

Cost-Effectiveness of Pediatric Cochlear Implantation in Rural China

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Objectives: To evaluate the cost utility of cochlear implantation (CI) for severe to profound sensorineural hearing loss (SNHL) among children from rural settings in P.R. China (China).

Research Design: A cost-utility analysis (CUA) was undertaken using data generated from a single-center substudy of the Cochlear™ Pediatric Implanted Recipient Observational Study (Cochlear P-IROS). The data were projected over a 20-year time horizon using a decision tree model.

Setting: The Chinese healthcare payer and patient perspectives were adopted.

Intervention: Unilateral CI of children with a severe-to-profound SNHL compared with their preimplantation state of no treatment or amplification with hearing aids (“no CI” status).

Main Outcome Measure/s: Incremental costs per quality adjusted life year (QALY) gained.

Results: The mean total discounted cost of unilateral CI was CNY 252,506 (37,876 USD), compared with CNY 29,005 (4,351 USD) for the no CI status from the healthcare payer plus patient perspective. A total discounted benefit of 8.9

QALYs was estimated for CI recipients compared with 6.7 QALYs for the no CI status. From the healthcare payer plus patient perspective, incremental cost-effectiveness ratio (ICER) for unilateral CI compared with no CI was CNY 100,561 (15,084 USD) per QALY. The healthcare payer perspective yielded an ICER of CNY 40,929 (6,139 USD) per QALY. Both ICERs fell within one to three times China’s gross domestic product per capita (GDP, 2011–2015), considered “cost-effective” by World Health Organization (WHO) standards.

Conclusions: Treatment with unilateral CI is a cost-effective hearing solution for children with severe to profound SNHL in rural China. Increased access to mainstream education and greater opportunities for employment, are potential downstream benefits of CI that may yield further societal and economic benefits. CI may be considered favorably for broader inclusion in medical insurance schemes across China. **Key Words:** Cochlear implantation—Cost-effectiveness analysis—Cost-utility analysis—Pediatric.

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Hearing loss affects about 5.3% (approximately 360 million) of the world’s population (1), of which 9% are children. Severe to profound hearing loss can be defined as hearing loss of 61 dBHL or more in the better hearing ear (2). The prevalence and severity of hearing loss vary with some factors including geographical location, socio-economic status, exposure to infections, consanguinity, and older age (3).

In many jurisdictions, cochlear implantation (CI) is the standard of care for permanent bilateral severe to profound sensorineural hearing loss (SNHL) (4). The intervention is safe with a major complication rate of 1.6% reported for children implanted bilaterally under the age of 18 years (5).

With increasing pressures on healthcare budgets, it is no longer sufficient to demonstrate that a device is safe and effective. It is now important to demonstrate that the intervention is also cost-effective in routine care. To improve access to CI across P. R. China (China), an economic evaluation was undertaken to assess the cost

utility of unilateral CI compared with no CI in children presenting with severe to profound SNHL.

MATERIALS AND METHODS

Patient Population

A cost-utility analysis (CUA) was conducted as a sub-study of the Cochlear Pediatric Implanted Recipient Observational Study (Cochlear P-IROS) in China. The Cochlear P-IROS is a prospective international patient-outcomes registry for children who are implanted in routine clinical practice with one or more hearing devices from a range of manufacturers (6,7). It aims to collect data on patient comorbidities, device use, auditory performance, quality of life, and health-related utilities, across different types of implantable hearing devices from a range of manufacturers (6,7). The CUA substudy enrolled new recipients aged less than or equal to 10 years, who underwent surgery for unilateral CI at The First Affiliated Hospital of the Anhui Medical University, Hefei, Anhui, P. R. China. All study participants were implanted with CI devices manufactured by Cochlear Limited. All children were from rural families and had bilateral severe to profound SNHL. Study participants were enrolled at the time of first fitting of the externally worn sound processor (baseline), and were followed up at 6-month and 12-month intervals. Recruitment commenced in April 2014 and ended in November 2014.

Ethics and Patient Consent

The study was conducted according to the Declaration of Helsinki (Fortaleza, Brazil, 2013) (8), and the International Conference on Harmonisation—Good Clinical Practice (ICH-GCP) Guidelines (9). The protocol was approved by the Hospital's Scientific Research Committee and the Clinical Research Ethics Committee. Patient informed consent was obtained from parent/ caregiver before enrolment.

Data Sources

Measures of Effectiveness: Utilities

At present, there is no established multi-attribute utility instrument (MAUI) appropriate for children who are deaf or hard of hearing and have undergone CI. The perceived health status of children was, therefore, observed using the modified EQ-5D version of the visual analogue scale (VAS) (10), further detailed in Supplementary Section 1.1, <http://links.lww.com/MAO/A508>. The VAS was administered to parents/caregivers of children at baseline (pre-CI use), and two post-CI follow-up intervals at 6 and 12 months. The VAS scores were transformed to health-related utilities using a conversion formula for time-trade off (TTO) scores, as reported previously (11).

Costs and Resource Utilization

Cost data related to the CI intervention and comparator were collected through the CUA substudy. The primary sources for costs and resource utilization were hospital billing data, and the Cochlear Implant Cost Questionnaire (CICQ) (12), which was administered to parents/caregivers of study participants at 6 and 12 months follow-up. Further details of itemised cost data collected from the primary sources are presented in Supplementary Section 1.2, <http://links.lww.com/MAO/A508>.

Economic Evaluation

Treatment

The treatment under investigation was unilateral CI in children age less than 10 years with bilateral severe to profound SNHL.

Comparator

An intra-subject comparator was used. The comparator under investigation was referred to as “no CI,” defined as using hearing aids (HAs) or no intervention for the treatment of bilateral severe-to-profound SNHL. The pre-CI status of recipients informed the costs and quality of life associated with “no CI” in the economic model. In the economic model, costs and quality of life of pre-CI HA-users and HA non-users were considered proportionately. This approach reflected routine clinical practices in the treatment of children eligible for unilateral CI as part of the standard continuum of the care in Anhui Province, China.

Economic Measure

Incremental cost-effectiveness ratios (ICER) were calculated for the intervention with CI compared with the no CI status. The ICER was defined as the incremental cost per quality of life year (QALY) gained. According to the World Health Organization (WHO), an ICER that falls within one to three times the national GDP per capita is considered to be “cost-effective” (13). The 2011 to 2015 GDP per capita in China was CNY 49,034 (USD 7,355) (14), which was similar to the 2015 GDP per capita of Anhui province (CNY 35,997, USD 5,400).

Perspective

Costs from the healthcare payer formed the base case and the “healthcare payer plus patient” perspective was also considered.

Time Horizon

A time horizon of 20 years was applied in the base case model, as this gives a long-term view without introducing an unreliable degree of uncertainty into the model. The impact of different time horizons was considered as part of structural sensitivity analysis.

Discounting

Direct medical costs and QALYs were discounted at 3% using the net present value formula (10).

Model Inputs

Costs of CI

Total direct medical costs related to CI were considered in the economic model. Indirect costs related to transportation, carer costs, and loss of productivity were not included in the model. The base year for costs was 2014. All direct medical costs were measured in Chinese Yuan Renminbi (CNY; 1 CNY = 0.15 USD, 2014).

Initial costs:

Initial costs of CI included the fixed cost of the initial CI system (implant and sound processor), preoperative assessments, including imaging and vestibular tests, and the hospital episode. For rural residents of Anhui Province, China, 70% of the combined costs of CI system and hospital episode were reimbursed through the New Rural Cooperative Medical

System (NRCMS) of China (15). Initial costs considered in the economic model included direct medical costs related to hospital stay, salaries of ward medical and ward nursing staff, allied health, imaging, pathology, pharmacy, critical care, operating theatre, anaesthesia and consumables, nursing and ward supplies, and other minor bed costs. All costs were obtained from hospital billing data. The costs of implant and sound processor were fixed for all patients. As HA trials were not mandatory for recipients of NRCMS funding, costs related to HA trials were not considered under treatment costs for CI.

Postoperative costs:

Annual visits to the audiologist, device maintenance (batteries, microphone protectors, etc.), and costs related to hearing habilitation through speech therapy were considered under postoperative costs. A range of hearing habilitation subsidisations from the China Disabled Person's Federation (CDPF) were reported by some families for the first year of CI use. For other families these costs were borne entirely out-of-pocket. The base-case economic analysis, thus, considered cost of hearing habilitation for the first year post-CI, and the impact of prolonged hearing habilitation was tested through sensitivity analysis. The base-case analysis also considered additional expenses related to out of warranty repair and maintenance of the CI system including spare parts and accessories, sound processor replacements every 6 years, and other out-of-pocket expense for families of CI recipients. Due to uncertainty in sound processor replacement costs, a range of prices were considered in sensitivity analyses reflecting the regular retail price of a range of sound processors manufactured by the Cochlear Limited (Sydney, Australia) and sold in China. Using the price of the least expensive sound processor as a starting point, the impact of increments of CNY 5,000 (USD 750) to the retail price, up to a maximum (most expensive) device price of CNY 75,000 (USD 11,250) was investigated.

Cost of No CI

For the no CI comparator status, costs were considered proportionately to the number of children using/not using HAs at baseline (pre-CI use). The HA retail price was not available through the Cochlear P-IROS registry, or the CICQ. Cost estimates were obtained from study investigators for this model input. Due to the uncertainty of the estimate, the impact of HA retail price was further tested through sensitivity analyses. All expenses represented out-of-pocket costs for families of HA users, and included the HA device costs, costs of fitting, annual hearing checks, and costs of HA replacement every 5 years.

Utilities

The VAS data collected at 12-month follow-up informed the average utility for CI use. The VAS data collected at baseline (pre-CI use) from parents/caregivers of children using/not using HAs informed the average utility of the "no CI" status.

CI and HA Non-Use

As there were no published evidence on rates of CI or HA non-use from China, published rates from international literature as well as clinical opinion were sought. There were limited published literature on rates of pediatric CI non-use (16–18), and rates of HA non-use among children (16). An older study from the United Kingdom reported a CI non-use rate of 7.1% (18); however, more recent studies from Turkey (17) and Australia (16) reported rates of 0.96% after 11 years and 0.86% after 3 years, respectively. The one study from Australia

reporting on pediatric HA non-use recorded a rate at 3.4% after 3 years (16). Based on these findings, and clinical opinion, our base case model conservatively assumed rates of CI and HA non-use in the Chinese context at 1.1 and 5.1%, respectively. Due to uncertainty in the estimate, potential rates of device non-use were considered from 0 to 10% in sensitivity analyses.

CI and HA Failure Rates

An annual rate of 1% for device failure was assumed in the base case model as per published evidence (19). Thus, a cumulative rate of revision surgery of 20% was assumed over a time horizon of 20 years. Due to limited published evidence, the rates of HA device failure were conservatively estimated at 0.5% per annum, based on clinical experience, which translated to a failure rate of 10% over 20 years. Given the uncertainties around failure rates, one-way sensitivity analyses were performed to understand the impact of higher failure rates on the cost-utility of CI. The prostheses costs related to device replacement were assumed to be covered by the manufacturer within the 10-year warranty period, and by individual families outside of this period. The costs of additional hospital episodes or clinical visits related to revision surgery were also assumed to be borne by individual families.

Model Type

A simple decision tree model informed the economic evaluation.

Sensitivity Analysis

Model sensitivity to uncertain input parameters was tested through one-way and two-way deterministic sensitivity analyses, and probabilistic sensitivity analysis. Uncertainties related to model structure were tested through: calculating ICERs from the perspective of healthcare payer plus patient, and healthcare payer only; considering time horizons from 20 to 76 years; using discount rates of 0 to 10%; and conducting scenario analyses related to medical insurance coverage, as detailed in Supplementary Section 1.3, <http://links.lww.com/MAO/A508>.

Statistical Analyses

Due to the small sample of 29 patients who participated in the CUA substudy, all cost estimates yielded from the study were bootstrapped over 1,000 iterations. Resulting bootstrap means and standard errors were subsequently used in the economic model. The significance of health-related utilities was tested through Mann–Whitney *U* tests, due to the non-normal distribution of utility parameters. For statistical analyses and decision tree modelling, Microsoft Excel (Microsoft Corp, Redmond, WA), and Ersatz software (EpiGear International, Sunrise Beach, Australia) were used.

RESULTS

Patient Characteristics

Characteristics of study participants are presented in Supplementary Section 2.1, <http://links.lww.com/MAO/A509>. The mean (standard deviation) and median age (interquartile range) at time of CI was 3.9 (2.8) years and 2.8 (1.9, 6.2) years, respectively. The majority (72.4%) of children were implanted at age more than or equal to 2 years. The most common type of hearing loss was congenital hearing loss (82.7%).

The pre-CI status of participants informed the costs and quality of life associated with "no CI" intervention.

Less than half of the cohort (44.8%, 13/29) used HAs before CI, with 31.0% (9/29) and 13.8% (4/29) participants using HAs in bilateral and unilateral configurations, respectively. The remaining participants (55%, 16/29) had not used any HAs before CI. Before surgery, 17.2% of children (5/29) had an auditory-oral mode of communication.

All patients received CI systems manufactured by Cochlear Limited (Sydney, Australia). The most common devices were the Cochlear™ Nucleus® Freedom™ cochlear implant with Contour Advance™ electrode, CI24RE (CA) implant (51.7%), and the Nucleus Freedom sound processor (41.4%).

More than half (58.6%) of the mothers of CI recipients had attained a secondary school education, while 13.8% did not received any formal education. Similar trends were also observed among the fathers of CI recipients. Consistent with the rural locations of these families, the majority of mothers (65.5%), were not employed, while the majority of fathers (86.2%) held jobs, most commonly as laborers or helpers (34.4%). The majority of the CI recipients (82.7%) came from low income families, defined as an income of less than CNY 75,000 (USD 11,250) per annum; while the remaining came from middle income families, classified as earning CNY 75,000 to 300,000 (USD 11,250–45,000) per annum. Results from the CICQ at 12 months follow-up suggested that 17.2% of CI recipients did not attend any hearing habilitation, and only 16.7% of the remaining recipients were fully reimbursed for their visits to the speech therapist through the CDPF.

Costs

Cost of CI and No CI

The expected cost of CI from the perspective of the healthcare payer only, and the healthcare payer plus patient, are presented Tables 1 and 2, respectively. The total cost of CI over a time horizon of 20 years averaged CNY 169,452 (USD 25,418), and CNY 447,864 (USD 67,180), respectively. The total cost of no CI status over a time horizon of 20 years was CNY 4,707 (USD 706), and CNY 53,865 (USD 8,080), from each perspective, respectively.

Utilities

The VAS scores, and corresponding utilities observed at pre-CI and post-CI intervals, are shown in Table 3. For children using/not using HA at baseline, mean VAS scores of 45.4 and 36.3 were estimated, corresponding to mean utilities of 0.61 (95% CI: 0.52–0.70) and 0.50 (95% CI: 0.43–0.58), respectively. An overall mean utility of 0.55 (95% CI: 0.49–0.61) was observed for the no CI status. At 12 months follow-up, a mean utility of 0.81 (95% CI: 0.77–0.85) was observed among children using CI, representing an incremental improvement of 0.26 (95% CI: 0.19–0.32) from the no CI status at pre-CI baseline.

Decision Tree Model

The decision tree from the healthcare payer plus patient perspective is shown in Supplementary Section 2.2, <http://links.lww.com/MAO/A509>.

ICERs

The discounted expected costs and QALYs and the corresponding ICERs for CI from each perspective are shown in Table 4. From the perspective of the healthcare payer plus patient, the ICER was CNY 100,561 (USD 15,084) per QALY. When considering the healthcare payer perspective only, the ICER was CNY 40,929 (USD 6,139) per QALY. Both ICERs fell either below or within the thresholds of CNY 49,034 (USD 7,355) and CNY 147,102 (USD 22,065), one to three times China's GDP per capita (2011–2015) (16,17).

Sensitivity Analysis

Parameter Sensitivity Analysis

One-Way Sensitivity Analysis

Results from one-way sensitivity analyses for each perspective are presented in Supplementary Section 2.3, <http://links.lww.com/MAO/A509>.

From the perspective of the healthcare payer plus patient, parameters including the regular retail price of HA, cost of replacement sound processors, and duration of participation in hearing habilitation had an impact on the ICERs. Increasing HA price improved the cost-effectiveness of CI (i.e., reduced the ICER); while increasing the costs of CI replacement sound processors resulted in unfavorable ICERs. Increasing the number of years of hearing habilitation from 1 to 2, and 5 years increased the ICER from CNY 100,561 (USD 15,084) per QALY (base case), to CNY 112,341 (USD 16,851) per QALY, and CNY 152,988 (USD 22,948) per QALY, respectively. Increasing cost of maintenance of CI and HA including costs of spare parts and accessories had a moderate effect on the ICER. Parameters including rates of device failures, non-use, and frequency of visits for hearing checks, had minimal impact on the ICER.

From the perspective of the healthcare payer only, all cost parameters that represented patient out-of-pocket costs had no impact on the base case ICER of CNY 40,929 (USD 6,139) per QALY. However, the frequency of years attending hearing habilitation, and the frequency of visits for hearing checks beyond first year had substantial impact on the ICER.

Two-Way Sensitivity Analysis

Results from two-way sensitivity analyses for each perspective are presented, and discussed in Supplementary Section 2.4, <http://links.lww.com/MAO/A509>.

Probabilistic Sensitivity Analysis

Monte Carlo simulation results from the healthcare payer plus patient perspective are presented in Figure 1A and B. Approximately, 90% of ICERs fell within the

TABLE 1. Costs (CNY) associated with treatment with CI over a 20-year time horizon

	Average Cost (CNY)	Units	HC Payer Perspective	HC payer + Patient Perspective	Source
Initial costs					
Hospital episode—reimbursed cost ^a	14,090	1	14,090	14,090	Hospital billing data (n = 29)
Unilateral CI + SP system					
Reimbursed cost ^a	119,000	1	119,000	119,000	Hospital billing data (n = 29)
Patient out-of-pocket cost ^a	39,056	1	—	39,056	Hospital billing data (n = 29)
Additional clinical visits for hearing checks ^b	250	4	1000	1000	Hospital billing data/ clinical experts
Sub-total			134,090	173,146	
Postoperative costs ^c					
Speech therapy—semi reimbursed ^a	12,000	1	12,000	12,000	CICQ (n = 15)
Speech therapy—semi patient out-of-pocket cost ^a	6,771	1	—	6,771	CICQ (n = 15)
Speech therapy—fully reimbursed ^a	13,861	1	13,861	13,861	CICQ (n = 5)
Speech therapy—fully patient out-of-pocket cost ^a	21,755	1	—	21,755	CICQ (n = 4)
No therapy ^a	—	—	—	—	CICQ (n = 5)
Sub-total			25,861	54,388	
CI maintenance					
Spare parts, batteries, and maintenance—patient out-of-pocket cost per year (out of warranty) ^d	5,083	10	—	50,830	In-house company database
Bi-annual hearing checks ^e	250	38	9,500	9,500	Hospital billing data/ clinical experts
Sub-total			9,500	60,330	
Total cost of CI—20 year horizon excl. SP replacements			169,452	287,864	
SP replacements					
SP end-user cost (assuming replacement every 6 yr)	48,000	3.3	—	160,000	Clinical experts/in-house company database
Total cost of CI—20 years horizon incl. SP replacements			169,452	447,864	

^aBootstrapped costs.

^bAssumes four visits for hearing checks in the year of implantation.

^cPostoperative costs considers hearing habilitation-related costs for the first year of CI use.

^dWarranty period = 3 years and accessories include rechargeable batteries, controller, microphone protector, drying briks/capsule, etc.

^eAssumes two visits per year for hearing checks (e.g., mapping) after the first year.

CNY 1 = USD 0.15 (2014).

CI indicates cochlear implant; CICQ, cochlear implant cost questionnaire; CNY, Chinese Yuan; excl., excluding; HC, healthcare; incl., including; SP, sound processor; yrs, years.

limits of one to three times China's GDP per capita (2011–2015) (12,13) (Fig. 1A). At a threshold of one time GDP per capita (CNY 49,034, USD 7,355) CI was not cost-effective (Fig. 1B). However, at thresholds of two times GDP per capita (CNY 98,068, USD 14,710), and three times GDP per capita (CNY 147,102, USD 22,065), the probability of cost-effectiveness improved to 50 and 100%, respectively (Fig. 1B).

The results from the perspective of the healthcare payer only, are presented in Figure 2A and B. Results from Monte Carlo simulations indicated that 76% of the ICERs fell below the threshold of one time GDP per

capita, and 24% of ICERs fell between one and two times GDP per capita, indicating that CI is highly cost-effective from the perspective of the healthcare payer (Fig. 2B). At a threshold of one time GDP per capita, the probability of cost-effectiveness of CI was 76%. The probability of cost-effectiveness improved to 100% at thresholds of two times GDP per capita (Fig. 2B).

Structural Sensitivity Analysis

Increasing the time horizon substantially improved the cost-effectiveness of CI, as per results presented in Supplementary Section 2.5, <http://links.lww.com/>

TABLE 2. Costs (CNY) associated with “no CI” (HA or no treatment) over a 20-year time horizon

	Average Cost (CNY)	Units	Proportion/ Weight	HC Payer Perspective	HC Payer + Patient Perspective	Source
Device costs						
Bilateral HA user out-of-pocket cost	10,000	2	0.31	—	6,207	Clinical experts (cost)/P-IROS registry (weight)
Unilateral HA user out-of-pocket cost	10,000	1	0.14	—	1,379	Clinical experts (cost)/P-IROS registry (weight)
Not using HA	—		0.55	—	—	P-IROS registry (weight)
Additional clinical visits for hearing tests ^a	250	4	0.45	448	448	Hospital billing data/clinical experts
Sub-total				448	8,034	
HA maintenance						
Spare parts and maintenance—bilateral HA user out-of-pocket cost per year (out of warranty) ^b	1,233	24	0.31	—	9,186	Clinical experts
Spare parts and maintenance—unilateral HA user out-of-pocket cost per year (out of warranty) ^b	1,233	12	0.14	—	2,041	Clinical experts
Bi-annual hearing checks ^c	250	38	0.45	4,259	4,259	Hospital billing data/clinical experts
Sub-total				4,259	15,486	
Total cost of HA—20 years horizon				4,707	23,521	
HA Replacements						
	Unit Cost	Units				
Bilateral HA-user out-of-pocket cost (assuming replacement every 5 yr)	10,000	8	0.31	—	24,828	Clinical experts/P-IROS registry
Unilateral HA-user out-of-pocket cost (assuming replacement every 5 yr)	10,000	4	0.14	—	5,517	Clinical experts/P-IROS registry
Sub-total				—	30,345	
Total cost of CI—20 years horizon incl. HA replacements				4,707	53,865	

^aAssumes four visits for hearing tests in the year of HA fitting.

^bWarranty period = 2 years.

^cAssumes two visits per year for hearing tests after the first year.

1 CNY = 0.15 USD (2014).

CNY indicates Chinese Yuan; HA, hearing aids; HC, healthcare; incl., including; P-IROS, pediatric implanted recipient observational study.

MAO/A509. When a time horizon of 76 years (the current average life expectancy in China) (20) was considered, ICERs of CNY 58,556 (USD 8,783) per QALY, and CNY 11,784 (USD 1,768) per QALY were yielded from the healthcare payer, and the healthcare payer plus patient perspectives, respectively. Doubling of discount rate to 6% resulted in ICERs of CNY 52,836 (USD 7,925) per QALY, and CNY 139,986 (USD 20,998) per QALY, from each of the perspectives, respectively. If 100% of costs of hearing habitation were reimbursed through medical insurance, 1 to 8 years of hearing habilitation resulted in ICERs of CNY 48,035 (USD 7,205) per QALY to CNY 142,879 (USD 21,432) per QALY, from the perspective of healthcare payer. While these ICERs were higher than a threshold of one time GDP per capita (CNY 49,034, USD 7,355), they were below the threshold three times GDP per capita (CNY 147,102, USD 22,065).

DISCUSSION

This is the first economic evaluation to assess the cost-effectiveness of unilateral CI in children with severe to profound SNHL in China. CI has been well documented as

a safe, clinically effective, and cost-effective intervention (5,21,22), establishing it as the gold standard treatment for children with significant sensorineural hearing disability, who cannot derive sufficient benefit from HAs. Similar health outcomes can be expected in China.

In this study, all children came from low-income rural families in the province of Anhui, China, and were supported by the NRCMS, one of the world's largest basic medical insurance schemes, mandated by China's Ministry of Health, and implemented by local and provincial governments (15). All families participating in our cost-utility substudy were reimbursed 70% of the CI system costs (CNY 119,000, USD 17,850), through the NRCMS. The remaining 30% of CI system costs represented out-of-pocket expenses for families of CI recipients. Policies such as the NRCMS, improve patient access, with approximately 95% of the population covered by an urban or rural medical scheme (23). Coverage for CI procedures varies among these schemes and across provincial and municipal jurisdictions.

The Economic Model

The costs in the model were evaluated from the healthcare payer and the “healthcare payer plus patient”

TABLE 3. Mean VAS scores and utilities of patients at baseline, 6 months, and 12 months intervals

	N	Mean VAS Score (95% CI)	Difference in Mean VAS Score from Baseline (95%CI)	Mean Utility Score (95%CI) ^a	Difference in Utility Score from Baseline (95% CI)
Baseline (presurgery)	29	40.5 (35.3–45.7)	—	0.55 (0.49–0.61)	—
HA users ^b	13	45.8 (37.6–53.9)	—	0.61 (0.52–0.70)	—
HA non-users	16	36.3 (30.1–42.4)	—	0.50 (0.43–0.58)	—
6 months	29	60.6 (56.8–64.4)	20.1 (15.9–24.3)	0.77 (0.73–0.80)	0.21 (0.17–0.26)
12 months	29	65.7 (61.2–70.2)	25.2 (18.8–31.6)	0.81 (0.77–0.85)	0.26 (0.19–0.32)

^aUtility scores were obtained through conversion of VAS scores to TTO scores using the formula, $U_{VAS} = 1 - (1 - V/100)^{1.6}$ published previously (11).

^bIncludes nine bilateral HA users and four unilateral HA users.

95%CI indicates 95% confidence interval; HA, hearing aid; VAS, visual analogue scale.

perspectives to reflect the financial burden of out-of-pocket costs borne by families covered by the NRCMS. The healthcare payer perspective considered various items of standard healthcare subsidised by medical insurance, and disability provisions, of the NRCMS, and the CDPF, respectively; and financed collectively by the China central, provincial, and local governments.

A conservative approach was undertaken to estimate uncertain parameters. A time-horizon of 20 years was considered in the base case analysis, as this gives a long-term view without introducing an unreliable degree of uncertainty into the model, particularly in the era of advancing technological development. The costs for the “no CI” group were assumed entirely out-of-pocket, and were weighed according to the proportions of bilateral HA users, unilateral HA users, and HA non-users, observed at the baseline (pre-CI use) of the CUA sub-study. The model also assumed 100% of CI revision surgeries were CI reimplantations, whereas recent evidence suggest this rate to be 85.5% (19). CI reimplantation surgeries are often more costly than other types of CI revision surgeries (19).

Summary of Findings

The ICERs generated by the economic model of CNY 40,929 (USD 6,139) per QALY and CNY 100,561 (USD 15,084) per QALY from each perspective, fell within one to three times China’s GDP per capita (2011–2015)

(16,17), suggesting treatment with unilateral CI compared with no CI is cost-effective in the Chinese province of Anhui. The base case ICER estimates may be conservative, given CI is known to enhance the opportunity for children to participate in mainstream education instead of Schools for the Deaf. Education in mainstream schools leads to greater downstream benefits such as higher employment opportunities and increased societal productivity. These downstream benefits have been shown to lead to societal cost-savings in previous economic evaluations (22,24–26).

Our sensitivity analyses indicated that the results were robust against the majority of model parameters. Sensitive parameters included the regular retail price of HA, the cost of CI sound processor replacements, and the frequency of replacements of CI sound processors and HAs. As the price of initial CI system was fixed for all patients in this setting, sensitivity analyses on initial CI device cost were not necessary. Structural sensitivity analyses revealed that our results were similarly robust against most parameters, and sensitive to assumptions around coverage of hearing habilitation, discounts rates, and time horizon. It is anticipated that the benefits of CI in children will last a lifetime. If a lifetime horizon of 76 years rather than 20 years was considered, the ICERs improved to CNY 11,784 (USD 1,768) per QALY, and CNY 58,556 (USD 8,783) per QALY, from both perspectives, respectively. These reductions are

TABLE 4. The incremental costs per QALY gained for CI over a 20-year time horizon

Healthcare Payer Plus Patient Perspective							
	Expected Cost (CNY)	Discounted Cost (CNY)	Expected Outcome (QALY)	Discounted Expected	Incremental Cost (CNY) (disc)	Incremental Effect (disc)	ICER (CNY)
No CI	52,386	29,005	12.1	6.7	—	—	—
CI	456,054	252,506	16.1	8.9	223,502	2.2	100,561 ^a
Healthcare payer perspective only							
No CI	5,155	2,854	12.1	6.71	—	—	—
CI	169,451	93,821	16.1	8.93	90,967	2.2	40,929 ^b

^aEquivalent to 15,084 USD (1 CNY = 0.15 USD, 2014).

^bEquivalent to 6,139 USD (1 CNY = 0.15 USD, 2014).

CI indicates cochlear implantation; HA, hearing aid; ICER, incremental cost-effectiveness ratio; QALY, quality-adjusted life years.

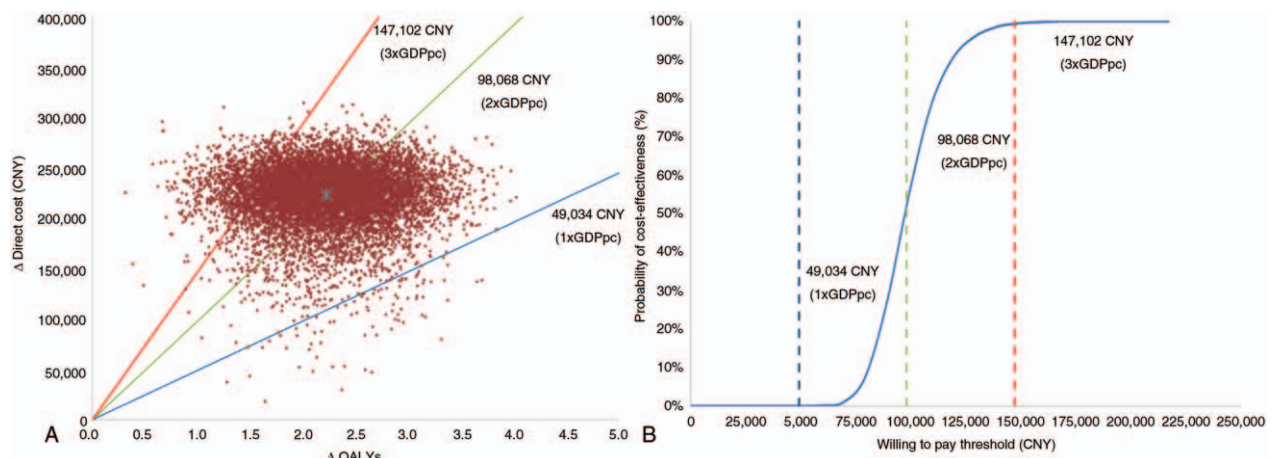


FIG. 1. A, Scatter plot presenting results from the Monte Carlo simulations (10,000 iterations), from the healthcare payer plus patient perspective. Incremental QALYs are plotted against direct costs (CNY) observed at 20 years. B, Cost-effectiveness acceptability curve presenting results from the Monte Carlo simulations (10,000 iterations). The probabilities of cost-effectiveness (%) corresponding to various thresholds are plotted, as observed at 20 years. GDPpc indicates gross domestic product per capita; QALY, quality-adjusted life years. Note: * symbol in the center represents the base case result.

substantial, suggesting unilateral CI compared with no CI is cost-effective, over a child's lifetime.

Cost-Effectiveness of Unilateral CI from Current Literature

The cost-effectiveness of unilateral CI compared with no intervention or HA is well-established in the international literature. In a National Institute of Health and Care Excellence (NICE) evaluation in the UK, CI was found to be cost-effective when compared with HAs and/or other non-implantable treatments for hearing loss in children (ICER: USD, 2014: 27,289 per QALY) (27). In the US, unilateral CI was deemed more cost-effective from a societal economic perspective among children implanted at age less than 18 months (15,594 per QALY) compared with age 18 to 36 months (USD 18,561 per QALY), and age more than 36 months (USD 19,938 per

QALY) (24). In another evaluation performed from the UK healthcare perspective, pediatric unilateral CI was found cost-effective (USD 26,034 per QALY) compared with non-surgical intervention, utilizing various methods for assessments of health-related utility, including the time-trade off (TTO) method, and the VAS (11). A similar VAS approach was also reported in Barton et al. (28), and was adopted in the current evaluation. By contrast, other economic evaluations, which additionally considered costs and benefits from mainstream education for CI recipients, showed societal cost savings from CI compared with no treatment or HAs (22,24–26).

The current evaluation revealed that unilateral CI leads to health-related utility gains over time (at 6 and 12 mo post-CI), resulting in additional QALYs for children using CI compared with no CI. An earlier study undertaken by Barton et al. (28) also reported consistent utility

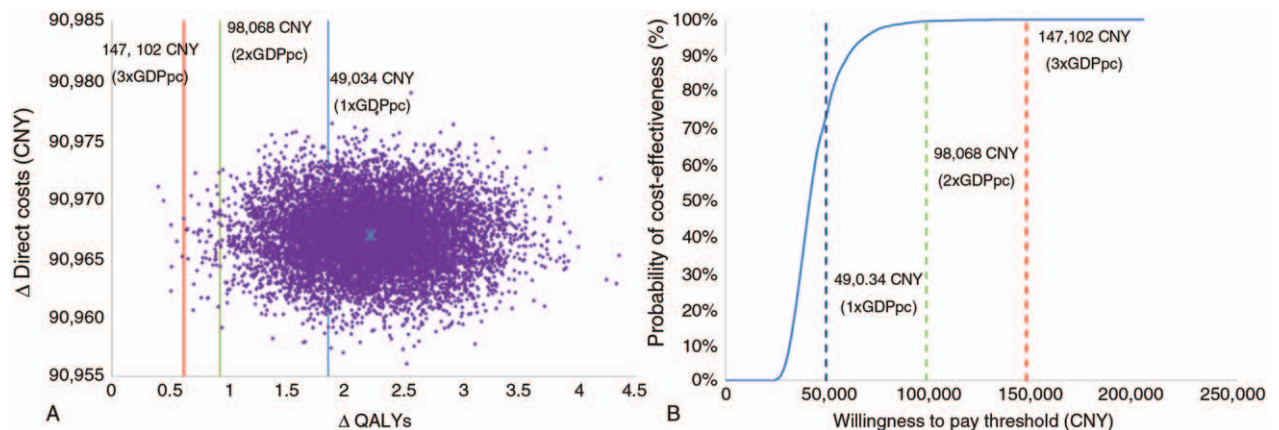


FIG. 2. A, Scatter plot presenting results from the Monte Carlo simulations (10,000 iterations), from the healthcare payer perspective only. Incremental QALYs are plotted against direct costs (CNY) observed at 20 years. B, Cost-effectiveness acceptability curve presenting results from the Monte Carlo simulations (10,000 iterations). The probabilities of cost-effectiveness (%) corresponding to various thresholds are plotted, as observed at 20 years. GDPpc indicates gross domestic product per capita; QALY, quality-adjusted life years. Note: * symbol in the center represents the base-case result.

gains over time for pediatrics using CI. These observations are meaningful as it shows consistent utility gains were observed by patients treated with CI, cross-temporally, and across geographies. Thus, suggesting that utility gains resulting from CI are consistently universal and transferable.

Similar health-related utility gains may also be observed among adult CI recipients leading to similar cost-effectiveness results. Evaluations conducted from the UK and Canadian healthcare perspectives showed that unilateral CI was cost-effective in adults when compared with HAs or no intervention (USD 33,144 per QALY; USD 9,624 per QALY; and USD 36,398 per QALY, respectively) (27,29,30). An earlier study (31) showed that unilateral CI in older adults aged more than 50 years is cost-effective from the US healthcare perspective (USD 12,954 per QALY). Lee et al. (32) demonstrated that unilateral CI in adults is cost-effective in the Korean healthcare context (USD 20,825 per QALY). These studies used the Health Utility Index (HUI), a MAUI, for measuring health-related QALYs. To-date, there has been no economic evaluation of CI performed for adults with severe to profound SNHL in China.

Impact of Early Implantation and Hearing Habilitation

The cost utility of unilateral CI may improve with earlier age at implantation, made possible through early identification of potential candidates through the continued roll out of new born hearing screening programs, and timely access to affordable care, including CI and hearing habilitation. Earlier implantation minimizes language delays, allowing age-equivalent language development (33) and possibly shorter durations of hearing habilitation (34). This translates into downstream benefits such as higher educational placement, enhanced employment opportunities, and productivity on the job (33).

The mean age at implantation is relatively high across China compared with that of countries with universal new born hearing screening, and a substantial proportion of rural recipients of CI may not attend hearing habilitation. In the current study sample, the mean and median age of implantation was age 3.9 years and age 2.8 years, respectively. Participation in speech therapy was limited to 83% of children, where only 17% received reimbursement in full by the CDPF in their first postoperative year. Factors mitigating higher participation rates in hearing habilitation include access to rehabilitation clinics, which are primarily located in urban areas, and limited subsidisation of hearing habilitation services for CI recipients under the age of 3 years. Due to inadequate evidence on the rates of prolonged participation in hearing habilitation of children in China, the present economic evaluation did not assume participation in hearing habilitation beyond the first year of CI use. For children implanted later, functional hearing performance and speech intelligibility outcomes could be further enhanced through improving access to extended hearing habilitation (speech therapy) (34). Our sensitivity analyses showed

that if hearing habilitation services were fully reimbursed for up to 8 years, CI is still cost-effective, not taking into account the long-term quality of life benefits associated with speech training.

Strengths and Limitations

While our evaluation was strengthened by use of prospective data, and pragmatic sensitivity analyses, it was limited by the use of secondary sources of data for regular retail price of HAs, number of years spent in hearing habilitation, rates of device non-use, and HA device failure rates. Furthermore, due to insufficient evidence in the Chinese context, this economic evaluation did not consider the potential costs and benefits (e.g., savings) from educational outcomes of children using CI, and changes to income level and socioeconomic status in the long-term. Further research is warranted to quantify these downstream benefits of CI in the long-term in the Chinese context.

CONCLUSION

This is the first economic evaluation of pediatric unilateral CI in China. Unilateral CI is a cost-effective hearing solution for children with bilateral severe to profound SNHL. Potential downstream benefits of CI include participation in mainstream education, and improved integration in the Chinese society through greater education and employment opportunities. CI may be considered favorably for broader inclusion in medical insurance schemes across China.

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