ORIGINAL ARTICLE

Experience of adult cochlear implantation at a tertiary hospital

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Abstract

Background: The prevalence of adult cochlear implant (CI) surgery is increasing. However, the relevant adult CI data in Taiwan are insufficient due to the relatively small number of adult implant patients. The two main factors hindering adult implantation are the high cost of the surgery itself and inadequate knowledge regarding the effectiveness of CI for hearing and suppression of tinnitus. Here, we present data regarding adult CI outcomes from a single tertiary hospital.

Methods: A total of 116 consecutive adult CI recipients (≥18 years old) who completed at least 12 months of speech perception tests (words and sentences) between January 1999 and December 2020 were enrolled in this retrospective population-based cohort study. Thirty patients completed speech perception (words and sentences) testing as well as three questionnaires relating to quality of life, and 71 completed full tinnitus suppression studies. Subjects' pre- and post-CI questionnaires were evaluated to assess overall CI outcome.

Results: For auditory evaluation, the scores of easy sentences (ES), difficult sentences (DS), and phonetically balanced (PB) word recognition tests reached a plateau at 3 months post-CI (p = 0.005, 0.001, and 0.004, respectively) in most subjects. The post-CI scores of bodily pain, mental health, and social role functioning were significantly higher than corresponding pre-CI scores on the SF-36 Health Survey–Taiwan version (p = 0.036, 0.019, and 0.002, respectively). Furthermore, the post-CI scores of basic sound perception, speech production, and advanced sound perception were significantly higher than the corresponding pre-CI scores on the Nijmegen Cochlear Implant Questionnaire (p < 0.001, 0.013, and <0.001, respectively). Self-esteem was significantly correlated with the Categories of Auditory Performance scale and Speech Intelligibility Rating scale at 3, 6, and 9 months post-CI. CI improved tinnitus in approximately 65.1% of 71 adults. Based on the Tinnitus Handicap Inventory, 66.7% of patients were in grade 3–5 before surgery. However, after CI, only 34.4% of patients remained in THI grade 3–5.

Conclusion: This study confirmed that CI can improve speech perception (words and sentences), physical health, mental health, social interaction, and self-esteem in adult patients with profound hearing loss. CI also significantly alleviated tinnitus. The outcomes of ES, DS, and PB tests at 3 months post-CI were non-inferior to other longer post-CI periods and could be utilized as references for recovery and evaluation of prognosis.

Keywords: Adult; Cochlear implant; Quality of life; Speech perception; Tinnitus

1. INTRODUCTION

Globally, about 47% of cochlear implant (CI) recipients are adults, indicating that many adults with severe or profound deafness require CIs. In Australia, where multi-channel CI was first introduced, the number of adult CI recipients is four times that of pediatric recipients, and adults also account for considerable proportions of recipients in the USA and Japan.

In Taiwan, the overall prevalence of hearing impairment is around 17.1%.[1] However, the ratio of adult to pediatric CI recipients is 23:77. The relatively low percentage of adults undergoing CI is due to the high cost of CI, lack of financial reimbursement from government as well as private business sponsorship, and inadequate knowledge regarding the effectiveness of CI. Insufficient data are available regarding the effects of CI on postoperative speech recognition and quality of life (QOL) in adults. Consequently, most studies of CI in Taiwan have focused on prelingually deafened or early implanted Mandarin-speaking children.[2,3] A meta-analysis by Gaylor et al. and a review article by Carlson *et al.* concluded that unilateral CI provides significant improvements in subjects' hearing outcome and QOL.[4,5] However, most of the articles included in these studies were from Western countries, and only a few articles about the effects of CI in adult Chinese Mandarin speakers were cited, and these articles regarding Chinese Mandarin speakers did not focus on adults.

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Conflicts of interest: The authors declare that they have no conflicts of interest related to the subject matter or materials discussed in this article.

Journal of Chinese Medical Association. (2022) 85: 469-477.

Received September 25, 2021; accepted December 6, 2021.

doi: 10.1097/JCMA.0000000000000690.

Tinnitus is another problem for adult patients with profound hearing loss. CI has been reported to suppress tinnitus.[6] However, there is also a paucity of data regarding the impact of CI on tinnitus in Taiwan.

This study was performed to investigate the clinical characteristics and outcomes of adult CI recipients in Taiwan to provide details regarding the use of CI as an intervention to treat adult hearing loss and tinnitus.

2. METHODS

We retrospectively reviewed the medical records of 116 adult CI recipients (≥18 years old) admitted to Chang Gung Memorial Hospital, Linkou, Taiwan, between January 1999 and December 2020. The demographic characteristics of the patients are shown in Table 1. The study population consisted of 116 deaf adults, 64 men and 52 women, who underwent CI in the right ear in 53 cases, left ear in 55 cases, and bilateral ears in eight cases. The mean age with standard deviation at recruitment was 51.1 ± 15.6 (range: 22.2-87.0) years, and mean age at CI surgery was 44.1 ± 16.1 (range: 18.9-80.3) years. Mean age at detection of deafness was 27.5 ± 21.3 (range: 0.0-72.0) years, mean duration of deafness was 4.3 ± 5.6 (range: 0.1-30.0) years, and mean duration of CI usage was 7.0 ± 5.0 (range: 1.0-19.2) years.

Table 1

Demographic and clinical data of adult CI recipients

Characteristic	Number	Mean ± SD	Range
Total recipients	116		
Male	64		
Female	52		
Right	53		
Left	55		
Bilateral	8		
Age at recruitment (y)		51.1 ± 15.6	22.2-87.0
Age at implantation (y)		44.1 ± 16.1	18.9-80.3
Age at detection of deafness (y)		27.5 ± 21.3	0.0-72.0
Duration of deafness (y)		4.3 ± 5.6	0.1-30.0
Duration of implant use (y)		7.0 ± 5.0	1.0-19.2
Etiologies of deafness	116		
Brain lesion	6		
Chronic otitis media	2		
Congenital cause	11		
IAC stenosis and CND	9		
Meningitis (labyrinthitis)	5		
Nasopharyngeal carcinoma	2		
Large vestibular aqueduct syndrome	8		
Otosclerosis	2		
Progressive cause	67		
Sudden deafness	4		
Complete hearing and QOL evaluation	30		
Male	15		
Female	15		
Right	10		
Left	20		
Age at recruitment (y)		46.0 ± 13.2	23.5-80.8
Age at implantation (y)		41.5 ± 13.7	21.7-74.1
Age at detection of deafness (y)		29.8 ± 18.8	3.2-55.0
Duration of implant use (y)		4.5 ± 2.8	0.5-10.1
Tinnitus suppression studies	71		
Male	39		
Female	32		
Right	34		
Left	37		
Age at recruitment (y)		52.7 ± 16.1	23.4-87.0
Age at implantation (y)		45.4 ± 16.4	18.9-80.3
Age at detection of deafness (y)		29.8 ± 18.9	0.0-55.0
Duration of implant use (y)		4.5 ± 2.8	0.5-10.1

CI = cochlear implant; CND = cochlear nerve deficiency; IAC = internal auditory canal; QOL = quality of life; SD = standard deviation.

The etiologies of deafness in the total population of 116 adults were brain lesions in six cases, chronic otitis media in two cases, congenital causes in 11 cases, mild internal auditory canal stenosis and cochlear nerve hypoplasia in nine cases, meningitis (labyrinthitis) in five cases, nasopharyngeal carcinoma in two cases, large vestibular aqueduct syndrome in eight cases, otosclerosis in two cases, progressive causes in 67 cases, and sudden deafness in four cases.

Among the 116 adult patients who completed speech perception tests (words and sentences), 30 completed comprehensive hearing function tests and QOL evaluations consisting of 15 men and 15 women (right ear in 10 cases and left ear in 20 cases). The mean age with standard deviation of these 30 patients at recruitment was 46.0 ± 13.2 (range: 23.5-80.8) years, and mean age at CI surgery was 41.5 ± 13.7 (range: 21.7-74.1) years. The mean age at detection of deafness was 29.8 ± 18.8 (range: 3.2-55.0) years and mean duration of CI usage was 4.5 ± 2.8 (range: 0.5-10.1) years.

Of the total population of 116 patients, 71 completed tinnitus suppression studies. (39 men and 32 women; 34 right ears and 37 left ears). The mean age with standard deviation of these 71 patients at recruitment was 52.7 ± 16.1 (range: 23.4-87.0) years, and mean age at CI surgery was 45.4 ± 16.4 (range: 18.9-80.3) years. Mean age at detection of deafness was 29.8 ± 18.9 (range: 0.0-55.0) years and mean duration of CI usage was 4.5 ± 2.8 (range: 0.5-10.1) years.

In this study, we applied subjective questionnaires and objective audiological tests to evaluate pre-CI and post-CI hearing function, QOL, monosyllabic word and sentence recognition performance, and effectiveness of CI on adult tinnitus. By self-assessment, all participants fulfilled three questionnaires preoperatively and 6 months after CI, that is, SF-36 Health Survey–Taiwan version (SF-36), Nijmegen Cochlear Implant Questionnaire–Taiwan version (NCIQ-T), and World Health Organization Quality of Life-Brief version (WHOQOL-BREF)–Taiwan version.

Before surgery and at 1, 3, 6, 9, and 12 months postoperatively, two speech specialists evaluated each patient's auditory ability and speech production intelligibility using the Categories of Auditory Performance (CAP) scale[7] and Speech Intelligibility Rating (SIR) scale.[8] In addition, three open-set speech perception tests, i.e., easy sentence perception test (ES), difficult sentence perception test (DS), and phonetically balanced words recognition test (PB), were administered to examine each patient's development of speech perception during these periods.

2.1. Test methods

2.1.1. Three open-set speech perception tests

The patients were examined using three open-set speech perception tests, i.e., ES, DS, and PB (Table 2). ES included 15 sentences varying in length from 2 to 10 words. Each sentence contained 1-7 seven keywords chosen from a corpus of words that were familiar to the subjects in their daily lives, such as "car" or "book."[9] The DS consisted of 20 sentences varying in length from 2 to 12 words. Each sentence embedded 1-10 keywords to be scored that were less familiar to children, such as "dormitory" or "examine."[10] In the PB, the patients were required to verbally repeat 25 monosyllabic words spoken by the examiner with their mouth covered.[11] The PB score was based on the number of words correctly repeated, which was converted into a percentage for further analysis.[12]

Table 2

Speech perception test results of adult CI recipients, and comparison of post-CI ES test, DS test, and PB word recognition test scores

Result	N	Maximum	Minimum	Median	Mean ± SD	*p*	Good, %	Fair, %	Poor, %
Pre-CI									
ES	30	96	0	11	22.5 ± 26.8				
DS	30	98	0	12	23.3 ± 28.2				
PB	30	56	0	4	9.9 ± 14.7				
Post-CI, 1 month									
ES	30	100	18	89	79.9 ± 21.9				
DS	30	100	18	87	77.4 ± 23.2				
PB	30	92	0	40	40.8 ± 25.0				
Post-CI, 3 months									
ES	30	100	0	95	85.9 ± 24.3				
DS	30	100	0	92	80.5 ± 26.5				
PB	30	88	0	52	51.6 ± 26.3				
Post-CI, 6 months									
ES	30	100	2	96	86.7 ± 22.1				
DS	30	100	2	94	82.2 ± 24.1				
PB	30	92	4	48	53.6 ± 22.9				
Post-CI, 12 months									
ES	30	100	8	100	90.2 ± 24.6				
DS	30	100	12	98	88.9 ± 23.5				
PB	30	100	0	60	57.4 ± 26.5				
Last three scores, Quiet									
ES	116	100	0	95	81.0 ± 27.7				
DS	116	100	0	91	77.5 ± 28.5				
PB	116	100	0	60	55.0 ± 28.5				
Last three scores, SNR+5									
ES	55	100	26	86	81.0 ± 18.8				
DS	55	100	2	80	77.0 ± 19.3				
PB	55	92	0	48	47.9 ± 23.1				
Post-CI 1 month versus 3 months									
ES						**0.005**			
DS						**0.001**			
PB						**0.004**			
Post-CI 3 months versus 6 months									
ES						0.118			
DS						0.789			
PB						0.843			
Outcome									
ES	116						71%	12%	17%

Last three scores, last time to evaluate ES, DS, and PB at least post-CI 12 months follow-up; Quiet, in quiet environment; SNR+5, in the environment of signal to noise ratio plus 5dB; Good, score > 80; Fair, score 50-80; Poor, score < 50; $p < 0.05$ are shown in bold.
CI = cochlear implant; DS = difficult sentence perception test; ES = easy sentence perception test; N = number; PB = phonetically-balanced word recognition test; SD = standard deviation.

2.2. SF-36 Health Survey

The SF-36 Health Survey is positively correlated with QOL (eg, housing, neighborhood, standard of living, family life, and friendships). It has been translated and validated in different languages and the norms of the SF-36 Health Survey–Taiwan version can serve as a valuable reference for future comparisons.[13] SF-36 consists of 36 items that measure different dimensions, that is, physical health, general health perception, physical functioning, physical role functioning, bodily pain, mental health, emotional role functioning, vitality, mental wellbeing, and social role functioning (Table 3). Item scores from 1 to 5 points are summed and transformed using a scoring algorithm into a scale from 0 (poor health) to 100 (good health).

2.3. NCIQ

The NCIQ contains several domains: basic sound perception, speech production, advanced sound perception, self-esteem, activities, and social interaction (Table 4). After calculation, the scores of each domain range from 0 (poor health) to 100 (good health). The reliability and validity of the NCIQ Chinese version have been confirmed.[14]

2.4. CAP and SIR scales

The CAP and SIR scales are designed to assess deaf patients' auditory ability and speech production intelligibility, respectively. The CAP is a nonlinear hierarchical rating scale with eight points (0 = unaware of environmental sounds; 7 = able to converse on the telephone with a familiar person). The SIR is a nonlinear scale that classifies children's speech production intelligibility into five levels (1 = unintelligible; 5 = easily understood by all listeners). Both scales have been widely used in the study of speech perception (Table 4).[15,16]

2.5. WHOQOL-BREF

The WHOQOL-BREF assesses physical health, psychological health, social relationships, environment, and overall QOL (Table 5).[17] The Taiwan version includes the 24 original items of WHOQOL and adds two culture-specific questions for Taiwan. Each individual item of the WHOQOL-BREF is scored from 1 to 5 and then transformed linearly to a scale from 0 (poor health) to 100 (good health). The reliability and validity of the WHOQOL-BREF–Taiwan version has also been confirmed.[18]

Table 3

Pre-CI versus post-CI results of SF-36, and correlation coefficients between post-CI SF-36 results and post-CI auditory ability and speech production intelligibility (only significant correlations are shown)

				Post-CI, 6M		Post-CI, 9M		
Evaluation	Pre-CI, Mean ± SD	Post-CI, Mean ± SD	p	ES	DS	ES	DS	PB
Physical health	74.72 ± 18.69	78.50 ± 17.10	0.162	0.562[a]	0.491[a]	0.564[a]	0.702[a]	-
General health perceptions	56.33 ± 25.83	59.17 ± 23.86	0.589	…	…	…	…	…
Physical functioning	88.83 ± 15.01	89.58 ± 14.59	0.867	0.533[a]	0.489[a]	0.614[a]	0.770[a]	…
Physical role functioning	61.72 ± 40.81	73.33 ± 39.90	0.231	…	…	…	…	…
Bodily pain	76.08 ± 22.08	82.83 ± 19.37	**0.036**	0.479[a]	0.438[a]	…	…	…
Mental health	52.99 ± 23.58	61.06 ± 20.74	**0.019**	…	…	…	…	…
Emotional role functioning	55.56 ± 44.06	72.22 ± 39.23	0.096	…	…	…	…	…
Vitality	51.17 ± 25.65	53.83 ± 20.91	0.659	…	…	…	…	…
Mental wellbeing	51.87 ± 21.82	56.40 ± 20.38	0.181	…	…	…	…	…
Social role functioning	55.42 ± 25.57	70.42 ± 20.10	**0.002**	0.477[a]	…	…	…	0.570[a]

Scores of Physical health were the average scores of general health perceptions, physical functioning, physical role functioning and bodily pain; scores of mental health were the average scores of emotional role functioning, vitality, mental wellbeing and social role functioning; $p < 0.05$ are shown in bold.

CI = cochlear implant; SF-36 = SF-36 Health Survey—Taiwan Version; SD = standard deviation.

[a]Indicates coefficients achieving significant difference.

2.6. Tinnitus Handicap Inventory

We used the translated and validated Mandarin version of the Tinnitus Handicap Inventory (THI) questionnaire to examine the effects of CI on suppression of tinnitus, which contains 25 questions regarding the influence of tinnitus on activities of daily life.[19] These questions consist of 11 regarding the functional effects of tinnitus, nine regarding the emotional responses to tinnitus, and five regarding catastrophic responses to tinnitus. For each question, patients responses are "yes" (4 points), "sometimes" (2 points), or "never" (0 points), which are summed to a score between 0 and 100 with higher score indicating greater severity of tinnitus.[20]

2.7. Exclusion criteria

Otologists were responsible for evaluating medical records and preoperative magnetic resonance imaging (MRI) results to determine the presence of any relevant pathology, such as intellectual disability or autism, and neurological disorders, which would require further referrals.[21] Recipients <18 years old, those with developmental impairment, congenital anomalies, cochlear nerve agenesis, or severe medical illness were excluded.

2.8. Statistical analysis

Statistical analysis was performed using SPSS software (version 17.0; SPSS, Inc., Chicago, IL, USA). The Chi-square test was used for categorical variables, and the paired-samples t test or Kruskal–Wallis test was used to compare pre-CI and post-CI continuous variables. Pearson's correlation analysis was performed to analyze the correlation coefficients. In all analyses, $p < 0.05$ was taken to indicate statistical significance.

2.9. Ethics statement

This study was approved by the Institutional Review Board of the Chang Gung Medical Foundation (IRB no. 103-0896B). The data were collected retrospectively, and all data were anonymized prior to data analysis.

3. RESULTS

Table 2 shows the speech perception results at 3, 6, 9, and 12 months or longer post-CI in a quiet environment and noisy environment (signal to noise ratio [SNR] +5 dB) along with comparisons of ES, DS, and PB scores. ES, DS, and PB all showed significant differences in comparison of 1 month to 3 months post-CI (p = 0.005, 0.001, 0.004, respectively). However, there were no significant improvements in comparisons of 3-6 months or longer post-CI (all $p > 0.05$). Post-CI speech perception outcomes were good in 71% of patients (ES score > 80), fair in 12% (ES score 50-80), and remained poor in 17% (ES score < 50).

Table 4

Pre-CI versus post-CI results of NCIQ, and correlation coefficients between post-CI NCIQ results and post-CI auditory ability and speech production intelligibility (only significant correlations are shown)

Post-CI period				3M	6M	9M	3M	6M	9M	9M	9M
Evaluation	Pre-CI, Mean ± SD	Post-CI, Mean ± SD	p	CAP	CAP	CAP	SIR	SIR	SIR	ES	PB
Basic sound perception	19.62 ± 18.10	51.06 ± 21.14	**<0.001**	…	…	…	…	…	…	…	…
Speech production	40.45 ± 17.95	50.30 ± 20.26	**0.013**	…	…	…	…	…	…	0.527[a]	0.631[a]
Advanced sound perception	25.15 ± 11.59	41.82 ± 19.08	**<0.001**	…	…	0.364[a]	…	…	…	0.566[a]	0.623[a]
Self-esteem	48.41 ± 13.34	54.70 ± 17.43	0.058	0.496[a]	0.438[a]	0.383[a]	0.501[a]	0.500[a]	0.529[a]	…	…
Activity	60.00 ± 25.94	62.42 ± 23.25	0.569	…	…	…	0.372[a]	…	…	…	…
Social interaction	54.32 ± 21.25	55.61 ± 24.41	0.421	…	…	…	…	…	…	…	…

"…" is "non-specific". $p < 0.05$ are shown in bold.

CAP = Categories of Auditory Performance scale; ES = easy sentence; M = month; NCIQ = Nijmegen Cochlear Implant Questionnaire; PB = phonetically-balanced word; SIR = Speech Intelligibility Rating scale.

[a]Indicates coefficients achieving significant difference.

Table 5

Pre-CI and post-CI results of the WHOQOL-BREF

Test	Pre-CI, mean ± SD	Post-CI, mean ± SD	p
Physical health	59.2 ± 15.7	56.0 ± 14.8	0.241
Psychological health	49.9 ± 15.0	48.9 ± 15.2	0.955
Social relationships	50.3 ± 17.4	51.0 ± 16.1	0.618
Environment sound	54.7 ± 15.2	53.5 ± 14.9	0.787
Overall quality of life	48.3 ± 20.7	50.8 ± 19.4	0.317

Significant differences are shown in bold.
CI = cochlear implant; SD = standard deviation; WHOQOL-BREF = World Health Organization Quality of Life-Brief Version (WHOQOL-BREF)—Taiwan Version.
$p < 0.05$.

The results of SF-36 showed that the patients' physical evaluation scores were generally higher than those of mental evaluations both preoperatively and postoperatively (Table 3). Furthermore, post-CI scores of bodily pain, mental health, and social role functioning were significantly higher than the corresponding pre-CI scores (p = 0.036, 0.019, and 0.002, respectively). The correlations between post-CI SF-36 results and post-CI auditory ability and speech production intelligibility were also examined. Both physical health and physical functioning were significantly correlated with ES and DS at 6 and 9 months post-CI. In mental evaluation, social role functioning was significantly correlated with ES at 6 months post-CI and PB at 9 months post-CI.

As shown in Table 4, the post-CI basic sound perception, speech production, and advanced sound perception scores in the NCIQ were significantly higher than the corresponding pre-CI scores (p < 0.001, 0.013, and <0.001, respectively). However, there were no significant differences between pre-CI and post-CI scores of self-esteem, activity, or social interactions (all p > 0.05).

The correlations of post-CI NCIQ results and post-CI auditory ability and speech production intelligibility are shown in Table 4. The speech production scores were significantly positively correlated with ES and PB scores at 9 months post-CI, and advanced sound perception scores were significantly positively correlated with CAP, ES, and PB scores at 9 months post-CI. The self-esteem scores were significantly positively correlated with CAP scores at 3, 6, and 9 months post-CI and with SIR scores at 3, 6, and 9 months post-CI. The activity scores were positively correlated with SIR scores at 3 months post-CI.

There were no significant differences between pre-CI and post-CI WHOQOL-BREF scores in all categories (Table 5).

Table 6 shows the speech perception test results of the subjects grouped according to age (≥18-40, 41-60, and ≥61 years). The scores of ES, DS, and PB in quiet and noisy environments (SNR +5 dB) showed no significant differences among the groups (all p > 0.05).

Table 6

Comparison of speech perception test scores among adult CI recipients grouped by age (three age groups: ≥18–40, 41–60, and ≥61 years)

Speech perception test	p
ES, Quiet	0.469
DS, Quiet	0.348
PB, Quiet	0.647
ES, SNR+5dB	0.733
DS, SNR+5dB	0.611
PB, SNR+5dB	0.663

CI = cochlear implant; DS = difficult sentence perception test; ES = easy sentence perception test; PB = phonetically-balanced word recognition test; Quiet = in quiet environment; SNR+5 = in the environment of signal to noise ratio plus 5dB.

Fig. 1 shows an outline of the design and results of the tinnitus suppression study. Of the total of 71 CI recipients enrolled in this study, 53 had preoperative tinnitus and the remaining 18 did not. Of the 53 recipients with pre-CI tinnitus, 10 failed to complete the post-CI tinnitus questionnaires. Among the 43 remaining recipients who completed the post-CI tinnitus questionnaires, 39 reported persistent tinnitus after CI and four reported that their tinnitus had stopped. Among the 39 patients who still had postoperative tinnitus, after the CIs were turned on, the tinnitus was eliminated in 13, quieter in 11, unchanged in 10, and louder in five. Overall, 65.1% of recipients (28/43) experienced an improvement in the level of tinnitus postoperatively (no tinnitus in 4 cases; eliminated in 13 cases; quieter in 11 cases). On the other hand, of the 18 patients without tinnitus before surgery, two developed tinnitus postoperatively.

Fig. 2 shows the pre-CI and post-CI distribution of patients according to THI grade. The results showed that the percentage of subjects who rated their tinnitus handicap as grade 3-5 was reduced from 66.7% to 34.4.% after CI surgery, suggesting obvious improvement of tinnitus severity with CI.

4. DISCUSSION

This study demonstrated the effectiveness, with regard to improvement of hearing performance, speech recognition, QOL, and tinnitus suppression, of adult CI surgery in Taiwan. The outcomes of speech perception in our cohort of adult patients at 3 months post-CI were non-inferior to those at any other later time point after implantation. CI also improved tinnitus in approximately 65.1% of cases. In addition to improved speech perception, the CI-specific NCIQ QOL questionnaire showed that adult recipients experienced improved advanced sound perception, such as holding conversations with two or more people, having telephone conversations, and enjoying music. Furthermore, with better speech perception, the recipients also showed meaningful improvements in the speech production subdomains, such as controlling the pitch and volume of their voice and producing a more natural-sounding voice.

Although there was no significant difference between pre-CI and post-CI scores in the psychological functioning (self-esteem) sub-domain, our data showed that self-esteem was correlated with improved auditory abilities within 1 year after CI surgery. This suggested that, as recipients' hearing improved with CI, they also experienced reduced depression and anxiety. Consequently, patients will show more confidence and feel more comfortable communicating with other people, with an enhanced ease of listening. Analysis of generic SF-36 assessments showed that our patients' scores on mental health, especially social role functioning, were significantly improved postoperatively.

This study demonstrated improved speech perception results with time after CI. There were significant improvements for ES, DS, and PB scores, from 1 to 3 months post-CI. However, there were no significant differences from 3 to 6 months post-CI or thereafter. Therefore, the greatest improvements in ES, DS, and PB scores occurred within 3 months after CI surgery. Previous reports indicated that adult CI recipients showed obvious increases in speech perception abilities within 6-9 months post-CI, after which there were only small degrees of improvement.[22,23] Our patients' speech perception reached a plateau at 3 months post-CI. This was consistent with the findings of Bassim et al,[24] who reported improvement within 3 months postoperatively in most adult recipients. The discrepancies were likely to be due to differences in composition of the hearing loss groups between studies. We found that patients with conditions or etiologies, such as progressive hearing loss that deteriorated

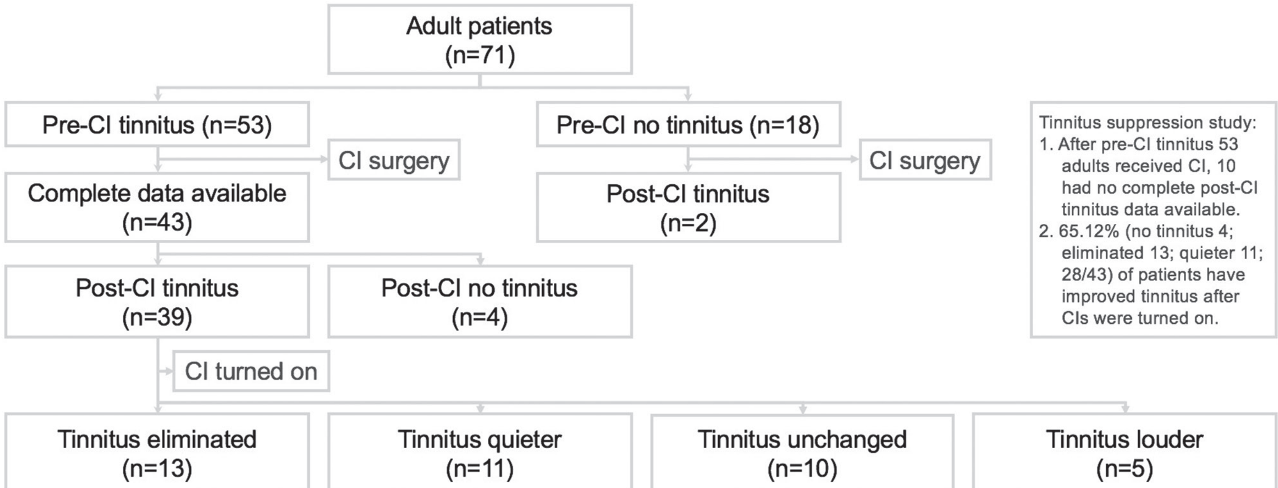

Fig. 1 Flowchart of 71 adult patients enrolled in the tinnitus suppression study.

to severe or profound within a short time, poor preoperative speech perception scores, sudden deafness, enlarged vestibular aqueduct, and shorter pre-CI duration of deafness showed rapid improvement in speech perception scores after the operation. For these patients, 3-month follow-up post-CI is adequate. With increasing numbers of patients requiring postoperative monitoring, it will become necessary to select a time-efficient follow-up schedule to provide better care for more patients. Therefore, it may be worth considering close monitoring of CI patients for 3 months after surgery, and then continuing with annual follow-ups assuming stabilization of the patient's condition.

Adult CI candidates often delay undergoing CI. The mean duration of deafness is about 4.3 years, and about half of our recipients are delayed by a further 2 years before seeking help in our outpatient clinic. Most of these patients did not have sufficient information about the benefits and effectiveness of CI, which prevented them from undergoing implantation earlier. This delay may have been avoided if the candidates had received more knowledge about CI through various channels. For example, we encountered many adult CI candidates with profound hearing loss >100 dB at 2-8 kHz on pure tone audiogram (PTA) and still wore hearing aids. After CI, their speech perception scores improved significantly, which indicated that hearing aids would be of only very limited benefit in these patients. A previous study suggested that successful hearing preservation with hearing aids is possible in subjects with preservation of low-frequency hearing.[25] In comparison with traditional hearing aids, improvement of speech perception is more obvious after CI because it can enhance high-frequency hearing. Combined electrical and acoustic stimulation of the inner ear with both CI and hearing aids can be achieved after CI surgery.[26,27] This is especially possible if sufficient residual hearing is preserved in the implanted ear. Residual low tone hearing could be preserved through CI surgery via the round window approach in about half of the patients in this cohort.

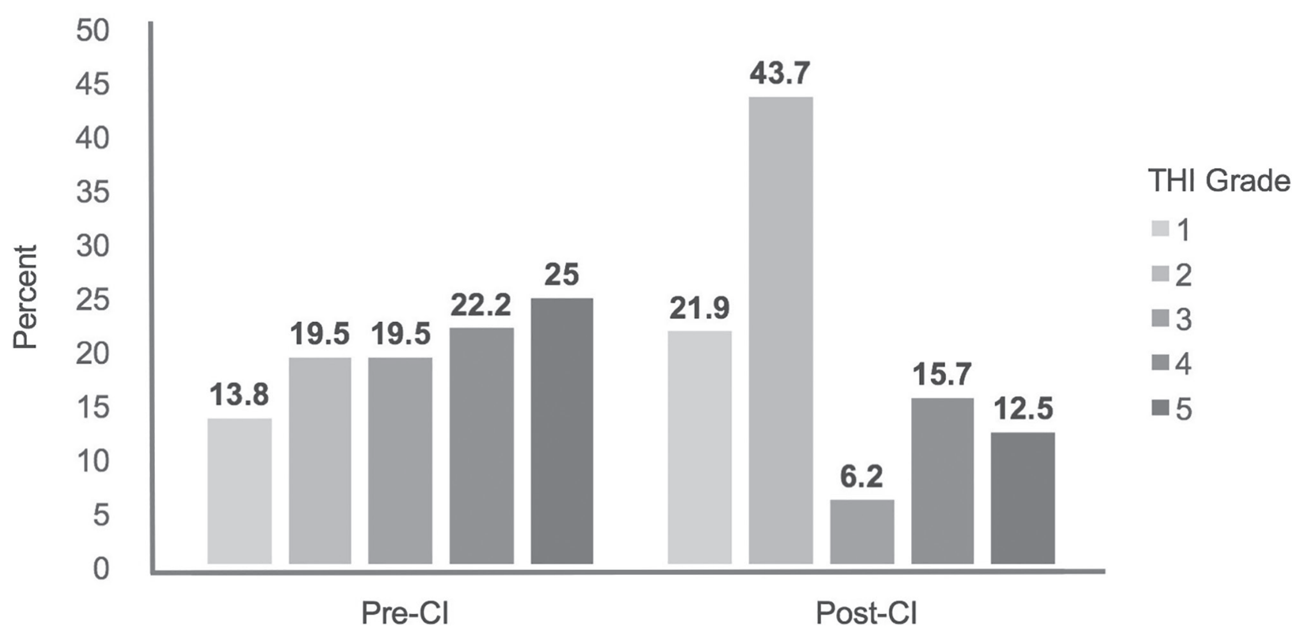

Fig. 2 Pre-CI and post-CI distribution of patients through THI grade. THI = Tinnitus Handicap Inventory.

Although 71% of our CI recipients showed good outcome based on their speech perception of ES (score > 80), speech perception remained poor (score < 50) in 17% of the recipients at 1-year follow-up. To predict post-CI outcome more accurately, we examined individual differences among recipients to determine the factors affecting CI outcome. Our observations indicated that meningitis, nasopharyngeal carcinoma after radiotherapy, inner ear malformations, and auditory nerve deficiency were associated with poor CI outcome. In addition to specific etiologies, the reasons for poor prognosis could be early-onset prelingual deafness and longer duration of deafness. The hearing and clinical manifestations of patients with prelingual deafness were significantly inferior to those with postlingual deafness in our cohort.

It is necessary to obtain a detailed medical history during preoperative evaluation, especially in relation to the cause of hearing loss, and imaging studies, usually 3D MRI, should be arranged to exclude anomalies of the inner ear, auditory nerve deficiency, and central lesions. Comprehensive case history taking will help in counseling patients with regard to post-CI outcome and in building appropriate expectations.

This study revealed no significant differences in scores on the WHOQOL-BREF questionnaire between pre-CI and post-CI. In addition to the sensitivity of the questionnaires, the small size of the study population may also have contributed to this lack of significant differences between pre-CI and post-CI WHOQOL-BREF questionnaire scores. Although our pre-CI and post-CI WHOQOL-BREF scores did not show significant improvement in QOL, the post-CI scores on overall QOL were notably higher than those pre-CI. This pattern suggested that, although a significant improvement in QOL was not reflected in our study, CI was associated with better QOL in some patients. It is also important to note that each questionnaire emphasizes different aspects of QOL and may not be suitable for every culture. Therefore, we suggest that each center should choose and apply more sensitive questionnaires to assess the QOL of CI recipients.

Over the past 10 years, bilateral CI implantation has been gradually considered around the world, and many groups have shown that bilateral CI has an advantage in hearing outcome over unilateral CI. Bilateral CI can achieve better sound resolution.[28,29] Compared with unilateral CI, the bilateral implanted CI can receive different signals on both sides and thus significantly increase the SNR.[30] In addition to the objective benefits listed above, the user's subjective feelings are of the utmost importance.[31] Our research indicated improved performance in advanced hearing, self-evaluation, work limitation, and social interaction, as evaluated by the NCIQ-T after compared to before the second CI, resulting in significant improvement of patients' QOL.

The number of CI recipients >60 years old has been increasing at our center over the past decade. Some studies have suggested that older adults (>61 years old) showed less improvement in speech perception scores after cochlear implantation in comparison to younger adults, while other studies showed no differences in the benefits of CI between the two age groups.[32,33] The results of the present study revealed no differences in speech perception scores between adults older and younger than 60 years. Our results can serve as local data for older adults who are considering CI as an intervention for hearing loss.

By definition, tinnitus is a phantom sound sensation without an external sound.[34] In the population of CI candidates, tinnitus has a reported prevalence of between 66% and 86%.[35–37] It remains controversial whether CI can suppress tinnitus. Some studies have reported that the electrical stimulation can effectively suppress tinnitus in CI patients.[38,39] Positive effects of CI on both the prevalence of tinnitus and the associated handicap were reported in up to 93% of patients.[40–42] Nevertheless, some studies questioned the tinnitus-reducing effects of CI.[36,43] Some patients began to experience annoying tinnitus after undergoing CI surgery,[44] and tinnitus was even suggested to be the most common post-CI complication.[45] The number of patients with deterioration of tinnitus after CI was reported to range between 4% and 26%.[46]

Liu et al considered that CI programming can not only improve tinnitus symptoms but also decrease impedance.[34] Our findings were consistent with those of Liu et al, and both studies were based on Chinese-speaking CI patient populations.

In our cohort, around 74.6% (53/71) of our CI candidates had annoying tinnitus in addition to hearing loss. Among these patients, 65.1% reported improved tinnitus after CI. Kim et al reported that tinnitus was eliminated or improved in 25% and 40% of their adult patients after CI surgery, respectively, and most of the tinnitus reduction occurred within 1 month of CI use.[47] Consistent with their results, the percentages of patients who rated their tinnitus as moderate, severe, and catastrophic, grades 3-5 in the THI, were reduced from 66.7% to 34.4% after CI surgery in the present study.

Physically, tinnitus is inhibited by electrical stimulation of the cochlea.[48,49] One study showed that CI was helpful in reducing tinnitus because the cochlear electrode stimulates the cochlea electrically.[50] We believe that effective tinnitus suppression, decreased tinnitus, and improved auditory ability may all contribute to the improvement of QOL in Chinese-speaking patients.

In an international CI candidacy survey, Vichers et al[51] reported that the majority of countries/clinics focus mainly on functional outcomes and utilize questionnaires and a range of speech-based outcome assessments to determine candidacy, while the tonal audiogram itself is becoming less of a stringent requirement. We use PTA and speech perception (words and sentences) testing, as well as questionnaires to determine candidacy and the side of implantation. Audiogram with a pure tone average indicating a certain degree of hearing loss is still a requirement for the selection criteria. However, we depend more on preoperative sentence and word speech perception results for candidacy selection. We have begun to use the data obtained in this study as a reference for CI candidacy. We used average speech perception scores measured at least 12 months post-CI from the 116 recipients (116 cases, mean ES score 81.0%, DS score 77.5%, PB score 55.0%; Table 2, last three scores, quiet). Patients with a pre-CI score below these averages should be considered as candidates for implantation. We suggest that each center should develop their own tools for assessment and create norms for specific populations.

Chinese has a logographic orthography that differs greatly from alphabetic writing systems, such as English. First, the orthography–phonology relationship in alphabetic scripts is transparent, whereas it is opaque in Chinese script.[52] Second, these two types of script exhibit different orthographic structures. The distinct orthographic units in alphabetic writing systems are words comprised of letters arranged horizontally from left to right. However, the distinct orthographic units in Chinese are characters, which are more like morphemes than words in English, and are arranged in squares of similar size.

Mandarin is a tonal language in which both segmental cues and tone patterns convey lexical meaning. However, the findings of our study regarding speech perception scores were similar to reports of adult CI from non-tonal language English-speaking countries. It is difficult to compare our results with those in the western literature because the measurement tools, participant selection, and follow-up times varied among different centers. Our previous study regarding adults with CI confirmed that visual input may help prelingually deafened adults with CI to recognize phonemes.[53] However, visual assistance may not enhance

Mandarin tone recognition. These results suggest that special considerations are required in rehabilitation strategies and audiological assessment protocols for implant recipients who speak tonal languages.

Other than improved speech understanding, patients are also encouraged to consider CI over hearing aids based on the ability to provide better intelligibility and sound quality. For example, some hearing aid patients are able to achieve a high sentence perception score because they are able to guess the words using context. However, when asked about the clarity of individual words within sentences, they would not be able to answer. This difficulty is often remediated after the patient receives a CI. With the clarity provided by the CI, most patients are able to understand each word in sentences without contextual cues.

Other than improving auditory performance, CI has many other benefits in the social and emotional domains.[5] Our pre-CI and post-CI results of the SF-36 showed that patients' scores on bodily pain, mental health, and social role functioning improved significantly after CI surgery. The scores of social role functioning were significantly correlated with the scores of speech perception (ES) and PB at 6 and 9 months post-CI, respectively. This pattern was similar to our previous study in pediatric CI recipients, in which we observed significant reductions in behavioral, emotional, and social problems after CI surgery.[54,55]

This study showed that the post-CI scores of basic sound perception, speech production, and advanced sound perception all improved significantly compared to pre-CI scores. Strong correlations between post-CI NCIQ results and speech perception scores of ES and DS were also observed. Our previous study showed that most pediatric CI recipients were able to reach the highest level of both CAP and SIR scales after 4-5 years of implant use.[56] Here, we found that adults' self-esteem was most significantly correlated with the highest CAP and SIR scales at 12 months post-CI. For postlingually deafened adult recipients, improved speech perception scores were seen as soon as 3-6 months after implantation. Improvements in several aspects of QOL were correlated with enhanced hearing abilities within 1 year after implantation. However, CI recipients still find it difficult to hear well in challenging listening environments (eg, noise, music) due to limited frequency resolution provided by the implant. Difficulty hearing in noisy environments can be improved by bimodal hearing or with bilateral CIs. In addition, music appreciation can be improved by music training programs. Adult recipients can expect more significant improvements in auditory outcome with extensive postoperative auditory–verbal training provided to patients with longer durations of deafness.

This study had some limitations. The majority of patients in the study population were male, which could represent a source of bias, although this is commonly seen in retrospective studies. Our research was conducted at a single tertiary hospital. Further validation of the results may be needed with inclusion of data from other institutions and language backgrounds.

The 116 patients recruited to this study had diverse and heterogeneous etiologies of hearing loss, and only approximately a quarter (30/116) of them had received complete hearing assessment and questionnaires. Retrospective longitudinal studies are usually limited by inadequate data collection. A future well-designed case–control study will overcome the inherent flaws and bias in this retrospective study.

In conclusion, CIs were helpful for auditory and speech development, as well as tinnitus suppression, which could lead to improved social role functioning and self-esteem. The adult CI users' self-evaluations of QOL and function were significantly correlated with auditory performance and speech perception ability during the first year after implantation. The results of this study may be used as a reference for clinicians and rehabilitation institutes to evaluate outcomes of CI surgery in deaf adults.

ACKNOWLEDGMENTS

This study was supported by the Chang-Gung Memorial Hospital Research Program (CMRPG3H0051-3).

The authors thank all members of the Department of Otorhinolaryngology-Head and Neck Surgery, Chang Gung Memorial Hospital Linkou, New Taipei Municipal TuCheng Hospital (Built and Operated by Chang Gung Medical Foundation) for their invaluable help. The authors would also like to thank all the adult CI recipients who participated in the study.

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