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Timing of Cochlear Implantation and Parents' Global Ratings of Children's Health and Development

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Abstract

OBJECTIVE—To assess children's health-related quality of life (HRQL) and development after cochlear implant (CI) surgery, and compare improvements between different age of implantation categories.

STUDY DESIGN—Prospective, longitudinal study comparing outcomes of deaf children post-CI with hearing controls.

SETTING—Six US CI centers.

PATIENTS—Deaf children who received CI (n=188) and hearing children of comparable ages (n=97).

INTERVENTION—CI before 5 years of age.

MAIN OUTCOME MEASURE—Parental ratings of global HRQL and development, as assessed over the first 4 years of follow-up using visual analog scales. Development scores assess parental views of children's growth and development, motor skills, ability to express themselves and communicate with others, and learning abilities. Associations of baseline child and family characteristics with post-CI HRQL and development were investigated using multivariable analysis, controlling for factors that influence post-CI language learning.

RESULTS—Baseline deficits of CI candidates relative to hearing controls were larger in development than HRQL. Development scores improved significantly by four years after CI, particularly in the youngest CI recipients. Developmental deficits of older CI recipients with early, extended hearing aid use were only partially remediated by CI. Overall, no significant health

deficits were observed in CI children after four years. Cognition and speech recognition were positively associated with both HRQL and development.

CONCLUSIONS—Parental perspectives on quality of their child’s life and development provide practical insight into the optimal timing of interventions for early onset deafness. Validity of parental global assessments is supported by clinical measures of speech perception and language learning and comparison with a well-validated health status instrument.

INTRODUCTION

The developmental consequences of early sensorineural hearing loss (SNHL) are broad and pervasive.¹ SNHL restricts access to acoustic and phonetic elements essential for speech understanding, constraining development of comprehension and production of spoken language. As both reading and writing rely on insights into the phonology of speech, early SNHL can diminish cognitive, behavioral, and social development, as well as communication. Negative effects of SNHL have been documented in selective attention, regulation of behavior, and socialization—areas of development that rely on bidirectional spoken interactions.²

Over half of children identified with severe-to-profound SNHL in the United States now receive a cochlear implant (CI).³ Perceptual benefits of the CI have been established by measuring a range of communication skills.⁴ Prior reviews have emphasized the importance of assessing other outcomes which reflect daily functioning, given the discrepancies documented between outcome measures in clinical vs. real-world settings.^{5,6}

The importance of parental assessment of developmental progress and health-related quality of life (HRQL) is underscored by evidence that the decision to seek CI intervention is associated more strongly with perceived limitations in functioning than objectively-measured hearing loss.⁷ The importance of incorporating HRQL measures as an outcome variable is highlighted further by reduced HRQL reported for children with hearing loss and the financial stress associated with CI technology to address SNHL.^{8,9} Regulatory¹⁰ and reimbursement¹¹ concerns have also motivated the use of patient-reported outcomes.

Because children under 5 years of age are cognitively incapable of reliably responding to standard health and development instruments,¹² it is often necessary to use parent reports of children’s HRQL.⁶ Prior studies indicate that parents can reliably report on their children’s health and functioning,^{13,14} and these proxy measures of HRQL effectively assess the CI in a child’s everyday life, particularly as it relates to the use of spoken language.¹⁵ A global rating instrument, such as a Visual Analog Scale (VAS), allows the proxy respondent to provide a global assessment of the patient’s health without the demands of precisely estimating specific aspects of health.¹⁶

We examine parents’ ratings of their children’s outcomes using a treatment cohort of children with early-onset SNHL who received a CI prior to age 5 years in the Childhood Development after Cochlear Implantation (CDaCI) Study.⁹ We expect that baseline HRQL and developmental assessments of CI recipients, based on parental ratings, will be lower than those of their normal hearing (NH) peers, but hypothesize that after 4 years of CI experiences, these deficits will largely disappear, especially among the youngest CI recipients.

PATIENTS AND METHODS

The inclusion and exclusion criteria for the CDaCI study have been previously published.⁹ Briefly, children under the age of 5 years who met criteria for a CI and similarly aged NH

children whose parents were committed to educating their child in English were eligible. Exclusion criteria were based on low screening scores of cognition and other conditions that would preclude testing with standard measures of language learning. Research protocol approval was granted from Institutional Review Boards at all participating centers, and written informed consent was obtained from legal guardians prior to enrollment.

Outcome assessments

VAS were presented as 10-centimeter “feeling thermometer(s)”¹⁷ with score between 0 and 100, upon which respondents mark the point that reflects their child’s current status. For the VAS-HRQL, parents were instructed to consider their child’s current overall health and well-being, level of pain, ability to get along with others, general disposition, and behavior. The scale was anchored with 100 as optimal health and 0 as no-health/death. This approach is consistent with well-validated VAS-type scales designed for adult self-report, such as the Quality of Well-Being Scale¹⁷ and EuroQoL-5D.^{18,19}

A second scale, the VAS-Development (VAS-D), was based on the conceptual framework of The Infant/Toddler Child Health Questionnaire,²⁰ again using 100 as perfect development. Parents were asked to consider their children’s growth and development, motor skills, ability to express themselves and communicate with others, and learning abilities. Importantly, parental reports of development reflect a child’s functional *performance* (i.e. abilities in real-world, home-based situations) rather than the functional *capacity* (i.e. abilities under ideal, clinical conditions) assessed with tests of speech and language.²¹

Parent reports were collected at baseline and annually through 4 years of follow-up. Convergent and discriminant validity^{16,22} for both VAS scales has been demonstrated. The validity of the VAS as a measure of perceived HRQL and development was further evaluated in relation to results from the well-established Parent Report Form of the Child Health and Illness Profile-Child Edition (CHIP-CE/PRF) concurrently assessed at the 48-month follow-up.²³

Clinical assessments

Age-appropriate measures of cognition, hearing sensitivity (pure tone average-PTA), speech recognition index score, and spoken language comprehension, as well as characterizations of demographics and hearing history are described in detail elsewhere.^{9,24} Available data from baseline through four years of follow-up are analyzed here.

Statistical Analysis

Baseline characteristics were expressed as means and standard deviations for continuous variables and as frequency distributions for categorical variables. Group differences were tested using analysis of variance (ANOVA) for continuous variables and chi-square tests for categorical variables. Children were stratified by age at enrollment (NH participants) or CI surgery: <18 months, 18-36 months, and >36 months. Longitudinal changes in all available VAS scores over the first 4 years of follow-up were displayed using locally weighted smoothing scatter (lowess) plots, identifying nonparametric mean trajectories over time. Mean trajectories were modeled with mixed-effects linear regression models, and if necessary using segment-linear models to approximate non-linear mean trajectories for ease of interpretation. Child-specific intercepts and slopes over the period of follow-up were included as random effects, while other covariates were modeled as fixed effects. The differential *rate* of change in VAS scores over time, associated with a given covariate, was modeled through the cross-product of follow-up time by covariate interaction term. All models were adjusted for study center and social demographic variables. Residual-based

diagnostics were used to evaluate validity of model assumptions. Baseline factors associated with age at implantation were included in a multivariable model using the generalized linear modeling approach. Pearson correlations compared scores from each VAS measure with the global CHIP-CE/PRF score, as well as satisfaction, resilience, comfort, risk avoidance, and achievement domain scores from the CHIP-CE/PRF.

Stata version 11 (StataCorp, College Station, TX) was used for correlations between VAS and CHIP-CE/PRF scores, and SAS version 9.2 (SAS Institute, Cary, NC) was used for all other analyses. All tests were two-sided ($\alpha = 0.05$).

RESULTS

A total of 188 CI candidates and 97 NH children were enrolled and completed more than 1 follow-up visit, of which 178 (95%) CI and 80 (82%) NH children completed the 4-year follow-up. Table 1 lists baseline characteristics. Children with cochlear implants and their hearing peers were similar social-demographically, except that the controls had significantly higher average family income. As expected, children with implants had lower average scores on speech and language tests before implantation and demonstrated lower baseline VAS scores than their hearing peers. However, the average development score was 20.8 points lower in children with implants relative to controls ($p < 0.001$), significantly lower ($p < 0.001$) than the 3.4 points between-group difference seen in health scores. These results suggest that VAS-D has greater sensitivity than VAS-HRQL in assessing parental perception toward the effect of hearing loss pre-CI.

Figure 1 displays average trajectories for VAS scores over 4 years for the CI and NH groups, stratified by age at baseline. Average gains in the health scores in CI children after 4 years of implant experience were small and did not reach statistical significance ($p = 0.36$). Average health scores did not differ significantly between children with implants and the controls (89.5 vs. 91.7, $p = 0.20$) at 4 years. In contrast, significant gains were observed in development scores 4 years post-CI (9.2 point average increase, $p < 0.001$). Despite this significant improvement, baseline deficits relative to controls were not fully offset, although the developmental gap was almost eliminated for children who underwent CI before they were 18 months old (Table 2).

We examined associations of health and development scores with implantation age, hearing loss severity, baseline cognitive screening score, and speech recognition and spoken language development over time (Table 3). Implantation age was separated into 3 component periods based on hearing history: length of time with normal hearing, length between diagnosis of hearing loss and fitting with hearing aid (LHL), and length with hearing aid before CI (LHA).

No associations were found between LHL or LHA with health scores after multivariable adjustment (Table 3). However, longer periods of LHL were associated with lower development scores at baseline. Additionally, children with longer LHL showed larger gains in *development scores* after implantation. For example, everything else held similar, SNHL children who stayed in unaided hearing loss state for 6 months was estimated to have 4.3 points lower development scores at baseline and would gain 3.1 points more in development rating, on average, comparing to CI children who stayed in unaided hearing loss state for only 6 months. Therefore, CI children who had 6 months longer experience in unaided hearing loss state would score 1.2 points lower, on average, in development rating after 4 years of implant experiences. Similarly, longer duration of hearing aid use was associated with lower baseline development scores and greater gain in development ratings over 4 years of CI experience. Importantly, even with their greater rates of development over 4

years of follow-up, the children with early use of hearing aids (and relatively late implantation of the cochlear device) did not make up the developmental deficit incurred early in life. After multiple covariate adjustment, children with longer durations of hearing loss and hearing aid usage had lower development scores 4 years after CI than the children with earlier CI surgery.

As expected, several aspects of communication were found to correlate with parental perceptions of their children's health and development. In CI children, speech recognition index score was associated with health and development scores during 4 years of implant use, after multivariable adjustment (Table 3). Gains in verbal communication were associated with greater development ratings, but not health ratings. Cognitive screening score was also correlated with VAS scores. Baseline hearing sensitivity was not significantly associated with health or development after multivariable adjustment.

Underlying disease-specific and parental factors appeared to influence the age at implantation, as indicated by associations with baseline characteristics (Table 4). Significantly later age of implantation was associated with lower family income, lower maternal education, higher speech recognition index score and verbal comprehension score (all $p < 0.04$ after multivariable adjustment). By comparison, earlier age at implantation was associated with congenital onset of SNHL, lower development score at baseline, and use of oral communication only (all $p < 0.03$ after multivariable adjustment).

Pearson correlation coefficients for global and domain-specific CHIP-CE/PRF scores for the combined CI and NH groups showed significant, modest correlations with both VAS measures at 48 month follow-up. Correlations with VAS health scores ranged from $r=0.48$ (satisfaction domain; $p<0.0001$) to $r=0.29$ (risk avoidance domain; $p<0.0001$), and was $r=0.49$ ($p<0.0001$) with the global score. For development ratings, the strongest correlation was observed for the achievement domain ($r=0.49$, $p<0.0001$), and the weakest correlation was for the comfort domain ($r=0.12$, ns), while the correlation with the global score was $r=0.40$. Correlations for CI parental ratings across the 5 domains tended to be weaker than those observed among NH parents. CHIP-CE/PRF scores were not available at baseline.

DISCUSSION

Our findings indicate that auditory skill and language development following cochlear implantation are associated with fundamentally important improvements in children's overall health and functioning, as assessed by parents. Furthermore, evidence that cochlear implantation before 18 months of age is associated with smaller parent-perceived delays in developmental progress supports auditory and language data that arrive at similar conclusions.²⁵ Although children with late implantation made greater average gains in development over the 4 years, their development lagged in comparison to children who had received CI before 18 months of age. The persistence of these deficits in children with longer periods of hearing loss, even when hearing aids were used, is consistent with developmental needs to establish effective communication early in childhood and evidence that attention regulation critical to development is affected by language impairment.²

The relevance of VAS health and development measures is supported by their relatively modest, but significant association with CHIP-CE/PRF scores assessed at the same time, demonstrating concurrent validity. The VAS-D adopted the conceptual framework of The Infant/Toddler Child Health Questionnaire so it bears content validity. VAS-D also showed predictive validity, as its measures obtained at earlier years was predictive of both VAS-D and CHIP values ascertained at 4 years (data not shown). Furthermore, VAS-D correlated well with functional capacity assessed through tests of speech and language under ideal,

clinical conditions thus demonstrated convergent validity. More specifically, the comprehension of verbal language, after accounting for speech recognition, was also associated with ratings of development, but not ratings of health, over time. This finding may indicate that parental perceptions of well-being in a CI recipient are influenced by factors extending beyond hearing and communication capacity. *Most* deficits in ratings of well-being disappeared during the first 4 years of CI use, possibly because the threat of SNHL to overall well-being was perceived as largely resolved by this time.

The relationship between age at CI and parental ratings of health and development highlights the importance of hearing and communication in the sensitive period before 18 months of age. Verbal language plays an important role in parent-child interactions, challenging hearing parents of deaf children to adequately promote health and development.²⁶ Prior work indicates that, in contrast to the relatively high baseline ratings of well-being in younger deaf children, those baseline ratings in older deaf children (mean age 7.4 years) are substantially lower.²⁷ Consistent with these observations, the impact of hearing loss in the youngest deaf children in this study was less apparent during the infant-toddler stage. The age of onset and characteristics of canonical babbling are variable in young infants with hearing loss.²⁸ As such, the effects of early detection of SNHL on timely intervention could be hampered by the robustness of pre-linguistic behaviors in vocal development.

Cognitive functioning also demonstrated a significant association with ratings of both health and development. It could be hypothesized that higher cognition can compensate for the reduced capacity to process acoustic-phonetic elements of speech. Greater cognitive capacity may be advantageous because speech comprises a continual stream of auditory information; delays in the processing of individual stimuli can impair the effective use of spoken language.²⁹ Children with higher cognitive ability may therefore compensate more effectively for the limitations imposed by hearing loss, improving their capacity to use electrical hearing and resulting in more age-appropriate interactions and better development.

The Centers for Disease Control and Prevention has expressed concern regarding the timeliness of clinical intervention in early-identified SNHL.³⁰ Our study provides quantified assessments of parental perceptions of children's global health status and developmental progress that are likely to influence the urgency with which intervention is sought for early-onset SNHL. Obstacles to early intervention stem from a variety of sources.³¹ However, recognition of the importance of hearing loss on health and development by clinicians and their active engagement with parents of infants with hearing loss are critical in prompting early intervention.³²

Interestingly, parents' awareness of the hearing loss itself did not alter their view of their children's level of early development, for example, in infancy and early toddlerhood. We observed relatively modest reductions in parental ratings of overall developmental status (VAS-D) for the youngest CI subjects (<18 months) at baseline. This is consistent with observations that children in this stage of development do not exhibit measurable delays in language, cognition, and socialization. Parents of children who underwent early implantation were thus likely motivated by an awareness of risks for developmental delay, beyond that already suggested by baseline ratings of development. VAS development scores appeared sensitive, by comparison, to the developmental disadvantages imposed by delayed and inadequate intervention of hearing loss in their older children.

The cross-sectional nature of baseline data does not allow for full longitudinal assessment of factors that influence parental awareness from onset of hearing loss to CI intervention. However, the hearing history previously reported documented longer durations of hearing

loss in older toddler stages.²⁵ Importantly, our adjusted models reveal that later age of implantation was associated with lower family income independent of the association with lower maternal education, and occurred in the context of speech recognition and spoken language growth with hearing aids (despite an advanced SNHL).

Given the importance of age at implantation in facilitating early access to the full range of acoustic-phonetic information that underlies spoken language development, our data suggest that parental ratings of development and general health reflect an under-awareness of the implications of SNHL for learning, despite early knowledge of the SNHL. Parents find it difficult to appreciate the risk of developmental delay associated with early SNHL in infancy, a trend that is worsened by low *family income and lower* maternal education. Compounding this problem is the fact that early intervention programs may not be widely available and linkages with pediatric/medical home providers may be tenuous, increasing an under-appreciation of the risks. Management models that heighten parental awareness and improve access to early intervention programs that promote spoken language are therefore critical.

Although VAS-D and VAS-HRQL are simple, global scales for development and health, respectively, they appeared to have face validity and correlated well with many developmental measures (Table 3). They also showed discriminant validity, as evidenced by strong but differing correlations across the 5 domains of the well-validated CHIP-CE/PRF, with VAS-D being most strongly correlated with achievement and VAS-HRQL being most strongly correlated with satisfaction. Both VAS measures demonstrated age-related differences in parental perception of developmental status and highlighted the need for a more reliable reference instrument in very young deaf children.

It remains to be determined whether VAS ratings of health and development correlate with measures of the emotional experience of parents in terms of their perceptions of the real-world effectiveness of their children's CI intervention. Further correlation and longitudinal follow-up may provide insights into whether parents' broader conceptualizations have implications for their commitment to rehabilitative measures needed to support this intervention. Further study is needed to understand how parental ratings of developmental deficits in older children change over time. Likewise, greater correlation between ratings of well-being and language comprehension may develop as the cohort ages and language takes on greater salience in daily functioning.

Parental perspective of early SNHL is critical. Developmental learning, directed behaviors, and socialization rely on effective, bidirectional interaction.^{15,28} The broad impact of deafness on development and insights into a caregiver's view of his or her child's daily function suggests the need for continued development of outcome measures, including HRQL as assessed by a parent proxy. Thorough characterization of the impact of early childhood deafness and CI on well-being is likely to facilitate better preoperative patient education, monitoring of postoperative rehabilitation, and the development of a comprehensive model of cost-utility analysis of early CI.^{27,33,34}

CONCLUSION

CI in children resulted in improved parental ratings of child development and stable parental ratings of child health. The validity of these by-proxy measures is underscored by significant correlation with several clinical measures. Such measures may provide insights into how parents perceive their children's attainment of outcome beyond hearing *per se* and further elucidate factors related to early decision making related to intervention.

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Full List of Abbreviations

CI	Cochlear Implant
HRQL	Health Related Quality of Life
VAS	Visual Analogue Scale
D	Development
SNHL	Sensorineural hearing loss
CDaCI	Childhood Development after Cochlear Implantation
NH	Normal Hearing
CHIP-CE/PRF	Parent Report Form of the Child Health and Illness Profile-Child Edition
PTA	Pure Tone Average
LHL	Length of Hearing Loss
LHA	Length with Hearing Aid

Figure 1.

Mean scores of VAS by follow-up time and age for HRQL (A) and Development (B), over 48 months; 188 children with severe-to-profound SNHL (black symbols) and 97 children with NH (gray symbols), stratified by age at enrollment: <18 months (solid line), 18-36 months (short dash), and >36 months (long dash).

Table 1

Baseline characteristics of 188 children with severe-to-profound sensorineural hearing loss and 97 children with normal hearing in the Childhood Development after Cochlear Implantation Study.

	Cochlear Implantation Recipients by Age at Baseline (Pre-implantation)				Normal Hearing Children by Age at Baseline			
	<18 Months	18 - 36 Months	>36 months	Total	<18 Months	18 - 36 Months	>36 months	Total
	N (%)							
Participants, No.	72 (38.3)	64 (34.0)	52 (27.7)	188	28 (28.9)	48 (49.5)	21 (21.7)	97
Gender, Female	32 (44.4)	31 (48.4)	35 (67.3) *	98 (52.1)	15 (53.6)	32 (66.7)	13 (61.9)	60 (61.9)
Race, White	58 (80.6)	42 (65.6)	40 (76.9)	140 (74.5)	22 (78.6)	39 (81.3)	16 (76.2)	77 (79.4)
Maternal Education, did not graduate high school	2 (2.7)	4 (6.2)	9 (17.2) *	15 (8.0)	0 (0.0)	4 (8.3)	2 (9.5)	6 (6.1)
Annual Family Income, < \$50,000	22 (30.6)	34 (53.1)	23 (44.2) *	79 (42.0)	2 (7.1)	5 (10.5)	8 (38.1) *	15 (15.5)
Congenital Hearing Loss	56 (77.8)	31 (48.4)	18 (34.6) ***	105 (55.9)	NA	NA	NA	NA
Oral Communication Mode [#]	33 (45.8)	21 (32.8)	18 (34.6)	72 (38.3)	NA	NA	NA	NA
	Mean (SD)							
Age, months	12.6 (3.1)	27.1 (5.5)	46.1 (7.3) ***	26.7 (14.5)	13.6 (2.4)	26.7 (4.3)	47.8 (7.9) ***	27.5 (13.1)
VAS-HRQoL	90.9 (9.1)	85.1 (15.6)	88.3 (11.8) *	88.3 (12.5)	92.4 (7.2)	91.4 (7.1)	91.7 (11.0)	91.7 (8.0)
VAS-D	77.3 (17.3)	68.6 (19.6)	69.5 (17.6) *	72.2 (18.5)	92.4 (9.0)	92.0 (9.7)	96.1 (4.9)	93.0 (8.8)
Speech Index Score	13.3 (19.3)	32.6 (44.6)	105.2 (115.8) ***	45.5 (77.2)	96.5 (24.3)	215.2 (67.0)	384.7 (75.1) ***	221.6 (118.2)
Reynell Verbal Comprehension	0.8 (1.7)	3.9 (6.4)	13.5 (13.4) ***	5.8 (9.8)	8.3 (4.5)	32.2 (10.3)	54.2 (7.4) ***	30.1 (18.3)
Cognition Screening Score	97.6 (19.9)	97.7 (19.5)	93.4 (24.9)	96.5 (21.2)	112.8 (12.6)	105.0 (14.9)	103.4 (16.9) *	106.9 (15.1)
Pure Tone Average (dB)	108.9 (15.6)	105.1 (15.6)	100.0 (17.4) *	105.1 (16.4)	15.6 (6.8)	16.1 (6.8)	8.1 (4.4) ***	14.2 (7.1)

Comparisons between age strata within the same hearing status group:

* p<0.05;

** p<0.01;

*** p<0.0001.

[#] Included 'Speech Only' and 'Speech/Sign, with Speech Emphasis'.

VAS-HRQoL and VAS-D scores as assessed by parental report at 4 years of follow-up, and changes in scores between baseline and 4 years of follow-up.

Table 2

Age Category	CI Cohort			NH Cohort		
	4 yr f/u (SD)	4 yr change*	95% Confidence Interval*	4 yr f/u (SD)	4 yr change*	95% Confidence Interval*
VAS-HRQL						
<18 mos	90.7 (10.7)	-1.0	-4.5, 2.6	89.0 (13.3)	-2.9	-8.1, 2.2
18-36 mos	90.7 (12.4)	5.7	1.5, 10.0	92.5 (12.1)	1.1	-3.3, 5.5
>36 mos	88.7 (13.3)	-1.8	-6.8, 3.2	92.0 (9.8)	1.0	-7.7, 9.8
VAS-D						
<18 mos	85.3 (15.5)	6.8	2.0, 11.6	89.5 (12.0)	-2.3	-6.1, 1.6
18-36 mos	80.4 (19.1)	11.4	5.2, 17.6	90.3 (11.6)	-1.0	-5.6, 3.5
>36 mos	80.0 (19.8)	10.0	2.0, 17.9	94.0 (5.2)	-0.7	-4.2, 2.8

Abbreviations: VAS-HRQL-Visual Analog Scale-Health-Related Quality of Life; VAS-D-Visual Analog Scale-Development; BL-baseline; f/u-follow-up; CI-cochlear implantation; NH-normal hearing.

* Estimates for 4-year difference and associated 95% confidence interval were derived from unadjusted mixed effects models with group and visit specific mean parameters and unstructured covariance matrix utilizing baseline, 12, 24, 36 and 48 months data.

Table 3

Predictors* of parent-rated mean VAS-HRQL and VAS-D scores over 4 years of follow-up after cochlear implantation in 188 children with severe-to-profound sensorineural hearing loss.

	VAS-HRQL			VAS-D		
	Estimate	95% CI	P-Value	Estimate	95% CI	P-Value
Cognition Screening Score, per 20 pts ↑	1.4	0.4, 2.4	0.01	1.4	0.1, 2.6	0.03
PTA in better ear, per 20 dB ↑	-0.2	-2.0, 1.7	0.87	0.1	-2.2, 2.5	0.91
Speech Recognition Index Score [†] , per 100 pts ↑	1.4	0.2, 2.5	0.02	1.6	0.2, 2.9	0.03
Verbal Comprehension Score [†] , per 10 pts ↑	-0.2	-1.3, 0.9	0.73	3.0	1.8, 4.3	<0.001
LHL, per 6 months ↑, on baseline score	-1.1	-2.6, 0.4	0.16	-4.3	-6.1, -2.5	<0.001
LHL, per 6 months ↑, on change of score over 4 years from baseline	0.9	-0.6, 2.5	0.23	3.1	0.8, 5.3	0.01
LHA, per 6 months ↑, on baseline score	-0.7	-1.7, 0.4	0.21	-2.5	-3.8, -1.2	<0.001
LHA, per 6 months ↑, on change of score over 4 years from baseline	0.5	-0.6, 1.5	0.39	2.2	0.7, 3.8	0.01

Abbreviations: VAS-HRQL-Visual Analog Scale-Health-Related Quality of Life; VAS-D-Visual Analog Scale-Development; PTA-pure tone average; LHL-length of hearing loss; LHA-length of hearing aid use.

* Mixed effects models included all variables listed in the Table, and were further adjusted for study centers, gender, race, ethnicity, maternal education, family income, baseline communication mode, congenital hearing loss status, length of normal hearing period, and bilateral implant status.

[†] Included in the models as time-dependent covariates.

Table 4

Association * of baseline characteristics with age at cochlear implantation in 188 children with severe-to-profound sensorineural hearing loss.

	Difference in Mean Age at Cochlear Implantation		
	Estimate (Months)	95% CI	P-Value
Income <\$50,000	4.3	0.2, 8.3	0.04
Maternal Education, less than High School Graduation	5.0	1.4, 8.5	0.007
Congenital Hearing Loss Status	-4.7	-8.4, -1.0	0.01
Oral Communication Mode	-4.8	-8.4, -1.1	0.01
VAS-D, per 10 points ↑	-1.1	-2.2, -0.1	0.03
Speech Recognition Index Score, per 30 points ↑	1.2	0.16, 2.2	0.02
Spoken Language Comprehension (Reynell Developmental Language Scales) ³⁵ , per 10 points ↑	6.9	4.2, 9.6	<0.001

Abbreviations: VAS-D-Visual Analog Scale-Development

* Adjusted for all other variables in the Table as well as additional baseline factors including 4 frequency pure tone average, cognitive function, maternal sensitivity, and VAS health-related quality of life score.