International Journal of Technology Assessment in Health Care, **19:2** (2003), 421–431.

EVIDENCE OF IMPROVING COST-EFFECTIVENESS OF PEDIATRIC COCHLEAR IMPLANTATION

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Abstract

Objectives: To examine the cost-effectiveness of pediatric cochlear implantation over time.
Methods: A prospective study based on ninety-eight children implanted between 1989 and 1996 at Nottingham's Paediatric Cochlear Implantation Programme, UK. The influence of outcomes and other variables on total costs was examined using multivariate regression analysis.
Results: Having controlled for potential confounding variables, total cost was negatively related to year of implant and positively related to the number of hours of rehabilitation ($p = .000$).
Conclusions: Having controlled for outcomes (Categories of Auditory Performance and Speech Intelligibility Rating), the cost-effectiveness improved over time. This finding may be due to a learning curve and have policy implications.

Keywords: Cochlear implants, Cost-effectiveness, Learning curve, Dissemination, Quality assurance

Cochlear implants are implanted electronic devices that provide a sensation of hearing to the profoundly deaf (17;25). The device is used both in adults and children, although it is in the latter context that the potential benefits for the individual are believed to be greatest. Implantation refers not just to the surgical insertion of the device but rather encompasses the multidisciplinary working of audiologists, psychologists, teachers of the deaf, speech

This research forms part of a programme of research funded by Cochlear UK, Ltd.

and language therapists, as well as surgeons working with the child and the family for what can be over many years (10).

The first implantation of a child in the UK occurred in 1989, and by 2001, it was estimated that over 1,600 children had been implanted (12). In the United States in 2001, it was estimated that approximately 14,000 people had implants, 7,000 of whom were children. Worldwide, the total number of implants (adults and children) was estimated at around 25,000 (13).

Several studies have examined the effects associated with implantation in children. The outcomes examined have included specific aspects of functioning such as enhanced speech intelligibility (1;23) and auditory perception (9;15;18), an enhanced likelihood of mainstream educational placement (3;14), as well as broader measures of outcome such as psychological well-being, social integration, and quality of life (2;8;10). As an example of outcomes, a study of 133 children in one UK center found that among those reaching the six-year interval (i.e., 6 years after implantation), the percentage able to understand conversation without lip-reading rose from 0% to 82% (15).

The intervention in a pediatric context has also been the subject of several economic evaluations. Cost-utility analyses in the United States, UK, and Australia, for example, have estimated the cost per quality of life year (QALY) gain associated with the intervention at between approximately $5,200 and $9,000 in the United States (6), $12,000 and $18,000 in the UK (21), and $2,600 and $5,600 (5) in Australia (all figures U.S. dollars, assuming exchange rate of £1 = $1.45, US$1 = AUS$1.97, the years of the studies being, respectively, 2000, 2001, and 1999). Although comparisons between studies must be undertaken with caution, as should the results of the studies themselves given the difficulties that exist in estimating indirect costs-this work nevertheless gives an indication of the intervention's potential value for money.

What these studies do not do, however, is provide insights into how the ratio of outcomes to costs associated with the intervention might change over time. That is, although economic evaluation in this area has largely demonstrated that pediatric cochlear implantation provides better value for money than many other interventions in absolute terms (24) (subject to the caveats already mentioned in relation to these studies), it has not provided information on the relative dynamic efficiency of implantation programs. In this study, we explore the relationship between costs, outcomes and factors likely to determine these, with the aim of shedding light on this area.

MATERIALS AND METHODS

Information on costs and outcomes were taken from a single implant programme-the Nottingham Paediatric Cochlear Implant Programme. The Nottingham Programme is the UK's largest and longest established paediatric implant programme. It began operation in 1989 and, at the time of writing, had implanted 333 children. Detailed information on all activity undertaken by the Programme with respect to each child is recorded and entered on a computerized database. This database is updated throughout the course of the child's contact with the Programme and includes information on hours of rehabilitation spent with the child (contact with teachers of the deaf and speech and language therapists), the number of medical consultations the child receives, preimplantation assessment, as well as implantation and implant maintenance. Data on these activities and their cost were provided by the Programme. Cost here represents actual resource costs rather than reimbursements. The study, therefore, takes a health care perspective, looking only at the additional programme costs (direct health care costs) of providing a cochlear implant programme. This perspective was chosen to explore the efficiency gains of a cochlear implant programme through learning-by-doing and economies of scale but also as a result of a lack of data on long-term costs and outcomes.

In relation to outcomes, a variety of measures are used by the Programme to assess the impact of implantation on the child and in particular functioning. Again data on these are recorded in the Programme's database. Two widely reported measures of functioning are the Categories of Auditory Performance (CAP) and Speech Intelligibility Rating (SIR) scales (1;23). These are ordinal measures used to assess the child's acquisition or development of audition and verbal skills. CAP outcomes range from a score of 0, where a child has no awareness of environmental sound, to a score of 7, at which level a child can use the telephone with a known speaker (4). SIR outcomes range from a score of 1, where connected speech is unintelligible such that only prerecognizable words are used in spoken language with manual communication being the primary mode of communication to a score of 5 where connected speech is intelligible to all listeners (1;23). Each child is surveyed at routine intervals to monitor development over time. Although development can continue for many years after implantation, an assessment of the effect of implantation is often nevertheless possible over shorter periods. For example, in relation to auditory performance-measured using CAP-although progress continues over many years, twenty-four months is considered an appropriate time scale for changes in outcomes of this type to become apparent (4). Similarly in relation to SIR-sixty months is considered an appropriate time scale for changes in outcomes of this type to become apparent (1). These measures of outcome were chosen for this analysis both because they are widely used by practitioners in this field and because data on a large number of children over several years were available on them.

Cost-effectiveness can vary because of variations in costs and/or in effects. In turn, these variations may relate to differences between children in terms of their capacity to benefit or in what the Programme does in terms of when and how it intervenes. Variations in costs, for example, may result from variations in the combination of inputs as well as variations in the amount of inputs used. (Variations in factor prices, are not possible within the centralized UK health service and certainly not within an individual programme. Variations in costs associated with variations in factor prices are not therefore a potential source of variation.) To disentangle the potential sources of cost-effectiveness variations, a multivariate analysis of costs and effects was undertaken, where attributes of the child were among the factors controlled for.

The analysis was undertaken in stages. First total direct costs (i.e., those falling on the health service) associated with implantation were calculated for each child. The total direct costs for each individual child were calculated based on the amount of resource inputs used (labor time, hardware, capital costs, etc.) multiplied by unit costs and were inclusive of preimplantation assessment, implantation, contact time with rehabilitation staff, and subsequent maintenance of the device. Data on the resource inputs used for each child were taken from the database collated by the Programme as a child moves through the Programme, whereas the unit costs were supplied by the Programme Coordinator. Travel costs associated with rehabilitation staff attending outreach visits (i.e., visiting children at home or school rather than seeing them at the implant center) were excluded from the analysis. This strategy was necessary because of difficulties in apportioning such costs to individual children where the purpose of staff members journey was shared with other tasks or between children. Total direct costs, thus, were somewhat underestimated as a result. As these represent just 0.025% of total Programme costs the extent of the underestimation is not thought to be significant, however, nor to greatly effect the variation in costs observed between children. As explained above, the costs represented activity generated by the child and were matched to the point at which outcome measures were taken −24, 36, 48, and 60 months after implantation in the case of CAP and 60 months after implantation in the case of SIR.

As both CAP and SIR are ordinal measures, it was not appropriate to treat a change in, say, CAP from level 3 to 4 as equivalent to a change from 4 to 5. These may not be the

same and cannot, therefore, be legitimately treated as such. As outcomes were measured using an ordinal scale, controlling for differences in these among children necessitated the specification of a set of dummy variables. Children were grouped by the initial value recorded on their outcome score—their initial CAP and SIR score. A set of dummy variables to reflect changes from this same initial point over time was then possible. This method would produce measures of CAP or SIR gain that would also be ordinal and need to be treated as such but with which like would be compared with like in terms of outcome CAP. Following this procedure established relatively small subgroups for analysis.

In practice only, children with an initial outcome score of zero provided a sufficient sample size for multivariate analysis. In relation to CAP, for example, excluding children who had been implanted for under twenty-four months (and for whom reliable measures of CAP, therefore, would not be available), meant that the largest group with the same initial score and meeting all other study criteria contained just ninety-eight children. These were children with the lowest initial scores of CAP and SIR possible. Numbers in other groups were simply too small to permit meaningful multivariate analysis. Of 128 children implanted for at least sixty months, 9 had to be excluded because they were either not implanted in Nottingham or were not under Nottingham's care for the full five years. Of the remaining 119, a further 21 children were excluded because they did not have a CAP score of zero preimplant (twelve children had a preimplant CAP score of one, six children had a preimplant CAP score of two, and three had a preimplant CAP score of three) or a SIR score of one preimplant (thirteen children had preimplant SIR scores of two, five had SIR scores of three, two had scores of four, and one had a preimplant Sir score of five). The outcomes of the 119 children preimplant to sixty months for both CAP and SIR are presented in Table 1.

The specification of the outcome variables was as follows. For CAP, a variable named *CAP yes* was included in the regression, taking a value of 1 where a child had reached a CAP score of six or seven at the interval of interest (either twenty-four, thirty-six, forty-eight, or sixty months) and zero otherwise. A CAP score of six or seven is seen as a clinically desirable outcome to reach. For SIR at sixty months, a series of dummy variables labeled Dum SIR zero, Dum SIR one, Dum SIR two, and Dum SIR three were included. The value one was given to children who'd made no gains in SIR score, one, two, or three gains respectively and a value of zero applied to children achieving four gains in SIR score (e.g. from SIR score 1 to score 5).

No work has hitherto been done in relation to variations between types of child in the cost of implantation. In part, this is understandable given the novelty of the technology and the small numbers of children implanted annually in any programme. Work thus far has

Table 1. CAP and SIR Outcomes by Year on Program for Children Implanted 60 Months or Less[a]

		Postimplant				
CAP score/**SIR score**	Preimplant	12 months	24 months	36 months	48 months	60 months
0	98			1		
1/**1**	12/**98**	0/**46**	0/**19**	0/**6**	0/**4**	0/**3**
2/**2**	6/**13**	0/**55**	0/**55**	0/**42**	0/**20**	0/**23**
3/**3**	3/**5**	7/**14**	1/**38**	1/**55**	2/**58**	1/**51**
4/**4**	0/**2**	74/**0**	28/**3**	10/**10**	6/**15**	6/**24**
5/**5**	0/**1**	29/**4**	61/**3**	59/**6**	43/**8**	37/**18**
6		7	18	27	40	33
7		2	9	21	21	31

[a] CAP = Categories of Auditory Performance; SIR = Speech Intelligibility Rating.

concentrated on establishing the efficacy of the implantation and its cost-effectiveness, which given the financial pressures programs operate under is also understandable. Studies on outcomes have shown the importance of age at implantation as a determinant of outcomes in pediatric cochlear implantation (11;16;20). A continuous variable, therefore, was introduced to allow for a possible relationship between this variable and costs when outcomes were controlled for. Similarly, etiology of the child (whether the child was born deaf [value one] or acquired deafness [value zero]) was controlled for-as a dummy variable named Onset. The child's gender was also controlled for as a dummy variable named Gender, where the variable took a value of one if the child was female and zero if the child was male.

In relation to activities by the Programme, implantation at an early age as opposed to a later intervention, as noted, may effect cost-effectiveness. This effect was controlled for by inserting the independent variable named Age at implant (LN), where age of the child was in years to two decimal places and specified as the natural logarithm. The potential to use rehabilitation services as a way of influencing outcomes was also recognized, and hours of rehabilitation time, therefore, were included as a variable Rehab. Finally, the possibility of cost-effectiveness changing through time, as the Programme acquired expertise in the performance of its tasks was recognized. A continuous variable named Year of implant, which took account of the year in which implantation took place, was also included among the independent variables included in the regression. Data were imported and analyzed in SPSS version 10.

RESULTS

A sample of ninety-eight children, implanted for sixty months or more, were used in the analysis of CAP gain at twenty-four, thirty-six, forty-eight, and sixty months. All had a preimplant CAP score of zero. The same analysis was undertaken for SIR outcomes at sixty months, where all children had a preimplant SIR score of one. The characteristics of this group in terms of etiology, gender, age at onset of deafness, and so on are shown in Table 2.

The results of the multivariate regression analyses of total costs on CAP at twenty-four, thirty-six, forty-eight, and sixty months and of SIR at sixty months are presented in Table 3.

Table 2. Demographic Details of All Subjects Included in the Study[a]

Characteristic	CAP 5-year sample (n = 98)	SIR 5-year sample (n = 98)
Etiology		
Congenital	46 (47%)	53 (55%)
Acquired	52 (53%)	45 (46%)
Gender		
Male	51 (52%)	53 (54%)
Female	47 (48%)	45 (46%)
Age (in years) at onset of deafness (mean/median/range)	0.83/0.25/0–6.58	0.69/0.17/0–3.08
Age (in years) at implantation (mean/median/range)	4.96/4.17/1.75–15.50	4.46/4.00/1.75–15.50
Duration of deafness (in years) (mean/median/range)	4.06/3.75/0.67–15.50	3.77/3.58/0.67–15.50
Electrodes inserted (number)		
>20	89 children (91%)	90 children (92%)
11–19	7 children (7%)	6 children (6%)
<10	2 children (2%)	2 children (2%)

[a] CAP = Categories of Auditory Performance; SIR = Speech Intelligibility Rating.

https://doi.org/10.1017/S0266462303000370 Published online by Cambridge University Press

Table 3. Results From the Multivariate Regression Analyses[a]

Variables	Model one—24 months (CAP) Coefficient (confidence interval) & *p* Value	Model two—36 months (CAP) Coefficient (confidence interval) & *p* Value	Model three—48 months (CAP) Coefficient (confidence interval) & *p* Value	Model four—60 months (CAP) Coefficient (confidence interval) & *p* Value	Model five—60 months (SIR) Coefficient (confidence interval) & *p* Value
Constant	567292 (312349, 822235), 0.000	733188.61 (450317, 1016061) 0.000	874393 (575948, 1172838) 0.000	1070714 (747508, 1393921) 0.000	1048579 (719807, 1377352) 0.000
Year of implant	−270.19 (−398, −143) 0.000	−351.71 (−493, −210) 0.000	−421.48 (−571, −272) 0.000	−518.62 (−680, −357) 0.000	−507.79 (−673, −343) 0.000
Gender	−16.13 (−366, 334) 0.927	39.21 (−349, 427) 0.841	56.77 (−356, 470) 0.785	158.04 (−280, 596) 0.475	211.22 (−219, 641) 0.332
Onset	11.07 (−398, 420) 0.957	−8.02 (−458, 442) 0.972	13.68 (−466, 494) 0.955	20.02 (−490, 530) 0.938	−23.35 (−561, 484) 0.927
Age at implant (LN)	−16.88 (−498, 434) 0.941	−280.67 (−798, 237) 0.284	−272 (−827, 283) 0.334	−559.08 (−1142, 24) 0.060	−462.24 (−1096, 172) 0.151
Rehab at 24, 36, 48 or 60 months	17.35 (12, 23) 0.000	17.78 (13, 23) 0.000	16.29 (12, 21) 0.000	16.10 (11, 21) 0.000	16.29 (12, 21) 0.000
CAP yes at 24, 36, 48 or 60 months	−98.41 (−554, 357) 0.669	−224.31 (−647, 198) 0.295	−16.60 (−456, 423) 0.940	−137.36 (−611, 336) 0.566	
Dum SIR zero					373.62 (−593, 1340) 0.444
Dum SIR one					404.58 (−503, 1312) 0.378
Dum SIR two					360.78 (−389, 1110) 0.341
Dum SIR three					83.59 (−767, 934) 0.846
R square	0.620	0.680	0.692	0.713	0.757
F statistic/ significance	24.430/ 0.000	31.852/ 0.000	33.660/ 0.000	37.203/ 0.000	30.072/ 0.000

[a] CAP = Categories of Auditory Performance; SIR = Speech Intelligibility Rating; Dum = dummy variable.

All costs were calculated using UK£2000 and discounted at a rate of 6%, the rate currently used by the UK treasury. Coefficients are reported alongside the standard error and P value. R^2 and F-statistics for the regressions are also reported.

The results presented in Table 3 demonstrate several significant findings. Controlling for outcomes, it can be seen that only the year of implantation together with hours of rehabilitation time were significant determinants of cost and thus of cost-effectiveness. In relation to the independent variable Year of implant, it can be seen that the later a child was implanted the lower was the cost, that is, the more cost-effective was the service provided. That is, given all the other factors controlled for, a child implanted in 1996 was implanted

Table 4. Mean Cumulative Number of Hours of Rehabilitation by Year on Program and Year of Implantation

	Year implanted		
Year on programme	1989–1992 (n = 29)	1993–1994 (n = 36)	1995–1996 (n = 33)
Two	155.19	116.20	101.66
Three	189.67	143.69	120.97
Four	206.95	157.99	132.14
Five	216.66	165.33	136.30

more cost-effectively than a similar child implanted in 1990. As can be seen from the coefficient attached to this variable at twenty-four months relative to longer intervals post implant not only were later implants more cost-effective but the extent to which they are more cost-effective becomes more apparent the longer the duration over which costs are examined. At twenty-four months post implant, implantation a year later had the affect of reducing total cost by approximately £270; at sixty months post implantation, implantation a year later reduced total cost by around £500.

Hours of rehabilitation provided was also a significant determinant of cost ceteris paribus and, therefore, of cost-effectiveness. The relationship is positive such that the greater the number of hours of rehabilitation provided the greater the cost and the lower the cost-effectiveness. This finding is perhaps to be expected because rehabilitation is the area where greatest potential to vary inputs by the Programme exists—that is, where the greatest potential to increase what the Programme does having implanted the child exists. Table 4 shows how the mean number of rehabilitation hours have been varied over time by year of implantation. That it is significant when outcomes are controlled for, however, does require careful interpretation and is an issue returned to below. All the remaining regressors were insignificant determinants of cost.

DISCUSSION

The aim of this study was to look at the relative cost-effectiveness of a pediatric cochlear implantation programme over time using individual data. It can be seen that, controlling for potential confounding variables, year of implant has a significant negative relationship with total cost. This finding indicates that the cost-effectiveness of the Programme has improved through time. Although relative to the overall cost of an implant, these changes may appear modest year on year, over time and spread over the annual number of implants performed by the Programme they are not insignificant (especially set against a background of health care cost inflation).

The mechanism by which these improvements are achieved may be a learning curve (22) whereby professionals learn through experience how better to deliver their services. If this is the case—and it seems a reasonable inference to draw—it follows that programs at different stages of the learning curve will experience differing levels of cost-effectiveness. This has potentially important implications within cochlear implantation and beyond. It illustrates, for example, that cost-effectiveness should not be viewed as a static value even when the basic technology being assessed has itself remained static (thus knowledge of how to use that technology may advance). Similarly, it highlights the importance of work related to the dissemination of best practice by programs themselves as well as organizations such as the Commission for Health Improvement in the UK. Such work effecting the operation of many programs and many implants has the potential to substantially increase the efficiency of the health care system.

An additional mechanism which explains improvements to cost-effectiveness over time is that of economies of scale (6). For example, although the Programme now implants approximately forty children a year compared with ten in 1991, it still only uses one operating theater and two surgeons. Therefore, it is likely that these resources are being used more efficiently. This indicates the need for further research to look at the optimal size and number of implant programs that operate in the UK. It may be the case that the UK currently has too many implant programs (twenty-one currently operate) or that the size of some of the smaller programs renders them less efficient compared with larger programs.

As noted, the only other variable to be statistically significant among the independent variables was hours of rehabilitation provided. The positive relationship between this and cost suggests that the cost-effectiveness of the Programme is poorer the greater the number of hours of rehabilitation undertaken. Care, however, is warranted in this interpretation. As noted, in relation to outcomes, often time is required before the effects of the intervention become apparent. This may similarly be the case with rehabilitation, the outcomes witnessed today being the product of rehabilitation in past time periods rather than the most recent period. If this is the case, it may be naive not to expect a positive relationship between costs and rehabilitation time in the same period when outcomes are controlled for—rehabilitation representing in essence an investment and, therefore, cost incurred today the benefits of which will be seen in future periods. What the appropriate time period is for such investments to pay-off, that is, the extent to which the effect of rehabilitation on outcomes will be lagged (and that this variable, therefore, should be lagged) is not known. This is an area that further research might shed light upon. The possibility, however, cautions against the interpretation that "too much" rehabilitation is being undertaken by the Programme and cost-effectiveness would be enhanced were less done.

A natural extension to the cost function explored in this study would be to produce a production function, where output or outcomes are a function of inputs such as labor, capital, and so forth. Such an approach would enable the independent effects of a multidisciplinary treatment team to be separated out such that different combinations of resource inputs could be explored to ensure optimum outcome success. This approach may aid our understanding as to what role rehabilitation plays in the achievement of outcomes.

All other explanatory variables used were insignificant; thus it could be concluded that these variables do not influence the cost-effectiveness of the Programme. Again, however, some caution is warranted here before reaching firm conclusions. To receive a cochlear implant, the candidate must complete a preimplantation assessment and implicitly meet the criteria for implantation used in that assessment. That certain characteristics—for example, onset of deafness—are not related to cost-effectiveness by means of the regression may indicate that they are indeed unrelated to cost-effectiveness or that Programme staff select candidates for whom the likely success of the intervention for that particular candidate is not adversely effected by this characteristic. All we can say is that, in relation to children implanted, such characteristics appear not to significantly impact upon cost-effectiveness. It should also be noted that the costs included in this analysis are those relating to the direct Programme cost, that the costs used relate to relatively short time spans, and that the conclusions reached may differ had other outcome measures been used—for example, quality of life, reading age, and so on. Having said this, the results presented here suggest that the cost-effectiveness of this intervention does not appear to depend on gender or whether the deafness was acquired or not.

Published studies pertaining to the outcomes of pediatric cochlear implantation have demonstrated a significant negative relationship between age at implantation and outcomes (11;16;20). This is, however, the first study to explore the relationship between cost-effectiveness and age at implantation. The results presented in Table 3 suggest that, although implantation at a younger age improves outcomes, it does not improve cost-effectiveness

as measured in terms of CAP and SIR—although nor does it adversely effect this. In the case of SIR, for example, at the sixty-month interval, implantation at a younger age seems to adversely impact on cost-effectiveness (positively on costs), although this impact is not statistically significant. Implantation at a younger age may not result in improved cost-effectiveness if the gains in outcome achieved by implanting earlier are offset by greater programme costs, but it again needs to be stressed that costs examined here relate to a relatively short time period and only to direct costs. It should also be noted that this analysis only included those implanted before the middle of 1996. Because the shift to implanting the very young at Nottingham did not occur until after this date, this finding may also explain the nonsignificance of this variable.

It is important to recognize that this study did not aim to measure in absolute terms whether pediatric cochlear implantation is cost-effective or not, this has been demonstrated comprehensively elsewhere (24). Nor did it consider the wider societal implications of cochlear implantation. The wider implications are important and as the data becomes available a fuller picture of the long-term costs and outcomes should be ascertained. Given such new data, cost-effectiveness could be more favorable given earlier implantation. By the same token, if other costs, such as the indirect costs of education and future productivity changes, were taken into consideration and more favorable outcomes were associated with lower education costs and/or superior earnings, this could influence the result reported here. For example, if children with superior CAP and SIR outcomes (those implanted earlier) require less educational support than those with poorer outcomes, ceteris paribus, a broader definition of costs may see the cost-effectiveness ratio of this group appear more favorable than indicated here. Again, this is an area where further research (as more observations become available and the postimplantation interval increases) may advance understanding.

Policy Implications

This study, by using individual level data, has demonstrated that the relative cost-effectiveness of pediatric cochlear implantation at Nottingham has improved over time, having controlled for confounding variables. This finding is consistent with the learning curve theory (22), which suggests that over time, professionals become more proficient through acquired experience. This finding has implications for the quality of care a cochlear implant team can provide and suggests that the efficiency of cochlear implant programs in the UK are unlikely to be identical given different dates of establishment and different numbers implanted annually. It may suggest that there is a role for disseminating good practice between programs and for the establishment of quality standards if the efficiency of the health care system is to be improved. It was also argued that the improvement found in cost-effectiveness could be a result of economies of scale. The policy implication of this finding is that there is a need for further research to examine whether the UK, or any country, has an optimal number of programs of an appropriate size to achieve maximum efficiency.

Independent of this learning effect, cost-effectiveness may be influenced by the amount of rehabilitation children receive. That there is a possible lagged effect in terms of the pay off from such rehabilitation, however, suggests further work is warranted here. Other areas that future work could also usefully extend to address include the cost-effectiveness related to other outcomes, longer time periods, and where a fuller definition of costs than that used here has been used. With reference to the first of these, use of other outcomes, this is important to capture the other quality of life benefits of pediatric cochlear implantation because outcomes do extend beyond just hearing and speech (2;3;8;10;14). However, such data are not yet available over longer time periods, such that a more complete assessment of the cost-effectiveness of this intervention is not yet feasible. This study focused on the

relative, rather than absolute, cost-effectiveness as specific to one implant programme over the period 1989-1996. However, absolute cost-effectiveness can also change over time and, therefore, as a fuller range of costs becomes available for longer periods of time, it will be important to extend the analysis performed in this study to include the wider implications of pediatric cochlear implantation.

To conclude, the cost function approach used in this study demonstrated that cost-effectiveness can change over time for pediatric cochlear implantation. Given that the cost-effectiveness of other interventions is also likely to change over time as the programs become established and mature, it is important that decision makers recognize and take into account that cost-effectiveness is not a static measure in decisions they make.

REFERENCES

1. Allen MC, Nikolopoulos TP, O'Donoghue GM. Speech intelligibility in children after cochlear implantation. *Am J Otol*. 1998;19:742-746.
2. Archbold SM, Lutman ME, Gregory S, O'Neill C, Nikolopoulos TP. Parents and their deaf child: Their perceptions three years after cochlear implantation. *Int Deafness Education*. 2002;4:12-40.
3. Archbold S, Nikolopoulos TP, O'Donoghue GM, Lutman ME. Educational placement of children following a three year period. *Br J Audiol*. 1998;32:295-300.
4. Archbold S, Lutman M, Marshall D. Categories of auditory performance. *Ann Otol Rhinol Laryngol*. 1995;104:312-314.
5. Carter R, Hailey D. Economic evaluation of the cochlear implant. *Int J Technol Assess Health Care*. 1999;15:520-530.
6. Cheng AK, Rubin HR, Powe NR, et al. Cost-utility analysis of the cochlear implant in children. *JAMA*. 2000;284:850-856.
7. Effective Health Care Bulletin. Hospital volume and health care outcomes, costs and patient access. *Effective Health Care*. 1996;2:1-16.
8. Filipo R, Bosco E, Barchetta C, Mancini P. Cochlear implantation in deaf children and adolescents: Effects on family schooling and personal well-being. *Int J Pediatr Otorhinolaryngol*. 1999;49:S183-S187.
9. Inscoe J. Communication outcomes after paediatric cochlear implantation. *Int J Pediatr Otorhinolaryngol*. 1999;47:195-200.
10. Kelsay DMR, Tyler RS. Advantages and disadvantages expected and realized by pediatric cochlear implant recipients as reported by their parents. *Am J Otol*. 1996;17:866-873.
11. Lesinski A, Battmer RD, Bertram B, Lenarz T. Appropriate age for cochlear implantation in children: Experience since 1986 with 359 implanted children. *Adv Otorhinolaryngol*. 1997;53:214-217.
12. Medical Research Council, Institute of Hearing Research. MRC Institute of Hearing Research, Nottingham, UK: University of Nottingham; 2001.
13. National Institute on Deafness and other Communication Disorders. Bethesda, MD: National Institutes of Health; 2001.
14. Nevins ME, Chute PM. Success of children with cochlear implants in mainstream educational settings. *Ann Otol*. 1995;104:100-102.
15. Nikolopoulos TP, Archbold SM, O'Donoghue GM. The development of auditory perception in children following cochlear implantation. *Int J Pediatr Otorhinolaryngol*. 1999;49:S189-S191.
16. Nikolopoulos TP, O'Donoghue GM, Archbold S. Age at implantation: Its importance in pediatric cochlear implantation. *Laryngoscope*. 1999;109:595-599.
17. O'Donoghue GM. Cochlear implants in children: Principles, practice and predictions. *J R Soc Med*. 1996;89:345P-347P.
18. O'Donoghue GM, Nikolopoulos T, Archbold SM, Tait M. Congenitally deaf children following cochlear implantation. *Acta Otorhinolaryngol Belg*. 1998;52:111-114.
19. O'Neill C, Archbold S, O'Donoghue G, Gibbin KP, McCormick B. Addressing clinical governance in paediatric cochlear implantation. *Br J Clin Gov*. 2002;7:13-21.
20. O'Neill C, O'Donoghue GM, Archbold SM, Nikolopolous TP, Sach T. Variations in gains in auditory performance from paediatric cochlear implantation. *Otol Neurotol*. 2002;23:44-48.

21. O'Neill C, Archbold SM, O'Donoghue GM, McAlister DA, Nikolopoulos TP. Indirect costs, cost-utility variations and the funding of paediatric cochlear implantation. *Int J Pediatr Otorhinolaryngol*. 2001;58:53-57.
22. Ramsey CR, Grant AM, Wallace SA, et al. Assessment of the learning curve in health technologies: A systematic Review. *Int J Technol Assess Health Care*. 2000;16:1095-1108.
23. Robbins MA, Kirk KI, Osberger MJ, Ertmer D. Speech intelligibility of implanted children. *Ann Otol Rhinol Laryngol*. 1995;166:399-401.
24. Sach T. Current knowledge and future directions: The economics of cochlear implantation. In: O'Neill C, ed. *Cochlear implantation: Cost creating or cost saving?* Proceedings of a Conference on Health Technology Assessment, Oxford: Hughes Associates; 2002:35-70.
25. Van den Broek P, Cohen N, O'Donoghue G, et al. Cochlear implantation in children. *Int J Pediatr Otorhinolaryngol*. 1995;32:S217- S223.