# Changes in Hearing Threshold and Auditory Performance After Cochlear Implantation

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## ABSTRACT
Hearing impairment is known to interfere with communication ability and may lead to social isolation, emotional distress, depression, and anxiety. Cochlear implant technology represents an effective rehabilitative solution for individuals with severe to profound hearing loss. This study aimed to evaluate the benefits of cochlear implant use through measurements of hearing thresholds and Categorical Auditory Performance II (CAP II) scores before implantation and after six months and one year of device use. A mixed-methods design with a pre–post group approach was employed, involving a sample of 60 cochlear implant users with more than six months of device experience who met the predetermined eligibility criteria. Data were obtained from the CMS database, questionnaire administration, and interviews with otolaryngologists, audiologists, therapists, and parents of cochlear implant users. Qualitative analysis demonstrated improvements in hearing thresholds and auditory performance following cochlear implantation, which subsequently enhanced verbal communication abilities. These improvements were associated with consistent device use, auditory listening therapy, and adaptation over time. Statistical analyses using Friedman, Wilcoxon, and multiple linear regression tests revealed a significant improvement in hearing thresholds, decreasing from a mean of 104.42 dB before implantation to 48.42 dB after six months and 33.33 dB after one year of use ($p < 0.05$). CAP II scores also increased substantially, from a mean of 0.57 pre-implantation to 3.08 at six months and 4.82 at one year. Age, baseline test results, and therapy consistency were identified as influential factors affecting final outcomes. In conclusion, younger age, consistent cochlear implant use, and adherence to auditory verbal or speech therapy were shown to significantly improve hearing ability and auditory performance in individuals with severe to profound hearing impairment.
**Keywords**: cochlear implant; hearing threshold; categorical auditory performance II

## INTRODUCTION

Hearing impairment is a major public health concern that affects an individual's ability to communicate and may lead to social and emotional isolation. According to the World Health Organization, an estimated 466 million people worldwide were living with hearing loss in 2020, including 34 million children, with approximately 1 to 3 per 1000 live births experiencing congenital deafness; this number increases to 2 to 4 per 100 infants in intensive care settings [1]. Indonesia is among the four Asian countries with the highest prevalence of hearing impairment, with an estimated national rate of 4.6%. The prevalence of moderate to profound hearing loss varies across global regions, reaching 5.5% in Asia [1]. Data from the 2023 Indonesia Health Survey further reported that the prevalence of hearing disability among individuals aged >1 year was 0.4% [2].

Current hearing-assistive technologies, such as hearing aids, can improve auditory function in individuals with mild to severe hearing loss. However, for those with severe to profound impairment in whom hearing aids no longer provide adequate benefit, the most effective intervention is cochlear implantation or, in specific anatomical conditions, auditory brainstem implantation. In Indonesia, cochlear implant devices approved by the Food and Drug Administration (FDA) include Advanced Bionics, Cochlear, and MedEl. Although each manufacturer offers various models, all cochlear implants share the same fundamental structure consisting of internal and external components. The surgical procedure involves placement of the internal implant within the cochlea and positioning of the external audio processor behind the ear.

The first cochlear implant surgery was performed in 1957 by Dr. Jacques Békésy, although modern and clinically effective cochlear implant systems were developed and widely implemented beginning in the 1980s. By 2022, cochlear implants were estimated to have restored auditory function in approximately one million individuals with severe to profound hearing loss [3].

Cochlear implantation begins with a comprehensive candidacy assessment to ensure that the patient is an appropriate candidate and that the family fully understands the implications, expectations, and long-term rehabilitation process associated with implantation. In *Cochlear Implantation: An Overview* by Deep from the Mayo Clinic, Rochester, candidacy guidelines for various age groups—from infants to adults—are described in detail [4]. The subsequent surgical procedure involves placement of the internal implant beneath the skin and into the cochlea. This procedure is considered relatively safe, with minor complications occurring infrequently; examples include vestibular disturbances and iatrogenic-related issues [5].

Activation of the cochlear implant typically occurs one to two weeks after surgery, once the incision has healed. This activation marks the beginning of the user's "hearing age," defined as the duration of auditory experience with the implant. Following activation, users do not immediately achieve functional hearing or speech. Instead, a structured and prolonged rehabilitation process is required, involving consistent device use and auditory-verbal therapy. Rehabilitation progresses gradually, with goals tailored to developmental milestones, enabling children to learn to detect their own voice, the voices of others, and environmental sounds, ultimately supporting the development of effective spoken communication [6].

Early implantation is strongly recommended, ideally before the age of two years, particularly for children with better pure-tone thresholds. Auditory perception outcomes after cochlear implantation are significantly better in children aged three years or younger compared with older children, as reflected in speech perception abilities and acquisition of early vocabulary and sentence production [7]. Age at implantation is positively associated with auditory and speech perception outcomes, with the optimal age identified at approximately 15 months; the earlier the implantation, the better the expected outcomes [8]. The youngest reported cochlear implant recipient to date was a two-month-old infant implanted by Dr. Joshua Wood, with device activation at three months of age in Memphis, Tennessee, United States [9]. In Indonesia, the youngest cochlear implant recipient underwent surgery at eight months of age.

The choice between unilateral and bilateral cochlear implantation depends on patient and family preference, although bilateral implantation provides superior sound localization and spatial hearing. Studies have demonstrated significant differences between unilateral and bilateral users across all age intervals [10]. Pantaleo reported that bilateral cochlear implants offer substantial subjective advantages over unilateral implants, particularly in noisy listening environments [11]. A study from Turkey similarly found that children with unilateral implants performed worse than bilateral users in speech-in-noise perception tasks [12].

Optimal cochlear implant use requires consistent daily wearing time. In a study on the *Evaluation of quality of life after pediatric cochlear implantation*, both age and duration of implant use were positively associated with quality-of-life outcomes [13]. Another study from Egypt, *Preoperative Variables Affecting Outcome of Cochlear Implant*, reported that age at implantation, duration of device use, and speech therapy participation were positively correlated with auditory and language development [14].

The present study was conducted to evaluate the benefits of cochlear implant use in individuals with hearing impairment through measurements of hearing thresholds and Categorical Auditory Performance II (CAP II) scores. The findings are expected to contribute to scientific knowledge by providing additional evidence regarding outcomes achieved through cochlear implant implementation. For policymakers, the study offers insights into the characteristics of hearing impairment and the importance of hearing technologies, serving as a basis for improving access to cochlear implants through national health insurance (BPJS Kesehatan), facilitating importation processes, and exploring the potential for local manufacturing. Such efforts would enhance accessibility to appropriate hearing technologies for individuals with hearing impairment and ultimately contribute to improving public health standards in Indonesia.

# METHODS

The study was conducted at the hearLIFE Hearing Center from April to August 2025. A mixed-method research design was employed, integrating both quantitative and qualitative approaches within a single framework to obtain a comprehensive understanding of the research problem. Mixed-method design is defined as a systematic procedure for collecting, analyzing, and integrating quantitative and qualitative data within one study or a series of studies to generate a more complete, valid, reliable, and objective interpretation of the phenomenon under investigation. This design was selected because the use of quantitative or qualitative methods alone would not sufficiently capture the complexity of auditory outcomes following cochlear implantation. The study adopted a one-group pre- and post-test approach to evaluate the effects of cochlear implant implementation by combining numerical measurements with in-depth qualitative insights.

The first methodological component consisted of qualitative inquiry. In this phase, semi-structured interviews were conducted with otolaryngologists, audiologists, auditory-verbal therapists, and parents of cochlear implant users. The purpose of this qualitative strand was to obtain a deeper understanding of changes in hearing thresholds and auditory performance after cochlear implantation, including factors influencing adaptation, therapy engagement, and daily device use. The qualitative data provided contextual explanations for the quantitative findings, particularly regarding user experiences, perceived improvements, and challenges encountered during the rehabilitation process.

The second methodological component consisted of quantitative data collection and analysis. Quantitative data were obtained from the CMS database of the hearLIFE Hearing Center and through questionnaire administration to parents or directly to cochlear implant users who were able to complete the questionnaire independently. A total of 60 participants were included, with data collection focused on service centers located in Jakarta, Surabaya, and Medan. The study population comprised individuals who had used a cochlear implant for more than six months. Inclusion criteria required willingness to participate, availability of aided audiometry results at six months and one year after implantation, and completion of the questionnaire assessing auditory performance using the Categorical Auditory Performance II (CAP II) method. The CAP II scoring system used in this study is presented in Table 1.

Table 1. Categorical Auditory Performance II (CAP II) scoring criteria

| Score | Criteria |
|---|---|
| 0 | Does not demonstrate awareness of environmental sounds |
| 1 | Begins to show awareness of environmental sounds |
| 2 | Responds to conversational speech sounds |
| 3 | Able to identify environmental sounds |
| 4 | Able to discriminate several speech sounds without lip-reading |
| 5 | Able to understand short sentences without lip-reading |
| 6 | Able to understand conversation without lip-reading |
| 7 | Able to communicate with familiar persons using the telephone |
| 8 | Able to follow group conversations in reverberant or noisy environments, such as classrooms or restaurants |
| 9 | Able to use the telephone with unfamiliar speakers when the conversational context is unpredictable |

Quantitative analysis included descriptive statistics to summarize participant characteristics and auditory outcomes, followed by inferential statistical tests to evaluate changes over time. The Friedman test was used to assess differences in repeated measurements of hearing thresholds and CAP II scores across three time points: pre-implantation, six months post-implantation, and one year post-implantation. Post-hoc analysis using the Wilcoxon signed-rank test was conducted to determine specific differences between paired time points. Multiple linear regression analysis was subsequently performed to identify predictors of auditory outcomes, including age at implantation, baseline hearing test results, and consistency of auditory-verbal therapy. These analytical procedures enabled the identification of both temporal improvements and contributing factors influencing auditory performance after cochlear implantation.

# RESULTS

## Qualitative findings

Qualitative interviews with parents, therapists, audiologists, and otolaryngologists revealed several thematic patterns related to age at implantation, unilateral versus bilateral use, geographical access, and therapy consistency. Parents consistently emphasized the importance of early implantation. One parent stated, *"Saya memutuskan untuk segera melakukan operasi implan koklea sedini mungkin walaupun ada sedikit rasa takut, namun ini untuk kebaikannya di kemudian hari agar dapat lebih cepat mendengar dan bicara"* ("I decided to proceed with cochlear implant surgery as early as possible even though I felt a bit afraid, because it is for my child's future so they can hear and speak sooner") (Parent). Another parent added, *"Saya segera melakukan operasi implan koklea saat audiologis dan dokter THT menjelaskan pentingnya anak belajar mendengar sedini mungkin, supaya anak saya dapat segera mendengar dan bicara seperti anak lainnya"* ("I immediately agreed to cochlear implant surgery when the audiologist and ENT doctor explained the importance of early listening development, so my child could hear and speak like other children") (Parent).

Regarding the choice between unilateral and bilateral implantation, therapists and parents highlighted the advantages of bilateral use. A therapist explained, *"Pasien yang menggunakan bilateral implan akan lebih mudah dalam proses belajar mendengar dan bicara"* ("Patients who use bilateral implants will find it easier to learn to listen and speak"). A parent noted, *"Saya sudah diinformasikan oleh dokter THT bahwa sebaiknya menggunakan kedua telinga, namun saat ini kami baru bisa menggunakan 1 telinga pada anak saya"* ("I was informed by the ENT doctor that using both ears is recommended, but for now we can only afford one implant for our child"). Another parent reported substantial improvement after bilateral implantation: *"Setelah menggunakan implan di kedua telinganya hasilnya jauh lebih baik dan respons mendengarnya menjadi lebih cepat"* ("After using implants in both ears, the results were much better and my child's hearing responses became much faster").

Geographical barriers were also evident. One parent stated, *"Saya tinggal di Kalimantan tapi harus ke Jakarta untuk melakukan operasi implan koklea karena di Kalimantan belum tersedia"* ("I live in Kalimantan but had to travel to Jakarta for cochlear implant surgery because it is not yet available in Kalimantan"). Therapists also described the need for remote therapy: *"Saat ini kami memberikan sesi terapi jarak jauh dengan online meeting karena belum tersedianya terapi AVT di semua kota di Indonesia"* ("We currently provide remote therapy sessions via online meetings because AVT therapy is not yet available in all cities in Indonesia").

Consistency in therapy emerged as a key factor. A parent shared, *"Sebelum menggunakan implan rasanya saya sulit melihat adanya perkembangan kemampuan mendengarnya, saat ini setiap kali terapi terasa sekali perkembangannya, sehingga sesi terapi ini jadi lebih semangat dan konsisten"* ("Before using the implant, it was difficult for me to see any progress in my child's hearing ability; now, during each therapy session, the progress is very noticeable, making us more motivated and consistent").

## Quantitative findings

Demographic characteristics of the 60 respondents are presented in Table 2. The largest proportion of participants underwent cochlear implantation at ages 0–3.5 years (56.7%). Females accounted for 56.7% of the sample, and 65% were unilateral implant users. Most respondents resided in Jakarta (45%), followed by Medan (28.3%) and Surabaya (26.7%). Therapy consistency improved after implantation, and 75% of respondents used their implant for more than 12 hours per day. Most parents had a university-level education (70%).

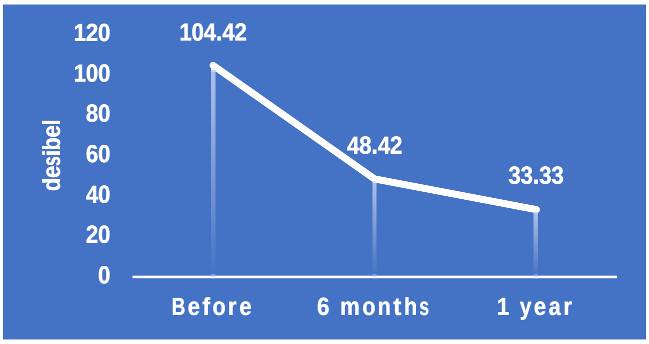


Figure 1. Improvement in hearing thresholds before and after cochlear implantation

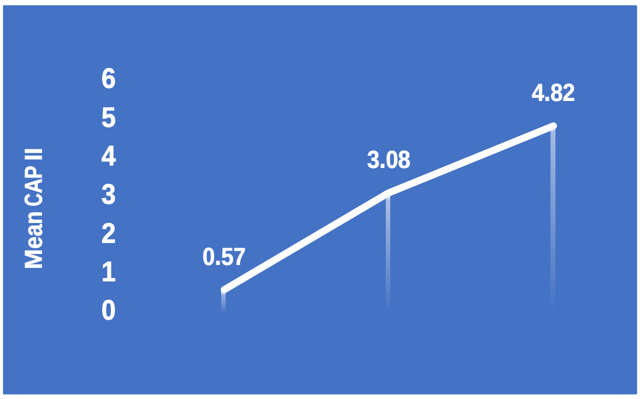


Figure 2. Improvement in CAP II scores before and after cochlear implantation

Table 2. Frequency distribution of age, sex, implant side, domicile, therapy, daily use duration, and parental education

| Characteristics | Frequency | Percentage |
|---|---|---|
| Age at cochlear implantation | | |
| 0–3.5 years | 34 | 56.7 |
| >3.5–7 years | 24 | 40.0 |
| >7 years | 2 | 3.3 |
| Sex | | |
| Male | 26 | 43.4 |
| Female | 34 | 56.7 |
| Implant side | | |
| Bilateral | 21 | 35.0 |
| Unilateral | 39 | 65.0 |
| Domicile | | |
| Jakarta and surrounding areas | 27 | 45.0 |
| Surabaya and surrounding areas | 16 | 26.7 |
| Medan and surrounding areas | 17 | 28.3 |
| AVT/Speech therapy before implantation | | |
| <2 sessions | 39 | 65.0 |
| 2–4 sessions | 20 | 33.3 |
| >4 sessions | 1 | 1.7 |
| AVT/Speech therapy after implantation | | |
| <2 sessions | 32 | 53.3 |
| 2–4 sessions | 23 | 38.3 |
| >4 sessions | 5 | 8.3 |
| Daily device use | | |
| 5–8 hours | 2 | 3.3 |
| 9–12 hours | 13 | 21.7 |
| >12 hours | 45 | 75.0 |
| Father's education | | |
| Primary school | 1 | 1.7 |
| Junior high school | 4 | 6.7 |
| Senior high school | 13 | 21.7 |
| University | 42 | 70.0 |
| Mother's education | | |
| Junior high school | 4 | 6.7 |
| Senior high school | 13 | 21.7 |
| University | 42 | 70.0 |

Audiometric threshold improvements are illustrated in Figure 1. The mean pre-implant hearing threshold was 104.42 dB, improving to 48.42 dB at six months (a 56 dB improvement) and 33.33 dB at twelve months (a 71.08 dB improvement). Interview data supported these findings. One parent stated, *"Sebelum implan anak saya sama sekali tidak dapat mendengar suara-suara di sekelilingnya… saat ini anak saya segera menoleh saat saya panggil"* ("Before the implant, my child could not hear any surrounding sounds at all… now my child immediately turns when I call or when something falls"). An audiologist confirmed, *"Sebagian besar pasien yang telah menggunakan implan koklea terdapat peningkatan ambang dengar yang lebih baik jika dibandingkan saat sebelum menggunakan implan koklea"* ("Most patients who have used cochlear implants show improved hearing thresholds compared to before implantation").

CAP II scores also improved substantially, as shown in Figure 2. The mean score increased from 0.57 pre-implant to 3.08 at six months and 4.82 at one year. Parents and therapists described meaningful auditory and speech development. One parent shared, *"Saat ini saya juga terus bicara untuk melatihnya tapi kini hasilnya sungguh sangat membahagiakan ketika akhirnya dia bisa memanggil mama"* ("I continue talking to train my child's hearing, and now the results are truly joyful because my child can finally say 'mama'"). A therapist added, *"Senang melihat anak-anak yang sudah memakai implan koklea… kemampuan bicaranya berkembang dengan baik"* ("It is wonderful to see children who use cochlear implants… their speech and language abilities are developing well").

## Regression analysis

Multiple linear regression was used to examine the relationship between the dependent variable and several independent variables. Initial modeling (Table 3) showed that pre-implant hearing test results had a significant partial relationship with changes in hearing thresholds from pre-implant to six months post-implant ($p < 0.05$). Other variables—including patient age, age at initial intervention, age at implantation, current hearing age, pre-implant CAP II score, daily device use duration, and AVT/speech therapy before and after implantation—did not show significant partial effects ($p > 0.05$).

Table 3. Initial multiple linear regression model for hearing threshold improvement

| Variable | B | Std. Error | Standardized Beta | t | Sig. | Tolerance | VIF |
|---|---|---|---|---|---|---|---|
| (Constant) | -7.432 | 34.798 | — | -0.214 | 0.832 | — | — |
| Patient age | 5.986 | 6.188 | 0.185 | 0.967 | 0.338 | 0.425 | 2.354 |
| Age at initial intervention | 1.686 | 7.368 | 0.037 | 0.229 | 0.820 | 0.584 | 1.713 |
| Age at cochlear implantation | -6.125 | 6.221 | -0.173 | -0.984 | 0.330 | 0.502 | 1.994 |
| Hearing age | -3.142 | 4.709 | -0.129 | -0.667 | 0.508 | 0.418 | 2.392 |
| Pre-implant hearing test | 0.731 | 0.292 | 0.340 | 2.505 | 0.016 | 0.846 | 1.182 |
| Pre-implant CAP II score | 1.501 | 2.332 | 0.092 | 0.643 | 0.523 | 0.754 | 1.327 |
| Daily device-use hours | -1.477 | 1.294 | -0.179 | -1.142 | 0.259 | 0.632 | 1.582 |
| Auditory verbal/speech therapy before implantation | 3.411 | 2.779 | 0.175 | 1.228 | 0.225 | 0.769 | 1.301 |
| Auditory verbal/speech therapy after implantation | -0.449 | 2.254 | -0.029 | -0.199 | 0.843 | 0.758 | 1.319 |

Table 4. Initial to final multiple linear regression modeling for hearing threshold improvement

| Variable | Initial model (p) | Without AVT after (p) | Without initial intervention age (p) | Without pre-implant CAP II (p) | Without hearing age (p) | Without patient age (p) | Without implant age (p) |
|---|---|---|---|---|---|---|---|
| (Constant) | 0.832 | 0.811 | 0.796 | 0.771 | 0.818 | 0.912 | 0.742 |
| Patient age | 0.338 | 0.323 | 0.320 | 0.346 | 0.571 | — | — |
| Age at initial intervention | 0.820 | 0.851 | — | — | — | — | — |
| Age at cochlear implantation | 0.330 | 0.334 | 0.296 | 0.322 | 0.456 | 0.507 | — |
| Hearing age | 0.508 | 0.475 | 0.455 | 0.421 | — | — | — |
| Pre-implant hearing test | 0.016 | 0.014 | 0.010 | 0.010 | 0.011 | 0.012 | 0.008 |
| Pre-implant CAP II score | 0.523 | 0.540 | 0.549 | — | — | — | — |
| Daily device-use hours | 0.259 | 0.258 | 0.258 | 0.315 | 0.199 | 0.245 | 0.227 |
| AVT/speech therapy before implantation | 0.225 | 0.223 | 0.223 | 0.173 | 0.143 | 0.120 | 0.140 |
| AVT/speech therapy after implantation | 0.843 | — | — | — | — | — | — |

Table 5. Initial multiple linear regression model for CAP II score improvement

| Variable | B | Std. Error | Standardized Beta | t | p-value | Tolerance | VIF |
|---|---|---|---|---|---|---|---|
| (Constant) | 3.286 | 2.562 | — | 1.282 | 0.206 | — | — |
| Patient age | 0.231 | 0.456 | 0.108 | 0.507 | 0.615 | 0.425 | 2.354 |
| Age at initial intervention | 0.096 | 0.543 | 0.032 | 0.176 | 0.861 | 0.584 | 1.713 |
| Age at cochlear implantation | -0.122 | 0.458 | -0.052 | -0.266 | 0.792 | 0.502 | 1.994 |
| Hearing age | -0.044 | 0.347 | -0.027 | -0.125 | 0.901 | 0.418 | 2.392 |
| Pre-implant hearing test | -0.005 | 0.021 | -0.038 | -0.248 | 0.805 | 0.846 | 1.182 |
| Pre-implant CAP II score | -0.098 | 0.172 | -0.091 | -0.568 | 0.573 | 0.754 | 1.327 |
| Daily device-use hours | -0.055 | 0.095 | -0.102 | -0.581 | 0.564 | 0.632 | 1.582 |
| AVT/speech therapy before implantation | 0.054 | 0.205 | 0.042 | 0.262 | 0.795 | 0.769 | 1.301 |
| AVT/speech therapy after implantation | 0.100 | 0.166 | 0.096 | 0.600 | 0.551 | 0.758 | 1.319 |

Variable elimination based on p-values (Table 4) confirmed that pre-implant hearing test results remained the only significant predictor of hearing threshold improvement. For CAP II score improvement (Tables 5 and 6), initial and final multivariate models showed that none of the variables had a significant partial relationship with CAP II score changes from pre-implant to six months post-implant ($p > 0.05$). All variables—

including age, intervention age, implantation age, hearing age, pre-implant hearing test results, pre-implant CAP II score, daily device use, and therapy consistency—were not significant predictors.

Table 6. Initial to final multiple linear regression modeling for cap ii score improvement

| Variable | Initial (p) | Without hearing age (p) | Without initial intervention age (p) | Without implant age (p) | Without pre-implant hearing test (p) | Without AVT before (p) | Without patient age (p) |
|---|---|---|---|---|---|---|---|
| (Constant) | 0.206 | 0.194 | 0.194 | 0.188 | 0.011 | 0.010 | 0.006 |
| Patient age | 0.615 | 0.586 | 0.596 | 0.607 | 0.567 | 0.538 | — |
| Age at initial intervention | 0.861 | 0.843 | — | — | — | — | — |
| Age at cochlear implantation | 0.792 | 0.804 | 0.873 | — | — | — | — |
| Hearing age | 0.901 | — | — | — | — | — | — |
| Pre-implant hearing test | 0.805 | 0.798 | 0.825 | 0.837 | — | — | — |
| Pre-implant CAP II score | 0.573 | 0.577 | 0.544 | 0.510 | 0.515 | 0.526 | 0.469 |
| Daily device-use hours | 0.564 | 0.515 | 0.517 | 0.519 | 0.505 | 0.503 | 0.671 |
| AVT/speech therapy before implantation | 0.795 | 0.777 | 0.789 | 0.805 | 0.838 | — | — |
| AVT/speech therapy after implantation | 0.551 | 0.556 | 0.514 | 0.478 | 0.481 | 0.433 | 0.436 |

## DISCUSSION

The respondents in this study consisted of 60 individuals, with the largest proportion belonging to the 0–3.5-year age group (56.7%), followed by those aged 3.6–7 years (40%), and a small proportion above 7 years. This distribution aligns with evidence from multiple studies indicating that auditory perceptual development after cochlear implantation is significantly better in children under three years of age, as reflected in superior speech perception outcomes and earlier acquisition of first words and sentences. The sex distribution showed that 56.7% of respondents were female and 43.4% were male. Previous literature has demonstrated variability in sex distribution among cochlear implant users, with no consistent pattern indicating dominance of one sex over the other. When examined by age group, males and females were distributed as follows: among children aged 0–3.5 years, 56.7% were female; in the 3.6–7-year group, the distribution was more balanced; and in the group above 7 years, all respondents were male. These findings suggest that sex is not a determining factor in the timing of implantation, consistent with existing research.

Bilateral cochlear implantation was more common than unilateral implantation in this study, consistent with literature indicating that bilateral implantation enhances speech perception and sound localization abilities. The present findings also demonstrated that bilateral users experienced greater improvement in hearing thresholds at six months post-implantation, with an average increase of 56.8 dB, compared with 54.2 dB among unilateral users. Significant improvements were observed from pre-implantation to six months post-implantation, with further gains at twelve months. These results are consistent with previous studies reporting meaningful improvements in hearing thresholds following cochlear implantation [15]. The progressive improvement from six to twelve months suggests an adaptive process in auditory development. After one year, bilateral users showed an average improvement of 72.05 dB, while unilateral users improved by 69.28 dB. Qualitative interview data supported these quantitative findings, with parents and therapists reporting noticeable improvements in responsiveness, and audiologists confirming threshold changes through aided audiometry.

In terms of geographical distribution, respondents originated from three cochlear implant service regions: Jakarta (45%), Medan (28.3%), and Surabaya (26.7%). The predominance of respondents from Jakarta is reasonable given the concentration of advanced hospital facilities, otolaryngologists, audiologists, and other specialized medical personnel in the capital city, as well as greater accessibility to cochlear implant services. Therapy consistency also improved after implantation. Before implantation, respondents attended Auditory Verbal Therapy (AVT) or speech therapy an average of 1.03 times per week (range 0–3 sessions), increasing to an average of 1.7 sessions per week (range 1–6 sessions) after implantation. This increase reflects greater motivation and commitment to therapy following noticeable auditory improvements. Parental education was predominantly at the university level (70%), suggesting that higher educational background may influence decision-making regarding cochlear implantation and adherence to therapy. Supporting evidence includes findings by Alenzi, who reported that maternal education correlates significantly with CAP scores in children with cochlear implants [16], and by Lee et al., who found that parental education influences language performance, including articulation, reading, and CAP scores [17]. Qualitative interviews further revealed that highly educated parents were more proactive in seeking information and solutions for their child's hearing impairment.

Daily device-use duration was high among respondents, with 75% using their cochlear implant for more than 12 hours per day, 21.7% using it for 9–12 hours, and only 3.3% using it for 5–8 hours per day. These findings indicate strong adherence to recommended device-use practices. Similar studies have reported average daily use of approximately 11.3 hours, with positive correlations between longer use and improved speech outcomes [18]. Urik also reported that long-term use exceeding 12 hours per day is typical among users with favorable outcomes, whereas those using the device for fewer than 12 hours tend to show comparatively lower performance [19]. Qualitative data in this study echoed these findings, with parents and therapists noting that longer and more consistent device use facilitated easier auditory learning and better developmental progress.

Significant improvements were observed among patients who had used cochlear implants for six and twelve months. Pre-implantation hearing thresholds averaged 104.42 dB (range 80–120 dB), indicating severe to profound hearing loss. After six months of cochlear implant use, thresholds improved by an average of 56 dB, reaching a mean of 48.42 dB (range 25–85 dB), corresponding to moderate hearing levels. After one year, thresholds improved further by approximately 70 dB compared with pre-implantation levels, with a mean of 33.33 dB (range 10–70 dB). These findings align with previous studies demonstrating significant improvements in aided hearing thresholds following cochlear implantation [15], including research by Achena [20] and Forli [21]. The progressive improvement from six months to one year reflects ongoing auditory adaptation and neural plasticity.

CAP II scores also showed meaningful improvement, consistent with findings from Alam [22], who reported CAP II scores of approximately 3 at six months and 5 at one year post-implantation. Similar trends were observed in the study by Bee See Goh [23], which demonstrated that CAP II scores increase with longer implant use. Qualitative interviews in the present study revealed that parents observed substantial improvements in auditory ability at both six and twelve months, with clearer therapy progress and enhanced communication skills. Therapists and otolaryngologists also confirmed that children with cochlear implants showed progressive language development, eventually achieving communication abilities comparable to their hearing peers. Multivariate analysis further demonstrated that pre-implantation hearing test results had a significant partial relationship with changes in hearing thresholds from pre-implantation to six months post-implantation ($p < 0.05$), indicating that baseline auditory status is a key predictor of early improvement.

This study has limitations, as data were collected from only one hearing center. Conducting similar research across multiple cochlear implant centers with longer follow-up periods would allow for a larger sample size and broader insights into auditory improvement after cochlear implantation.

## CONCLUSION

Cochlear implantation significantly improves hearing thresholds and CAP II scores, with progressive gains from six to twelve months indicating ongoing auditory adaptation. Qualitative insights show that verbal communication, social interaction, and confidence improve markedly, although success requires consistent device use, structured therapy, and strong family support. Pre-implant hearing test results were the only variable with a significant partial association with early threshold improvement. Overall, cochlear implants provide an effective solution for severe to profound hearing loss, enabling children to develop communication skills comparable to their hearing peers.

## Ethical consideration, competing interest and source of funding


- Ethical considerations were addressed throughout the research process. All participants and parents of child participants received detailed information regarding the study objectives, procedures, potential risks, and benefits. Written informed consent was obtained prior to participation. Confidentiality of personal and clinical data was strictly maintained, and all data were anonymized during analysis. The study adhered to ethical principles of autonomy, beneficence, non-maleficence, and justice, and received approval from the appropriate institutional ethics committee prior to data collection.
- There is no conflict of interest related to this publication.
- Source of funding is authors.


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