

## Original Article

# Comparison of evaluation criteria of rehabilitation effects in children after cochlear implantation and the impact of age and gender on evaluation criteria

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**Abstract:** Objective: The aim of the current study was to compare four evaluation criteria of rehabilitation effects in children after cochlear implantation (CI), exploring influencing factors of these evaluation criteria. Methods: A total of 100 children with Freedom cochlear implants were enrolled and randomized into four groups (25 cases in each group), according to different evaluation criteria. Groups included: 1) Group A, for standard testing program and vocabulary tables for assessment of hearing, language, and learning abilities for hearing-impaired children; 2) Group B, for modified Categories of Auditory Performance (CAP-II) rating scale; 3) Group C, for the Parent Version of the Speech, Spatial, and Qualities of Hearing Scale (SSQ-P); and 4) Group D, for Speech Intelligibility Rating (SIR). Evaluation levels or scores of the four evaluation criteria before and at 1, 3, 6, 12, 18, and 24 months after CI were recorded. Pre- and post-operative auditory and speech and learning abilities of the children were compared. Results: Evaluation levels or scores of the four evaluation criteria at 6, 12, 18, and 24 months after CI were significantly higher than those before CI. Differences were statistically significant (all  $P < 0.05$ ). Levels or scores of the four criteria gradually increased with the extension of rehabilitation times. Younger ages led to faster increases in levels and scores of SIR. Levels and scores of CAP-II and SIR, regardless of gender, increased significantly after CI. Regarding CAP-II, gradual increases in the speed of improvement were shown from 1 to 12 months after CI. A slowdown was shown from 12 to 24 months. For SIR, gradual increases in the speed of improvement were presented from 1 to 18 months after CI. A slowdown was shown from 18 to 24 months. There were no significant gender differences between CAP and SIR. Levels and scores of SSQ-P and SIR increased gradually with the extension of rehabilitation times. The fastest increase in speed of improvement was from 3 to 18 months after CI. Slowdown was after 18 months. Moreover, younger ages led to a faster speed of improvement in hearing. Conclusion: Postoperative auditory performances, speech behaviors, and verbal intelligibility levels of children patients after CI were improved. No significant gender differences were shown, with younger ages leading to faster hearing recovery times.

**Keywords:** Cochlear implantation, prelingual deafness, speech rehabilitation, auditory and speech ability

## Introduction

Hearing loss, known as hearing impairment, is characterized by a partial or total inability to hear in one or both ears, due to various reasons, with difficulty in normal language interaction with ordinary people. The WHO reported that the number of hearing loss patients, worldwide, reached 360 million by 2017, including 32 million children [1, 2]. In China, there are more than 120,000 child patients suffering with hearing loss [3]. Studies have shown that hearing loss has significant adverse effects on the study performance of children. Difficulty in

communication with people, followed by loneliness, isolation, and frustration, may occur among people with hearing impairment. If not provided with access to sign language during childhood, child patients with congenital hearing loss may feel isolated and resist social interaction [4].

At present, many evaluation criteria concerning auditory ability have been designed for clinical use, including vocabulary table for assessment of children's hearing, language and learning abilities and standard testing program, Categories of Auditory Performance-II (CAP-II)

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rating scale, Parent Version of the Speech, Spatial, and Qualities of Hearing Scale (SSQ-P), and the Speech Intelligibility Rating (SIR). Each method has special advantages. For example, the standard assessment table and testing program is to assess the ability to use speech breathing and control airflow in children with hearing impairment. It evaluates the fluency, strength, and volume of airflow for pronunciation. The CAP-II test is a grading evaluation criterion assessing the degree of behavioral response of all children with hearing impairment to external sounds.

Cochlear implantation (CI), an effective treatment for severe and extremely severe sensorineural deafness, has been widely used in clinical practice [5]. It has provided improvement, not only in children's speech perception, but also in their quality of life [6]. However, evaluation for the effects of CI is a complex task. At present, vocabulary table for assessment of hearing, language, and learning abilities, vocabulary tables for assessment of auditory ability, and assessment of auditory and speech rehabilitation for hearing-impaired children are frequently used to evaluate speech discrimination, auditory perception, and rehabilitation effects of CI after operations. Sampath et al. found that the vocabulary table for assessment of hearing, language, and learning abilities for hearing-impaired children is the best for evaluating CI child patients. However, Kirkham E et al. held the view that the vocabulary table for assessment of auditory ability for hearing-impaired children could better reflect postoperative rehabilitation effects of CI child patients [7, 8]. Therefore, this study aimed to compare the four evaluation criteria of rehabilitation effects in CI child patients, unifying the evaluating methods for a more standardized operation of CI on hearing-impaired children. The current study further hopes to improve the rehabilitation effects of auditory and speech abilities of children after CI.

### Materials and methods

#### *Baseline characteristics*

A total of 100 children with Freedom cochlear implants, admitted to Children's Hospital of Shanghai, Children's Hospital of Shanghai Jiaotong University, from June 2014 to June 2017, were included in this study. The study

included 48 males and 52 females. All patients were native speakers of Mandarin. Implantation ages ranged from 12 to 94 months. The 100 enrolled child patients were randomized into four groups, including group A for standard testing program and vocabulary tables for assessment of hearing, language, and learning abilities for hearing-impaired children, group B for CAP-II rating scale, group C for SSQ-P, and group D for SIR. Each group contained 25 cases. The study was approved by the Medical Ethics Committee of Children's Hospital of Shanghai, Children's Hospital of Shanghai Jiaotong University. Written informed consent was obtained from the families of each child.

#### *Inclusion and exclusion criteria*

**Inclusion criteria:** Patients diagnosed with hearing loss in line with diagnosis and treatment standards of sensorineural hearing loss established by the Division of Otolaryngology Head and Neck Surgery, Chinese Medical Association; Patients diagnosed with severe and extremely severe congenital hearing loss before surgery; Patients used hearing aids before surgery for more than 3 months with poor effects in hearing; Patients showed no abnormalities in imaging examinations of the aural region [9].

**Exclusion criteria:** Patients with complete absence of cochlea or severe stenosis of the inner ear; Hypoplasia or absence of cochlear nerves; Patients with non-neurological mental retardation; Patients unable to cooperate with rehabilitation training; Patients with acute or chronic otitis media and mastoiditis; Patients with cochlear fractures or deformities.

#### *Cochlear implantation*

All patients were examined for brainstem auditory evoked potential, otoacoustic emission, and acoustic impedance before implantation. Thin-slice CT scans of the temporal bone, three-dimensional reconstruction of the cochlea, and magnetic resonance imaging of internal auditory canals were conducted for these patients before implantation. The type of cochlea implanted in this study was Advanced Bionics HiRes 90K cochlear implant device made by the US. Operation method. After entering the operating room, the patients were monitored for vital signs and received general static inhalation combined anesthesia. The retro-auricu-

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lar incision approach was adopted. The skin, subcutaneous tissues, and deep anatomy were dissected. The flap was turned back to expose the cortex of bone in the mastoid region. Next, the facial recess was opened. This was followed by the opening of the scala tympani. After full exposure of the implantation area, the stimulator of cochlear implant was placed on the bone bed. The stimulation electrode was inserted into the scala tympani and the reference electrode was placed on the skull surface underneath the temporal muscle.

### *Hearing loss classification*

According to 1997 guidelines of the World Health Organization (WHO-1997), the average hearing loss is equal to the average of hearing thresholds of air conduction at 500, 1,000, 2,000, and 4,000 Hz [10]. Classification of hearing loss was as follows: 1) Average hearing loss of 25 decibels or less indicates normal; 2) An average between 26 and 40 decibels indicates mild hearing loss; 3) An average between 41 and 60 decibels indicates moderate hearing loss; 4) An average between 61 and 80 decibels indicates severe hearing loss; and 5) An average of 81 decibels or more indicates extremely severe hearing loss.

### *Evaluation criteria for rehabilitation effects*

*Standard testing program and vocabulary tables for assessment of hearing, language, and learning abilities for hearing-impaired children:* Speech sound or filtered complex tones were used as the test tones of function evaluation. Vocabulary tables for assessment of hearing, language, and learning abilities for hearing-impaired children mainly presented in the form of pictures compiled by Sun of China Rehabilitation Research Center for Deaf Children were used in this evaluation criterion. Assessment of the tables involved natural sound recognition, tone recognition, monosyllabic, disyllabic and trisyllabic words recognition, short sentence recognition, speech recognition, number recognition, and selective auditory ability. It is suitable for auditory ability evaluation among children aged 3 to 17 years old and evaluation of hearing rehabilitation effects among hearing-impaired children after wearing hearing aids or receiving CI. It provides a basis for hearing aid fitting, cochlear implant

adjustments, and development of hearing intervention programs [11].

Standard testing program combined with vocabulary tables for assessment of hearing, language, and learning abilities for hearing-impaired children is suitable for pre-school children with hearing impairment. It assesses their language ability before and after CI. It combines six items involving articulation of speech, including vocabulary size, grammar ability, comprehension ability (listen and recognize pictures), expression ability (read pictures and speak), and communication ability (theme dialogue). The evaluation was divided into four levels. Higher levels indicate better rehabilitation effects. Assessment data was collected in the game through pictures and sounds. Each vocabulary table for testing was applied within ten minutes.

*CAP-II:* This evaluation criterion was carried out by close contacts of the patients. The patients were graded according to behavioral responses to all external sounds, including environmental sounds and speech sounds. They were graded using a scale of 1 to 8. Level 1: Unable to perceive environmental sounds; Level 2: Able to perceive environmental sounds; Level 3: Able to respond to speech sounds; Level 4: Able to recognize environmental sounds; Level 5: Able to recognize some speech sounds without lip reading; Level 6: Able to understand common short sentences without lip reading; Level 7: Able to communicate with people without lip reading; Level 8: Able to communicate with familiar people using a phone [12].

*SSQ-P:* This evaluation criterion evaluates, in detail, auditory abilities of daily life. Three parts, including speech perception, spatial hearing, and other hearing characteristics, were the main targets of this evaluation. It contains 23 questions involving eight aspects, including dialogue under quiet conditions, dialogue under noisy conditions, multi-language flow of dialogue in context, positioning, distance and movement, sound quality, and sound recognition [13]. The criteria contains ten levels, with higher levels indicating better rehabilitation effects.

*SIR:* This evaluation criterion evaluates speech ability. Five levels are presented in SIR. Level 1:

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**Table 1.** Comparison of baseline characteristics of the four included groups

	Group A (n=25)	Group B (n=25)	Group C (n=25)	Group D (n=25)	F/X <sup>2</sup>	P
Age (month)	35.3±6.7	36.7±6.2	34.5±7.0	36.4±5.6	0.760	0.859
Gender (male/female)	11/14	14/11	13/12	10/15	1.401	0.705
Hearing loss classification (severe/extremely severe)	14/11	12/13	12/13	13/12	0.440	0.932
Education level of parents					3.641	0.725
Junior high School	12	11	10	10		
Senior high School	5	6	10	6		
Undergraduate	8	8	5	9		
Economic capacity					2.244	0.523
Average	15	12	10	11		
Well-off	10	13	15	14		

Note: group A: standard testing program; group B: Categories of Auditory Performance-II (CAP-II) rating scale; group C: Parent Version of the Speech, Spatial, and Qualities of Hearing Scale (SSQ-P); group D: Speech Intelligibility Rating (SIR).

**Table 2.** Overall evaluation results of different rehabilitation stages after cochlear implantation

	Group A (n=25)	Group B (n=25)	Group C (n=25)	Group D (n=25)
Before implantation	1.01±0.22	0.88±0.12	0.93±0.13	0.95±0.18
After implantation				
1 month	1.12±0.41	1.54±0.33	1.53±0.36	1.07±0.43
3 months	1.54±0.24	1.93±0.32 <sup>#</sup>	2.74±0.23 <sup>#</sup>	1.55±0.32
6 months	1.65±1.03 <sup>#</sup>	2.36±1.01 <sup>#</sup>	3.26±0.73 <sup>#</sup>	2.02±0.62 <sup>#</sup>
12 months	2.45±0.89 <sup>#</sup>	4.82±1.34 <sup>#</sup>	4.89±0.87 <sup>#</sup>	2.79±0.32 <sup>#</sup>
18 months	3.53±0.93 <sup>#</sup>	4.97±0.99 <sup>#</sup>	5.38±0.79 <sup>#</sup>	3.42±0.48 <sup>#</sup>
24 months	3.67±1.22 <sup>#</sup>	5.22±1.02 <sup>#</sup>	6.34±1.03 <sup>#</sup>	3.76±0.28 <sup>#</sup>

Note: group A: standard testing program; group B: Categories of Auditory Performance-II (CAP-II) rating scale; group C: Parent Version of the Speech, Spatial, and Qualities of Hearing Scale (SSQ-P); group D: Speech Intelligibility Rating (SIR); <sup>#</sup>P<0.05: within-group comparison between overall evaluation result at a time point and that before implantation.

Coherent speech was not intelligible. Words in spoken language could be recognized only before surgery. The main way of communication was sign language or gestures; Level 2: Coherent speech was not intelligible, but patient speech could be understood by listeners, mainly through some recognized words combined by context and lip reading; Level 3: Coherent speech could be understood by listeners focusing their attention with the help of lip reading; Level 4: Coherent speech could be understood by people with no experience listening to deaf people; Level 5: Coherent speech could be understood by everyone. It could be easily understood by children in the daily context [14].

### Evaluation times and form of assessment

The patients received evaluations using certain criterion before CI. Evaluation times after CI

were set at 1, 3, 6, 12, 18, and 24 months. Consultations with relevant experts, face to face or through the internet or telephone, were the form of evaluation in this study.

### Statistical analysis

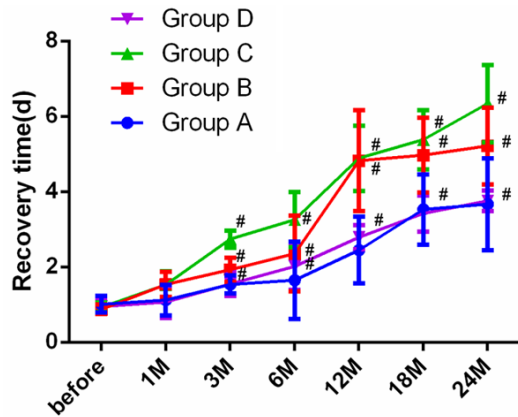
Statistical analysis was performed using SPSS 19.0 software. One-way analysis of variance was performed for each child patient before CI and at 1, 3, 6, 12, 18, and 24 months after CI. SNK testing was used for pairwise comparisons. *P* values <0.05 indicate statistical significance.

## Results

### Baseline characteristics

There were no significant differences in age, gender, hearing impairment grade, parent edu-

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**Figure 1.** Overall evaluation results of different rehabilitation stages after cochlear implantation. Note: group A: Standard testing program; group B: Categories of Auditory Performance-II (CAP-II) rating scale; group C: Parent Version of the Speech, Spatial, and Qualities of Hearing Scale (SSQ-P); group D: Speech Intelligibility Rating (SIR); M: month(s). #P<0.05: within-group comparison between overall evaluation result at a time point and that before implantation.

cational levels, and economic abilities among the four groups (all P>0.05). See **Table 1**.

### *Changes in auditory speech rehabilitation after cochlear implantation with time*

In group A, levels or scores of the effects of auditory speech rehabilitation were significantly higher at 6, 12, 18, and 24 months after CI than those before CI. Differences were statistically significant (all P<0.05). Levels or scores of group B at 3, 6, 12, 18, and 24 months after CI were elevated significantly, compared with those before CI. Differences were statistically significant (all P<0.05). Significant elevations of levels or scores were shown at 3, 6, 12, 18, and 24 months after CI in group C, compared with levels before CI. Differences were statistically significant (all P<0.05). Levels or scores of group D showed significant elevation at 6, 12, 18, and 24 months after CI, compared with those before CI. Differences were statistically significant (all P<0.05). See **Table 2** and **Figure 1**.

### *Impact of gender on evaluation criteria for rehabilitation effects after implantation*

Levels or scores of CAP and SIR in child patients, regardless of gender, increased significantly after CI (both P<0.05). For CAP, a gradual increase in speed of improvement was

shown from 1 to 12 months after CI. A slowdown was shown from 12 to 24 months. For SIR, a gradual increase in speed of improvement presented from 1 to 18 months after CI. A slowdown showed from 18 to 24 months. Levels or scores of CAP and SIR between male and female child patients showed no significant differences (P<0.05). See **Table 3** and **Figure 2**.

### *Impact of age on evaluation criteria for rehabilitation effects after implantation*

Levels and scores of SSQ-P and SIR increased gradually with the extension of rehabilitation times. For both SSQ-P and SIR, the fastest increases in speed of improvement presented from 3 to 18 months after CI. Slowdowns presented after 18 months. Moreover, younger ages led to faster speeds of improvement in hearing. See **Figure 3**.

## Discussion

Cochlear implants are electronic devices for restoration, improvement, and reconstruction of the auditory function of hearing-impaired people through conversion of sound into an electrical signal in a certain coding form by the speech processor outside the body and direct excitement of the auditory nerve by the electrode system implanted in the body. At present, cochlear implants have been used as routine treatments for severe or complete deafness. Implantation has also become the best means for treatment of nerve deafness [15]. Studies have shown that the recovery rate of auditory and speech function of hearing-impaired children receiving CI has reached as high as 75% [16, 17]. Therefore, CI has become more and more important for rehabilitation of hearing-impaired children.

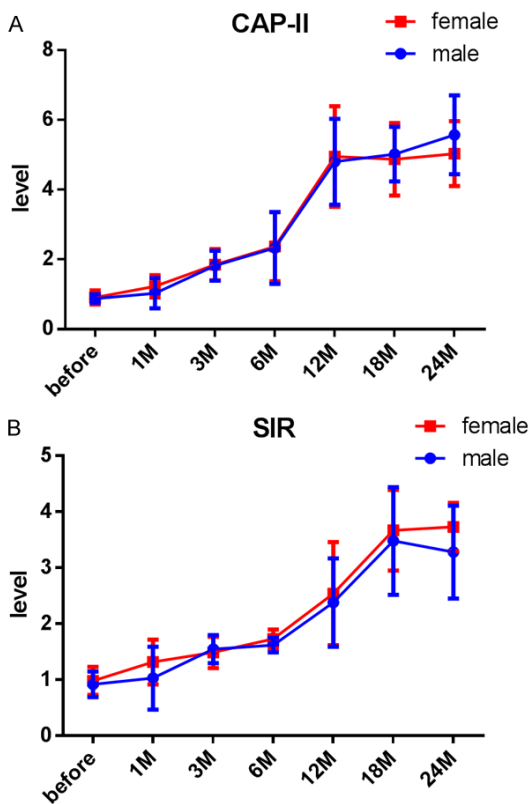
The current study found that levels or scores of the effects of auditory speech rehabilitation in the standard testing program were significantly higher at 6, 12, 18, and 24 months after CI than those before CI. Levels or scores in CAP-II at 3, 6, 12, 18, and 24 months after CI were elevated significantly, compared with those before CI. Significant elevation of the levels or scores in SSQ-P were shown at 3, 6, 12, 18, and 24 months after CI, compared with those before CI. Levels or scores in SIR showed significant elevations at 6, 12, 18, and 24 months after CI, compared with those before CI. All

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**Table 3.** Comparison of evaluation results of different rehabilitation stages between male and female patients in CAP-II and SIR after cochlear implantation

	CAP-II		P	SIR		P
	Male (n=14)	Female (n=11)		Male (n=10)	Female (n=15)	
Before implantation	0.88±0.12	0.91±0.20	0.657	0.92±0.23	0.98±0.25	0.550
After implantation						
1 month	1.03±0.43	1.23±0.32	0.198	1.03±0.56	1.32±0.40	0.144
3 months	1.82±0.43	1.85±0.45	0.866	1.55±0.25	1.49±0.28	0.590
6 months	2.33±1.03	2.37±0.99	0.922	1.62±0.13	1.73±0.17	0.097
12 months	4.80±1.23	4.95±1.44	0.783	2.38±0.79	2.54±0.92	0.657
18 months	5.02±0.78	4.87±1.04	0.689	3.48±0.96	3.67±0.72	0.577
24 months	5.57±1.13	5.03±0.93	0.203	3.28±0.83	3.73±0.43	0.088

Note: CAP-II: Categories of Auditory Performance-II rating scale; SIR: Speech Intelligibility Rating.



**Figure 2.** Comparison of evaluation results of different rehabilitation stages between male and female patients in CAP and SIR after cochlear implantation. Note: CAP-II: Categories of Auditory Performance-II rating scale; SIR: Speech Intelligibility Rating; M: month(s); before refers to evaluation results before implantation; 1M, 3M, 6M, 12M, 18M, 24M refer to 1, 3, 6, 12, 18, 24 months after implantation, respectively.

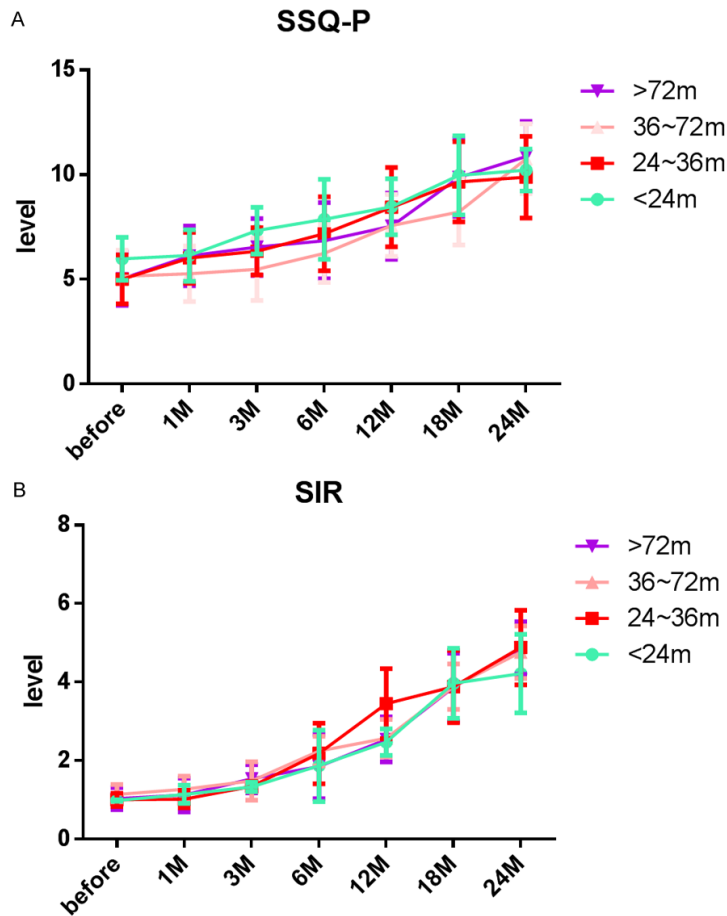
four evaluation criteria can detect significant increases in auditory and speech ability levels after CI. The four criteria for auditory and

speech evaluation are all meaningful. CAP-II and SSQ-P are more sensitive and more suitable for early implantation.

Studies have found that more than 80% of children aged 1-3 years with severe or extremely severe sensorineural hearing loss can achieve normal auditory and speech function after three years of rehabilitation training subsequent to CI [18, 19]. Results of this study suggest that auditory abilities increased in different age groups, with younger children showing faster CAP-II increases. Moreover, the fastest increase in CAP-II among child patients of different age groups was shown at 3-12 months after CI. The possible reason is that younger children are more sensitive to speech perception. Therefore, CI for children before the age of three is more conducive to the recovery of auditory and speech function.

Results showed no gender differences in hearing recovery effects among hearing-impaired children after CI. In terms of CAP, gradual increases in the speed of improvement was shown from 1 to 12 months after CI. A slowdown was shown from 12 to 24 months. Gradual increases in speed of improvement, as to SIR, presented from 1 to 18 months after CI. The slowdown presented from 18 to 24 months. Moreover, no significant differences were shown in the patterns of changes of CAP and SIR between male and female child patients. Guest et al. found that gender presented no significant effects on CAP and SIR in children undergoing CI [20, 21]. However, some studies have shown that female children with hearing impairment have a higher verbal ability and larger vocabulary size than male children

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**Figure 3.** Comparison of evaluation results of different rehabilitation stages among different age groups in SSQ-P and SIR after cochlear implantation. Note: SSQ-P: Parent Version of the Speech, Spatial, and Qualities of Hearing Scale; SIR: Speech Intelligibility Rating; M, m: month(s); before refers to evaluation results before implantation; 1M, 3M, 6M, 12M, 18M, 24M refer to 1, 3, 6, 12, 18, 24 months after implantation, respectively.

from birth to 26 months, which may possibly explain the reason that the level of protein encoded by FOXP gene in the cerebral cortex of female children is 30% higher than that of male children at the same age. Loizou et al. found that female children could earlier communicate with familiar people by phone or with people without lip reading. They could earlier recognize some speech sounds without lip reading [22, 23].

However, there were still some shortcomings in this study. This study only observed differences of auditory and speech function using the above four evaluation criteria within 24 months of rehabilitation. The time should be extended to 3-5 years to further explore the effects of CI on the recovery of auditory and speech func-

tion in severe and extremely severe hearing-impaired children. Recovery of auditory and speech function is a long-term process. Rehabilitation training must be adhered to in order to achieve expectative clinical effects. Certainly, many influencing factors are present during the recovery period, including age and gender, inner ear malformations, time of wearing hearing aids, and other complicative factors. These can affect the postoperative auditory and speech rehabilitation of hearing-impaired children. In future research, more influencing factors will be included, providing valuable reference for clinical rehabilitation.

In conclusion, postoperative auditory performance, speech behavior, and verbal intelligibility levels of child patients after CI were improved, with no significant differences shown between males and females. Moreover, younger ages led to faster recovery times.

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### Disclosure of conflict of interest

None.

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