Cost-Utility Analysis of the Cochlear Implant in Children

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Context Barriers to the use of cochlear implants in children with profound deafness include device costs, difficulty assessing benefit, and lack of data to compare the implant with other medical interventions.

Objective To determine the quality of life and cost consequences for deaf children who receive a cochlear implant.

Design Cost-utility analysis using preintervention, postintervention, and cross-sectional surveys conducted from July 1998 to May 2000.

Setting Hearing clinic at a US academic medical center.

Participants Parents of 78 profoundly deaf children (average age, 7.5 years) who received cochlear implants.

Main Outcome Measures Direct and total cost to society per quality-adjusted life-year (QALY) using the time-trade-off (TTO), visual analog scale (VAS), and Health Utilities Index—Mark III (HUI), discounting costs and benefits 3% annually. Parents rated their child's health state at the time of the survey and immediately before and 1 year before implantation.

Results Recipients had an average of 1.9 years of implant use. Mean VAS scores increased by 0.27, from 0.59 before implantation to 0.86 at survey. In a subset of participants, TTO scores increased by 0.22, from 0.75 to 0.97 (n=40) and HUI scores increased by 0.39, from 0.25 to 0.64 (n=22). Quality-of-life scores were no different 1 year before and immediately before implantation. Discounted direct costs were $60228, yielding $9029 per QALY using the TTO, $7500 per QALY using the VAS, and $5197 per QALY using the HUI. Including indirect costs such as reduced educational expenses, the cochlear implant provided a savings of $53198 per child.

Conclusions Cochlear implants in profoundly deaf children have a positive effect on quality of life at reasonable direct costs and appear to result in a net savings to society.

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Impairment of hair cell function induces profound deafness in approximately 0.3% of children younger than 5 years.[1,2] Cochlear implants may affect the auditory rehabilitation of an estimated 200000 US children with profound deafness who fail to benefit from conventional hearing aids. Rising health care costs, due in part to advances such as the cochlear implant, have led to pressures that discourage the use of cost-increasing technology. Two thirds of US health care plans cited "no timely cost-effectiveness data" as a barrier to reimbursement.[3] Policymakers, third-party payers, and pediatricians have called for more cost-effectiveness data on pediatric cochlear implantation.

Conversely, costs associated with profound deafness are already substantial. The expected lifetime cost to society for a child with prelingual onset of profound deafness exceeds US $1 million, largely because of special education and reduced work productivity.[4] Cochlear implantation may result in a net savings to society if benefits translate into reduced educational costs and increased earnings.

A recent multicenter study of the cochlear implant in postlingually deaf adults reported a reasonable cost-utility of $14670 per quality-adjusted life-year (QALY) using the Health Utility Index (HUI).[5] Published cost-utility ratios of pediatric cochlear implantation have been limited by using hypothetically estimated utilities[6-9] or visual analog scale (VAS) scores obtained from adult patients.[10-12] Empirical data are necessary, and utilities from adult patients may not capture the impact of issues unique to childhood deafness, including development and language acquisition.

We conducted a cost-utility analysis of the cochlear implant in children from the societal perspective using 3 different instruments to measure quality of life.

METHODS

Study Design

We conducted preintervention, postintervention, and cross-sectional surveys of parents of profoundly deaf children (average hearing loss ≥90 dB for both

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ears) each of whom have received or will receive a cochlear implant. The institutional review board of The Johns Hopkins Hospital approved the study. All participants gave informed consent. The VAS was mailed to parents of each child who received an implant at The Listening Center at Johns Hopkins. The HUI, appropriate only for children aged 5 years or older, was mailed to families of school-aged children who responded to the VAS. The time-trade-off (TTO), which is more demanding in time and emotions, was conducted as parental interviews during routine appointments, following standardized protocols with visual aids.[13]

To assess potential selection or recruitment bias, we compared sociodemographic and audiological characteristics and VAS scores of all participants (n=78) with subgroups that also completed the TTO (n=40) or HUI (n=22). We also compared these characteristics of study participants with characteristics of parents of children who had received an implant but who did not participate.

Measurement of Health Utility

Each parent rated his/her child's health state at survey, immediately before and 1 year before the implantation using the VAS and TTO instruments, and at survey and before implantation using the HUI.

The VAS is presented as a vertical 10-cm "feeling thermometer" with grid marks from 0 (death) to 100 (perfect health); respondents mark a number corresponding to perceived quality of life. In the TTO,[14] respondents are offered 2 alternatives. Alternative 1 is current health state (deaf without cochlear implant) for time t (rest of life expectancy). Alternative 2 is perfect health for time x. The x is then varied until the respondent is indifferent between the 2 alternatives, at which point health utility is expressed as x/t.

The HUI,[15] a population-based health utility instrument, postulates the domains of health as hearing, speech, vision, emotion, pain, ambulation, dexterity, cognition, and self-care. Respondents are mapped into 1 of 972 000 health states depending on their functional capacity based on a 15-question survey. For example, deafness without other comorbidities would generate a score of approximately 0.61 because in the derivation of the HUI, 532 nondeaf adults representing the general population rated the state of being deaf as 0.61 using the standard gamble.

Mean group VAS scores can also be transformed into TTO scores by a power function. Several investigators, in mapping the relationship between VAS and TTO scores obtained from individuals who completed both, found concordance in the formula $TTO = 1 - (1 - VAS)b$, with b ranging from 1.55[16] to 1.61[17] to 1.81.[18] Transformed scores using these coefficients can be compared with empirically obtained TTO scores as another means of evaluating the validity of the TTO assessments.

Because of the possibility of recall bias in retrospective assessment of quality of life before the implantation, we also administered the instruments to parents of deaf children who were eligible but had not received an implant. Parents rated their children's health state at the time of the survey and 1 year ago. We also retested a small group of patients to assess test-retest reliability. For those who completed multiple instruments, Pearson correlations were calculated.

Measurement of Costs

Direct medical costs were estimated using the Medicare resource-based relative-value scale (RBRVS) for inpatient and outpatient preoperative, operative, and postoperative services covered by the Physician Fee Schedule,[19] average Medicare blended payment for hospital costs,[20] wholesale cost of the device, average cost per surgery of complications and device failure, processor upgrade costs, and patient-borne costs of warranty, loss or damage insurance, and batteries.

Wholesale device cost was used because this aspect of Medicare reimbursement is substantially below cost (Health Care Financing Administration Common Procedure Coding System code L8614, $14 500 for outpatient surgery; diagnosis related group [DRG], 49; $11 000 global fee for inpatient surgery).[19,20] Device, warranty, and battery costs were estimated as the average between the most common implants currently used at The Listening Center: Nucleus-24 (Cochlear Corp, Englewood, Colo) and Clarion (Advanced Bionics, Sylmar, Calif). An internal device failure rate of 0.2% was calculated based on observed failure rates in all children worldwide with the Nucleus-22 for over 5 years, the Nucleus-24 for over 1 year, and the Clarion for over 2 years (P. Parker, BA, Cochlear Corp, oral communication, October 1999; J. Grant, BA, Advanced Bionics, oral communication, October 1999). Because our observed complication rates have been lower than reported figures, we derived the costs of complications from a previous study of 2751 patients[21] to obtain more conservative and stable estimates.

Indirect costs included time off from work, travel expenses, change in educational costs, and change in future earnings. For time off from work, we estimated 4 hours per visit and a weighted-average salary based on employment status and sex. We used the parents' work until their children would be aged 18 years and then used the recipient's work; 3 days off were given at time of surgery. Change in educational costs was based on differences in school placement before and after receiving the implant as previously described.[22] Change in future earnings took into account differences in school placement and nondeaf and deaf employment rates and wages.[1,4,23]

Measurement of Life-Years

We used a life table to estimate remaining average life expectancy.[24] We assumed the cochlear implant would not alter life expectancy and that the implant would be used for the remainder of life.

Calculation of the Cost-Utility Ratio

By definition,

$$\text{Cost-Utility} = \frac{\text{Costs (in US\$)}}{\Delta\ \text{(QALYs)}} = \frac{\text{Costs (in US\$)}}{\Delta\ \text{(Life-years} \times \text{Health Utility)}}$$

Health utility is the numerical valuation of one's quality of life on a linear scale from 0.00 (death) to 1.00 (perfect health). Both costs and benefits are discounted at the recommended 3% rate to express future expenses and earnings in today's dollars.[25]

We calculated cost-utility using 3 different utility instruments. To explore the effect of potential recall bias, we also calculated cost-utility using cross-sectional comparisons of preimplantation at-survey ratings of candidates with after implantation at-survey ratings of recipients.

Sensitivity Analysis

We performed 1-way sensitivity analysis for both direct and total costs, varying the covariates about their ranges to test the robustness of the cost-utility analysis.

RESULTS

Study Population

Response rates were 78 (74%) of 105 eligible families for the VAS, 40 (77%) of 52 for the TTO, and 22 (73%) of 30 for the HUI. The 78 children had an average age of 7.5 years and had used their implants for an average of 1.9 years.

There was no significant difference in characteristics among the VAS, TTO, and HUI subgroups, nor between the recipient and candidate cohorts, in VAS scores or sociodemographic and audiological characteristics (TABLE 1). There were also no significant differences between recipients whose parents participated in the study and those who did not.

Measurement of Health Utility

Mean VAS scores (n=78; age 7.5 years with 1.9 years of implant use) increased 0.27 on a scale from 0 to 1, from an immediately before implantation score of 0.59 to a postimplantation score of 0.86 (FIGURE and TABLE 2). Twenty-six respondents repeated the VAS a second time (average time, 9.6 months); test-retest correlation was 0.62. The mean (SD) retest response was slightly lower than the original response (Δ, 0.02 [0.18]).

Mean TTO scores (n=40; age 7.4 years with 1.7 years of implant use) increased 0.22. The 1-year-before implantation score was 0.75, followed by an immediately before implantation score of 0.75 and an at-survey score of 0.97. When asked, the 40 TTO respondents reported that their 1-year-before and their immediately before VAS scores did not differ.

Mean VAS scores were transformed into TTO scores by the power function described in the "Methods." Transforming the VAS scores (0.59 preimplantation to 0.86 postimplantation) yielded scores of 0.75 to 0.95 (Δ, 0.20), 0.76 to 0.96 (Δ, 0.20), or 0.80 to 0.97 (Δ, 0.17), respectively. This agreed with TTO results of 0.75 to 0.97 (Δ, 0.22).

HUI scores (n=22; age 10.0 years with 2.8 years of implant use) increased 0.39, from 0.25 before implantation to 0.64 at survey. Of the 9 health domains, hearing and speech were solely responsible for the significant overall improvement in utility (Table 2).

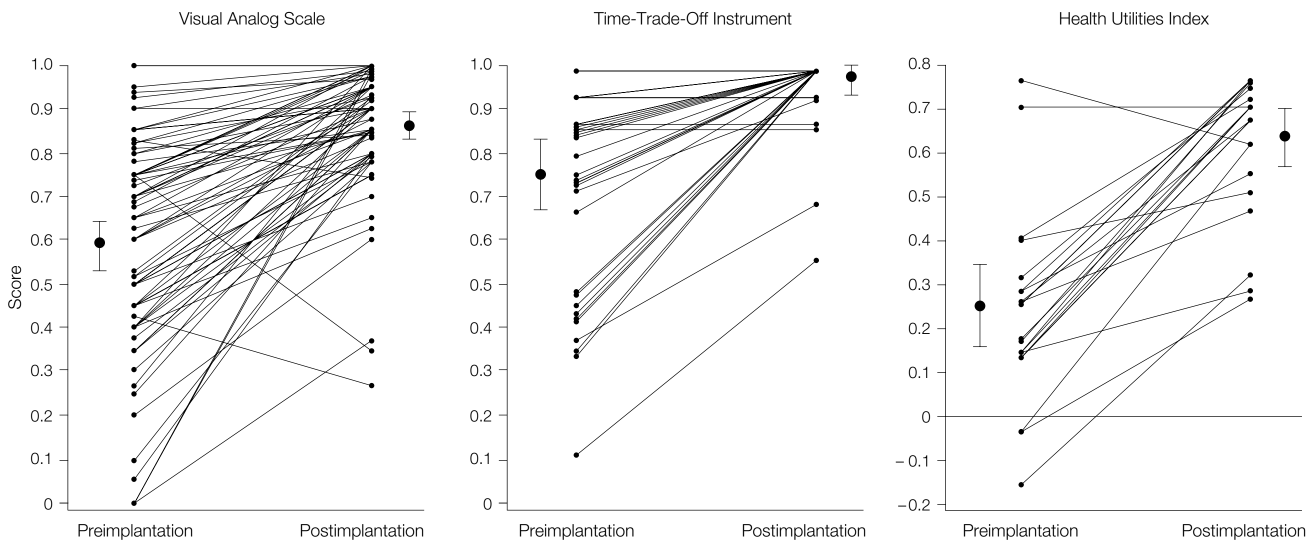
Ninety-two percent of parents perceived an improvement in quality of life in terms of VAS scores; 4% no change (n=3, representing 2 scores of 100 to 100; 1 of 90 to 90); and 4% a decrease (n=3). Of those with decreased scores, one patient required reimplantation, a

Table 1. Characteristics of Recipient Cohort*

Characteristic	VAS (n = 78)	TTO (n = 40)	HUI (n = 22)
Current age, y, mean (SD)	7.5 (4.5)	7.4 (5.3)	10.0 (4.9)
Cochlear implant use, y, mean (SD)	1.9 (2.0)	1.7 (1.7)	2.8 (2.8)
Age at implantation, y, mean (SD)	5.7 (4.2)	6.1 (4.7)	6.4 (4.7)
Age at onset of deafness, y			
Prelingual (<3)	93	90	91
Perilingual (3-5)	3	10	9
Postlingual (>5)	4	0	0
Duration of deafness, y, mean (SD)	4.5 (3.6)	4.3 (4.3)	5.4 (3.9)
Origin of deafness, %			
Congenital	73	63	67
Meningitis	18	25	25
Progressive	9	13	8
Female child	46	44	40
Female parent	89	90	87
Parent age, y, mean (SD)	38.3 (6.1)	39.8 (5.2)	39.2 (5.0)
Parent race			
White	86	90	93
Black	5	2	0
Asian	2	0	0
Other	7	8	7
Parent education			
High school or less	18	22	13
Some college	23	20	24
College degree	29	34	26
Graduate degree	30	24	27
VAS scores			
Preimplantation mean (SD)†	0.59 (0.24)	0.58 (0.21)	0.69 (0.19)
Postimplantation mean (SD)	0.86 (0.14)	0.87 (0.12)	0.91 (0.08)
Δ mean (SD)	0.27 (0.23)	0.29 (0.18)	0.22 (0.17)

*VAS indicates visual analog scale; TTO, time-trade-off; HUI, Health Utilities Index—Mark III. Data are presented as percentages unless otherwise indicated. Among the VAS, TTO, and HUI subgroups, there were no significant differences (ie, $P<.05$) in any of the above characteristics, with statistical testing conducted by unpaired t tests for means or χ^2 test for proportions. Parent characteristics represent the responding parent.
†Preimplantation indicates surveys taken immediately before implantation.

Figure. Retrospective Health Utility Scores From Parents of Children With Cochlear Implants



The mean change in utility (postintervention−preintervention scores) was 0.27 for the visual analog scale, 0.22 for the time-trade-off instrument, and 0.39 for the Health Utilities Index. Mean scores (95% confidence intervals) are indicated by data points and error bars.

second patient had difficulty in rehabilitation, and third patient is doing well in language acquisition. Ninety-five percent of HUI scores improved and 5% decreased (n=1); the one decreased HUI score correlated with a decreased VAS score. Seventy-eight percent of TTO scores improved and 22% had no change, reflecting the fact that a significant decrement in quality of life must generally occur before respondents are willing to trade-off years of life.

Pearson correlations were moderate between changes in VAS and TTO scores (n=40; *R*, 0.57), VAS and HUI (n=22; *R*, 0.44), and TTO and HUI (n=15; *R*, 0.48).

Table 2. Health Utility Scores Using 3 Different Instruments*

Instrument	No. of Children Tested	Preimplantation Score	Postimplantation Score	Δ
Visual analog scale	78	0.59 (0.53 to 0.64)	0.86 (0.83 to 0.89)	0.27 (0.22 to 0.32)
Time-trade-off	40	0.75 (0.67 to 0.83)	0.97 (0.93 to 1.00)	0.22 (0.15 to 0.28)
Health Utilities Index	22	0.25 (0.16 to 0.34)	0.64 (0.57 to 0.70)	0.39 (0.31 to 0.46)
Hearing		0.65 (0.61 to 0.68)	0.86 (0.83 to 0.89)	0.22 (0.17 to 0.26)
Speech		0.80 (0.75 to 0.84)	0.93 (0.91 to 0.94)	0.13 (0.09 to 0.17)
Emotion		0.96 (0.93 to 1.00)	0.99 (0.99 to 1.00)	0.03 (0.00 to 0.06)
Cognition		0.94 (0.91 to 0.98)	0.97 (0.95 to 0.99)	0.03 (−0.01 to 0.06)
Ambulation		0.98 (0.94 to 1.00)	0.99 (0.98 to 1.00)	0.01 (−0.01 to 0.04)
Vision		0.98 (0.95 to 1.00)	0.98 (0.94 to 1.00)	0.00 (−0.01 to 0.00)
Pain		1.00 (0.99 to 1.00)	1.00 (0.99 to 1.00)	0.00 (−0.01 to 0.00)
Dexterity		0.99 (0.97 to 1.00)	0.99 (0.97 to 1.00)	0.00 (0.00 to 0.00)

*Data reported as mean (95% confidence interval). Preimplantation indicates surveys taken immediately before implantation.

Measurement of Costs

Using fiscal year 1999 data, lifetime direct medical costs of the implantation and associated services were \$60 228 at a 3% discount rate and \$51 900 at a 5% rate (TABLE 3). Five percent were preoperative costs; 9%, operative costs; 32%, device costs; and 55%, postoperative costs. Indirect costs were a reduction of \$113 426 at a 3% discount rate and a reduction of \$82 374 at a 5% rate, largely because of educational savings (TABLE 4) and increased future earnings. Combining all costs, cochlear implantation would save \$53 198 per child at a 3% discount rate and \$30 474 at a 5% rate.

Measurement of Life-Years

The average age at implantation in our cohort was 5.7 years. With 54% males and 46% females, we projected an average life expectancy of 78 years and therefore 73 years of implant use.

Cost-Utility Ratios

Direct medical cost per QALY was \$9029 per QALY using the TTO, \$7500 per QALY using the VAS, and \$5197 per QALY using the HUI (TABLE 5). Before discounting, changes in utility were assumed to remain stable for the remainder of life. Differences between the preimplantation at-survey scores of candidates and the after implantation at-survey scores of recipients reflect similar improvements in utility, resulting in cross-sectional cost-utility ratios of \$10 131 per QALY using the TTO, \$8809 per QALY using the VAS, and \$5957 per QALY using the HUI (Table 5). Total cost per QALY, after incorporating indirect costs, was less than \$0.

Table 3. LIfetime Costs of Pediatric Cochlear Implantation (1999 US Dollars)*

Variables	No. of Years	Costs, US $
Direct costs		
Preoperative costs	1	2863
Operative costs		
Cochlear implant device	1	19 153
Hospital and surgery charges	1	4612
Medical complications, if any	1	710
Total operative	1	24 475
Postoperative costs		
Audiology follow-up	1-73	5148
Rehabilitation follow-up	1-2	8984
Device failure, if any	1-73	1007
Loss or damage insurance	1-73	4013
Extended warranty, external	4-73	7341
Special batteries	2-73	1293
Processor upgrade	2-73	5104
Total postoperative	2-73	32 890
Total Direct Costs		**60 228**
Indirect costs		
Time off from work†	1-73	4623
Travel expenses	1-73	4830
Parking expenses‡	1-73	589
Change in educational costs	1-13	−65 558
Change in future earnings§	14-73	−55 574
Special equipment	1-73	−1012
Total Indirect Costs		**−113 426**
Total Costs		**−53 198**

*Assumes average age at implantation 5.7 years, 73 remaining years of life, and 3% discount rate. Negative numbers represent savings due to cochlear implantation. Criteria for cost estimates are available on request.
†Assumes time off from work as 4 hours per visit and 2080 work hours per year. Average parent salary based on employment (of the 40 participants 30% had full-time jobs, 18% had part-time jobs, 52% homemakers, and 0% were unemployed). By sex, full-time salary was $35 345 for men and $25 862 for women.[23] Homemaker salary estimated as median professional housekeeper salary of $17 449[41]; part-time salary estimated as average of full-time and homemaker salaries. Parent's salary was deducted until the recipients became 18 years old, then recipient's projected salary was deducted.
‡Parking costs per visit were $5; travel expenses per visit were calculated as round-trip miles between home city and Baltimore, Md (n = 69; 94 miles) multiplied by standard reimbursement rate of $0.31/mile.[26]
§Differences between nondeaf and deaf employment rates and wages, tabulated by age groups 18-44, 45-64, and 65 years or older, suggest a lifetime earning gap of $421 768 ($148 198 after discounting).[1,4,23] Increased earning potential was based on 75% of those attending mainstream classes to attain the average nondeaf employment profile and the rest of the cohort to remain at the average deaf employment profile.

Table 4. Educational Placement and Costs*

Placement	Cost per Year, US$†	Percentage of Patients (n = 44) Preimplantation	Postimplantation	Change
Mainstream class with hearing peers	6680	13‡	63	50
Partial mainstream	13 521	4	5	1
Self-contained class with deaf peers	15 801	71	27	−44
State school for the deaf, day student	31 728	13	5	−8
State school, residential student	45 948	0	0	0
Average cost per year, $		16 753	10 737	−6016

*Average current age 6.6 years, with 2.3 years implant experience. Negative numbers represent savings due to cochlear implantation. Preimplantation indicates surveys taken immediately before implantation.
†From the 1995 budget of the Maryland Department of Education as previously described,[22] inflated to 1999 dollars using the Consumer Price Index for All Urban Consumers.[27]
‡Consistent with 10% for deaf children without cochlear implants in 2 national surveys.[28,29]

Sensitivity Analysis

Varying relevant covariates about their ranges still generated consistently favorable cost-utility results (TABLE 6).

COMMENT

This analysis suggests that the cochlear implant is highly cost-effective in children, with a net expected savings of $53 198 over a child's lifetime. Considering only direct medical costs yields cost-utility ratios of $9029 per QALY using the TTO, $7500 per QALY using the VAS, and $5197 per QALY using the HUI. For public policy, cost-utility analysis is useful because its measure of benefit—the QALY—incorporates the dimensions of both quantity and quality of life, permitting comparison of all interventions on a uniform scale. Medical interventions with a cost-utility less than $20 000 to $25 000 per QALY are generally considered to represent acceptable value for money, ie, cost-effective. [30,31] The cost-utility of pediatric cochlear implantation compares favorably with many other procedures that use implants, including (inflated to 1999 dollars[32]) the defibrillator implant, which costs $34 836 per QALY[33]; knee replacement, $59 292/QALY[34]; and adult cochlear implantation, $11 125 per QALY,[35] using the VAS; $16 061 per QALY[5] using the HUI. Previous pediatric cochlear implant studies, all postulating hypothetical or adult utilities and performed in England or Australia, reported cost-utility ratios ranging from less than $0 to $25 942 per QALY,[6-12] generally including educational savings but being inconsistent in treatment of other costs. To our knowledge, this is the first cost-utility study of pediatric cochlear implantation that uses US cost data or directly elicits utilities from recipients or their parents.

Of the 7 empirical adult studies, 4 used the VAS, 2 used the HUI, and 1 used the Quality of Well-being Scale.[36] This is the first cochlear implant study to use the TTO. The TTO elicited robust gains in utility, but the scores were consistent with transformed VAS scores using established power functions described in the literature. The preoperative baseline TTO score may be considered conservative compared with an average standard gamble score (generally similar to TTO) of 0.61 for being deaf obtained in the derivation of the population-based HUI. The TTO and standard gamble scores for being deaf from the general population may therefore require further assessment. Comparing benefits to direct costs, all 3 instruments yielded favorable results, ranging from $5197 to $9029 per QALY. This convergence of results provides confidence that the true cost-utility lies within or close to this range. Varying other covariates in a sensitivity analysis confirms the robustness of this analysis.

Several limitations of our study deserve comment. Recall bias, inherent in any retrospective study, may have caused overestimation of utility gains. However, recall bias in cochlear implant patients' preoperative utilities may be less substantial. Patients revisit the state of being deaf when the processor is removed daily for bathing and sleeping, when the battery power is exhausted, and when equipment failure is experienced. Patients and their families probably appreciate the communication and sensory difficulties of profound deafness even many years after cochlear implantation. Consistent with this, candidates similar in key characteristics generated prospective preoperative scores nearly identical to recipients' retrospective preoperative scores.

Parental proxy bias also may have caused overestimation of utility gains.[37,38] We thought it necessary and desirable to use hearing parents as proxies because average age of those at the time they received their implants was younger than 5 years and as young as 1 year, greater than 90% of deaf children are born to hearing parents, and parents must make this decision. However, future longitudinal assessments that include self-reported

Table 5. Cost-Utility of the Cochlear Implant in Children Using Direct Medical Costs*

	Cochlear Implant Recipients						Cochlear Implant Candidates		
	No. of Children Surveyed	Preimplantation†	Postimplantation	Gain in Utility†	Gain in QALYs†	Cost-Utility Cost per QALY, US $†	No. of Children Surveyed	At Survey	Cost-Utility Cost per QALY, US $‡
TTO	40	0.75	0.97	0.22	6.54	9209	32	0.77	10 131
VAS	78	0.59	0.86	0.27	8.03	7500	48	0.63	8809
HUI	22	0.25	0.64	0.39	11.59	5197	12	0.30	5957

*Assumes average age at implantation 5.7 years, 73 remaining years of life, direct medical costs of $60 228, and 3% discount rate. QALY indicates quality-adjusted life-year; TTO, time-trade-off; VAS, visual analog scale; and HUI, Health Utilities Index—Mark III.
†Determined retrospectively, based on recipients' preimplantation (immediately before implantation) and postimplantation utilities.
‡Determined cross-sectionally, based on candidates' preimplantation utilities and recipients' postimplantation utilities.

Table 6. Sensitivity Analysis Using Time-Trade-Off Instrument*

Variables	Base Estimate	Range of Estimate (Best Case to Worst)	Direct Costs, US $, Cost-Utility Cost per QALY (Base Case, 9209)	Total Costs, US $, Savings to Society (Base Case, −53 198)
Gain in health utility	0.22	0.39 to 0.10	5196 to 20 278	. . .
Implant use, y	73	90 to 40	8966 to 10 719	−52 467 to −39 169
Discount rate, %	3	0 to 5	4987 to 10 912	−131 066 to −29 474
Direct medical costs, US $	60 228	31 856 to 99 678†	4871 to 15 241	−84 263 to −16 441
Cochlear implant device	19 153	14 027 to 37 016‡	8425 to 11 940	−58 324 to −35 335
Surgery	4612	3000 to 10 000	8963 to 10 033	−54 810 to −47 810
Audiology and rehabilitation, US $	14 133	7381 to 17 067§	6755 to 10 770	−59 950 to −50 264
Warranty and insurance, US $	11 354	0 to 11 354	7473 to 9209	−64 552 to −53 198
Frequency of processor upgrades	2	0 to 6‖	6755 to 10 770	−58 302 to −42 990
Time off from work, hours per visit	4	0 to 8	. . .	−57 821 to −48 982
Salary, parent taking time off, US $	21 209	0 to 100 000	. . .	−57 821 to −38 547
Travel distance, miles	47	5 to 200	. . .	−56 353 to −48 056
Additional children mainstreamed, %	50	70 to 30	. . .	−85 449 to −45 667
Gain in future earnings, US $	−55 574	−148 198 to 0¶	. . .	−145 822 to 2376
Special living equipment, US $	−1012	−38 374 to 0#	. . .	−90 560 to −52 186

*All costs and benefits discounted at 3% per year. Negative numbers indicate savings; ellipses, no change; and QALY, quality-adjusted life-year.
†Minimum costs represent preoperative evaluation, operative costs, and 1 year of audiology and rehabilitation only; maximum costs represent summing maximum estimates of all direct costs.
‡Range of reported device costs in a recent multicenter study.[5]
§Length of rehabilitation therapy depends on age, school, and preoperative hearing; base case represents median length of 1.5 years, with a range of 1 to 2 years.
‖Two lifetime processor upgrades consistent with observation that approximately one third with 10 years' implant use have upgraded (The Listening Center, unpublished data, 2000); provided is range of 0% to 100% of recipients upgrading every 10 years.
¶$148 198 represents discounted lifetime earnings gap between average nondeaf and deaf individual.[1,4,23]
#$38 374 represents discounted savings in special living equipment estimated in a previous study.[6]

ratings from the older children would be informative.

This study is also subject to potential selection bias, only representing deaf children who have received or will receive an implant at a large tertiary care center. It does not include those who did not receive implants for ideological, medical, or insurance-related reasons, nor does it address the controversy within the deaf community about adverse effects on deaf culture.[39] However, ability to pay has no bearing on candidacy at The Listening Center, which we currently regard as "no substantial growth in speech sound recognition and age-appropriate verbal language abilities despite continued use of powerful hearing aids, fit for both ears."[40] We also demonstrated no recruitment bias among the VAS, TTO, and HUI subgroups by comparing key characteristics. Our cohort had higher socioeconomic status than the general population, but utilities were similar across strata of parent educational level.

Our estimates of indirect costs are probably conservative. In our cohort, with average implant experience of 2.3 years, 63% attended mainstream school classes, compared with 75% with at least 4 years' experience in a previous study.[22] Of those in mainstream classes, we only assumed that 75% (instead of 100%) would attain the average nondeaf employment profile. The rest of the cohort is assumed to remain at the average deaf employment profile, a probable underestimation of earnings. One study estimated a savings of $38 374 in special living equipment after implantation[6]; we only included the commonly used telephone text device.

In summary, direct medical cost ranged from $5197 to $9207 per QALY using 3 utility instruments and total cost per QALY was less than $0. The cochlear implant is extremely cost-effective, generating important health benefits in children at reasonable direct costs and providing a net savings to society.

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