></td>
<td>1</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Congenital</td>
<td>24</td>
<td>18</td>
<td>.40</td>
<td>18</td>
<td>17</td>
<td>.63</td>
</tr>
<tr>
<td>Follow-up, y, mean (SD)§</td>
<td>3.2 (2.3)§</td>
<td>3.7 (2.0)§</td>
<td>.40</td>
<td>3.4 (2.2)</td>
<td>3.7 (2.0)</td>
<td>.63</td>
</tr>
<tr>
<td>Residual hearing, %, mean (SD)§</td>
<td>8.2 (5.8)</td>
<td>11 (5.3)</td>
<td>.06</td>
<td>8.1 (5.2)</td>
<td>11.4 (5.6)</td>
<td>.03</td>
</tr>
</tbody>
</table>

*For explanation of abbreviations, see footnote to Table 1.
†Χ² Test.
‡Fisher exact test.
§F Test (2-tailed, unequal variance).

Thirteen patients had postlingual deafness and did not qualify for inclusion in the study. Of 120 patients with prelingual deafness, 60 were excluded from the PPVT group and 68 were excluded from the EOWPVT group. Exclusion criteria included patients who did not possess 2 or more assessment scores after implantation, either because of their not being tested or because the obtained scores fell outside the sensitive range of the language tests.

The mean age at implantation was 5.1 years for the PPVT group and 5.3 years for the EOWPVT group (range, 1.9-11.6 years for both groups). Accordingly, on subgrouping the populations by age at implantation, we chose a cutoff point of 5 years. These subgroups (<5 years and ≥5 years) are referred to as “younger” and “older” groups.

The subgroups were not different statistically in follow-up duration (PPVT, P = .40; EOWPVT, P = .63) or in proportions of sex (PPVT, P = .51; EOWPVT, P = .28), communication mode (PPVT, P = .72; EOWPVT, P = .48), or etiology of deafness (PPVT, P = .42; EOWPVT, P = .31). There was a significant difference between the subgroups in mean residual hearing in the EOWPVT group (P = .03), but not in the PPVT group (P = .06). These results are given in Table 2.

All children used their implant devices consistently. They had been followed up for a mean of 3.5 years (range, 12 months to 9 years for both groups). Most were oral communicators (85% of both groups), with only 1 child using American Sign Language. The remainder used total communication (Table 1).
time point. Finally, the growth pattern of the scores of the younger and older groups do not appear different. Figure 1B is a plot of the EOWPVT age-equivalent scores against time after implantation. It has been constructed in a similar fashion to Figure 1A, and the same observations can be made on it, the major difference being the steeper growth curve of the mean EOWPVT scores. However, because the growth curves were constructed using mean scores at separate time points, with variable numbers of patients at each point, caution is advised on interpretation, as many of the details of the data are lost in this representation.14 The results of the method of summary statistics we used for the definitive analysis follow.

RATE OF CHANGE OF THE AGE-EQUIVALENT SCORES

Figure 2 illustrates the mean rates of change in the age-equivalent score per year in the 2 vocabulary tests for the whole group and for the older and younger subgroups.

Although the mean PPVT rates are not notably different, the older group has a greater mean EOWPVT rate than the younger group; however, this difference is not significant ($P > .05$). The details of the results are given in Table 3. The mean PPVT rate for the whole group was 0.71 age-equivalent score per year (SD, 0.50; 95% CI, 0.20), while the EOWPVT rate was 0.93 age-equivalent score per year (SD, 0.66; 95% CI, 0.99). For the PPVT, the older group’s mean rate was less than that of the younger group (0.69 vs 0.72), but the difference was not significant ($P = .90$). For the EOWPVT, the older group’s rate was higher (1.06 vs 0.83), and again this difference was not significant ($P = .23$).

THE GAP INDEX

Figure 3A shows histograms representing means of the earliest and latest PPVT gap indices for the whole group and for the older and younger subgroups. There is a significant decrease in the older group’s gap index ($P < .01$). Figure 3B shows the mean earliest and latest gap indices of the EOWPVT. There is a similar and statistically significant decrease in gap index, over time, for each of the 3 groups.

The results comparing the earliest and latest gap indices of the PPVT and EOWPVT are given in Table 4 and Table 5. The gap index value is expressed as a fraction of the ideal score for age at the time of testing. A
significant difference was demonstrated between the means of the earliest and latest available gap indices of the whole population. The PPVT gap indices changed from 0.53 to 0.49 (P = .05; 95% CI, −0.0002 to 0.08) and those of the EOWPVT from 0.45 to 0.38 (P < .001; 95% CI, 0.04-0.10).

Within the younger and older groups, comparisons of earliest and latest available gap indices demonstrated significance. The PPVT gap indices of the older group changed significantly from 0.62 to 0.55 (P = .005; 95% CI, 0.04-0.12), while the younger group had a non-significant change from 0.47 to 0.46 (P = .57). For the EOWPVT, the gap indices of the older group also changed significantly from 0.47 to 0.38 (P < .001; 95% CI, 0.02-0.10), while for the younger group gap indices changed significantly from 0.43 to 0.37 (P < .01; 95% CI, 0.02-0.10).

An intergroup comparison of the younger and older groups’ earliest available and latest available indices demonstrated that, while the younger patients had significantly lower gap indices for receptive vocabulary, the 2 groups showed no significant difference with respect to expressive vocabulary (earliest index, P = .83). The details of these results are found in Table 5.

MULTIPLE REGRESSION ANALYSIS

For the PPVT, multiple regression analysis using a backward stepwise model showed male sex and oral communication mode to be significant factors (P = .04 and .03, respectively). For the EOWPVT, running a best subset model demonstrated residual hearing as the only significant predictive factor (P = .03). Table 6 contains the results of the multiple regression analysis for the 2 test groups.

Presentation of the results in the form of a gap index and a rate is necessary to provide as extensive an evaluation as possible of the evolving vocabulary skills of these children. The rate (calculated as the coefficient of regression of the age-equivalent scores over time) represents performance over time and takes into consideration every score for the individual patient. At the same time, the gap index allows an evaluation of the end product and compares it with the state at a starting point. It is our view that neither
is exclusive to the other, especially given that the rate of language acquisition demonstrates considerable intersubject and intrasubject variation.

In our study, rates of vocabulary development of children with cochlear implants demonstrated considerable individual variation, as evidenced by the wide SDs (Figure 2 and Table 3). This is in agreement with previous reports. In the absence of a concurrent control group, our findings cannot support those of other reports that children with cochlear implants equate or superecede rates of vocabulary acquisition of their counterparts without hearing abnormalities.

On analyzing the subgroups by age at implantation, there was no demonstrable difference in vocabulary growth rates. The older group tended to acquire expressive vocabulary faster, but this may be partly explained by their significantly higher residual hearing, especially as it was the only significant predictor for the EOWPVT on multiple regression analysis. Comparison of the corresponding gap indices (Table 5) showed that the receptive vocabulary indices of younger patients were significantly better than those of the older children, whereas the expressive indices were similar for the 2 groups. Although this supports the notion that earlier implantation may reduce the receptive vocabulary loss caused by the duration of auditory deprivation, as others have suggested, expressive vocabulary may not be similarly affected. In addition, the younger children did not improve their receptive indices to any demonstrable degree, whereas the children who underwent implantation after a longer period of auditory deprivation demonstrated benefit over time.

There was a reduction in the gap index as a proportion of the ideal score for age at testing. This can be illustrated by a hypothetical example (Figure 4) of a child aged 3 years at implantation and followed up for 3½ years. According to mean gap indices, the PPVT gap would change from 1.65 years at the 6-month assessment after implantation to 2.99 years after 3½ years of follow-up. On the other hand, the child’s EOWPVT gap of 1.51 years would change to 2.41 years. Although the rates of vocabulary growth prevented a perpetual increase in the initial delays and led to their decrease in the expressive test, the gaps amounted to 46% of the age-appropriate PPVT scores for age and 37% of the EOWPVT scores.

The only significant predictive variables were residual hearing for the EOWPVT and male sex and oral communication mode for the PPVT. Although the sex effect has not been found previously in investigations on children undergoing implantation for deafness, another author found a similar result in a population without deafness with respect to the same test. Meanwhile, children with oral communication did better, probably because our testers administered the tests only in the oral mode, irrespective of the communication mode of the child. This is slightly different from the findings of Miyamoto et al, most likely because they administered their tests in the preferred mode of the child. Age at implantation was not a significant predictive factor, irrespective of prior expectations.

Despite the retrospective design, there are several strengths of our investigation. It is one of the larger studies of communication in children undergoing implantation for prelingual deafness, and its follow-up has extended longer than that of most others. Regarding the tools of the investigation, the tests were administered only in the oral mode, unlike those of Dawson, Miyamoto, Robbins, and Bollard and their colleagues and most other investigations. Using only the oral mode eliminated all nonauditory sensory inputs from the results as far as feasible, allowing more credible extrapolation of our results. Our elimination of the data before implantation is well-founded, because it was only available for some patients and hard to accurately designate on a time scale. This limits our conclusions to the course of events after implantation.

As an effectiveness study, we introduce the use of the gap index as a potential outcome measure that simplifies the analysis of serial measurements of scores that grow over time. It allows comparison of different age groups and assessment of end stage in relation to the initial one.

Further research should be directed at conducting prospective longitudinal clinical trials that compare concurrent groups of children with profound deafness: those who have been fitted with hearing aids, those who received cochlear implants, and those who received neither. The credibility of such trials would be enhanced if the outcome measures used are reflective of real-life communication and the extent of inclusion of these children in mainstream activities.
CONCLUSIONS

The evaluation of language development of children with deafness after cochlear implantation should include, in addition to the rate of such development over time, an expression of the language gap at the latest point in the follow-up. Age at implantation, on its own, cannot preclude a beneficial outcome but may suggest a different pattern of development.

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REFERENCES


