Review Article

A Systematic Review of the Clinical Effectiveness of Cochlear Implant Surgery in Pediatric and Adult Patients

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Abstract

Hearing loss, also termed as hearing impairment, is an ailment where hearing is impaired partially or fully. About one in eight people suffer from hearing loss worldwide. The main aim of this current systematic review was to analyze the clinical effectiveness of cochlear implant (CI) surgery in pediatric and adult patients. The current study was carried out as a systematic review, following the PRISMA guidelines. We systematically searched PubMed, MEDLINE, EMBASE, and Google Scholar databases to identify eligible articles on the clinical effectiveness of CI surgery with the appropriate key terms (MeSH). This review included 73 studies which met the inclusion criteria. The studies included in unilateral CI in adults showed significant improvement in terms of perceptive abilities. Bilateral CI studies with respect to unilateral CI provide benefits in hearing in quiet conditions and sound localization. In the performance of post CI outcomes in patients, the age is not a determinant factor. CI is an effective aid in communication and speech perception for a majority of people with mild to severe hearing loss. Further studies are needed with large databases, patient registries for long term follow up details, higher quality reporting, and longer duration to develop stronger evidence.

Keywords: *Adult patients, bilateral CI, cochlear implants, hearing loss, pediatric patients, unilateral CI*

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Introduction

Worldwide, more than 550 million individuals suffer from hearing loss problems. About 60 million individuals experience severe hearing loss or worse.[1,2] One of the most important developments in modern medicine is cochlear implants (CIs).[3-4] CI surgery produces impressive outcomes, with many infants having a CI at an age younger than 12, experiencing typical language developments.[5] Previously, CI has been used predominantly in deaf children. Recently, pediatric and adult patients with, for example, progressive hearing loss following a middle ear operation, severe sensorineural hearing loss, and progressive hearing loss were also possible candidates to use CI.[6] The internal implantation surgery with the CI device is not completely risk-free and will cause complications that would need revision surgery, although CI surgery is a relatively low-risk procedure.[8]

Studies found that around 45% of people had symptoms of vertigo following implantation.[6,7] These complications associated with either device failure or foreign body implantation or surgical techniques.[3] Minor complications are treated by audiological interventions or conservatively with medical techniques such as nonauditory stimulations and wound infection. The middle air infection requiring revision surgery because of flap necrosis, permanent facial paralysis, electrode failure, meningitis, and implant site skin infection are the major complications of CI surgery.[9] Numerous research studies regarding the clinical effectiveness of CI surgery in pediatric and adult patients have been reported frequently.[10–12] However, a systematic review of these studies has been reported very limited

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in number,[13,14] and also, these studies were performed approximately 10 years ago. Additionally, to date, none of the systematic reviews was performed for the clinical effectiveness of CI surgery in both pediatric and adult patients. To connect this information gap and promote the research on CI surgery, an updated systematic review of the clinical effectiveness of CI surgery is essential. Thus, the main aim of this research was to identify the clinical effectiveness of unilateral CI and bimodal stimulation versus unilateral CI versus bilateral CI surgeries in pediatric and adult patients.

Materials and Methods

Study design

PRISMA guidelines were followed for this systematic review.[15]

Search strategy

A literature search was performed on the following databases: PubMed MEDLINE, Scopus, and Cochrane databases with the appropriate key terms (MeSH). We were looking specifically for articles on the clinical effectiveness of CI surgery. Different combinations of keywords were used for the search strategies and medical subject headings (MeSH) to generate two subsets of citations: one for "Cochlear Implant" using the MeSH and terms like "unilateral", "bilateral", and "bimodal stimulation" and the other for its management using terms and MeSH like surgery, resection, and bypass. In order to search other databases, the key words were changed according to each database's searching protocol including pediatric CI surgery, adults' CI surgery, CI surgery in children, unilateral CI surgery, bilateral CI surgery, and bimodal stimulation.

Inclusion and exclusion criteria

All original research articles published between 2000 and 2020 on the clinical effectiveness of CI surgery in the English language were included in this review. Exclusion criteria were (a) gray literature, including presented abstracts, letters to the editors, commentaries, systematic review, or meta-analysis articles; (b) unavailability of the full text of the article; and (c) non-English studies and studies published below the year 2000.

Strategy to assess the quality of studies

Two authors independently executed the article screening process and eligibility assessment. In case of some contradictions between the authors, the decision was made by an unbiased third party. The articles were initially screened on the basis of its title, followed by the abstract of the article. In case the title and abstract of the articles were irrelevant to the present investigation, these were excluded from the secondary screening.

Data extraction

In an initial literature search, a total of 2086 articles were found on the clinical effectiveness of CI surgery. Relevant articles were chosen for full-text screening after application of the eligibility criteria. The full-text-assessed articles were further excluded based on insufficient information related to the clinical effectiveness of CI surgery. The author's name and year, sample size, study design and age, devices, results, and outcomes were extracted from the selected articles.

Outcome measure

The main outcome measure of the current review is the clinical effectiveness of CI surgery (i.e., language and communication results and audiological results), followed by the type of CI surgery (i.e., unilateral, bilateral) and categorizations of patients (i.e., adults, pediatrics).

Results

Eligible studies

A total number of 2086 articles were yielded by literature search from various databases including Google Scholar, Ovid, PubMed, and Science Direct, of which 1574 articles were excluded at the initial stage due to repetition and irrelevance. Out of 512, 358 articles were further excluded after analysis of the titles and abstracts at the first screening level. A total of 154 potentially relevant articles have been selected for full-text assessments, of which 81 articles were further excluded as the studies related to cost-effective analysis (n = 42) and full texts cannot be accessed (n = 7), with review, a systematic review, and meta-analysis articles (n = 32). Finally, 73 studies on the CI surgery in the pediatric and adult patients were included in this current systematic review study as represented in the PRISMA flow chart [Figure 1].

Study characteristics

oAmong the included 73 articles in the current systematic review, 19 articles were on unilateral CI surgery in adult patients, 17 articles were on bilateral (sequential-simultaneous) CI surgery in adult patients, nine articles were on unilateral CI surgery on pediatric patients, and 28 articles were on bilateral (sequential-simultaneous) CI surgery in pediatric patients. The sample size of the bilateral (sequential-simultaneous) CI surgery on adult patients ranged from 7 to 164 patients, with a total of 536 patients. The sample size of the unilateral CI surgery on pediatric patients ranged from 3 to 47 patients, with a total of 168 patients. The sample size of the bilateral (sequential-simultaneous) CI surgery on pediatric patients ranged from 9 to 88 patients, with

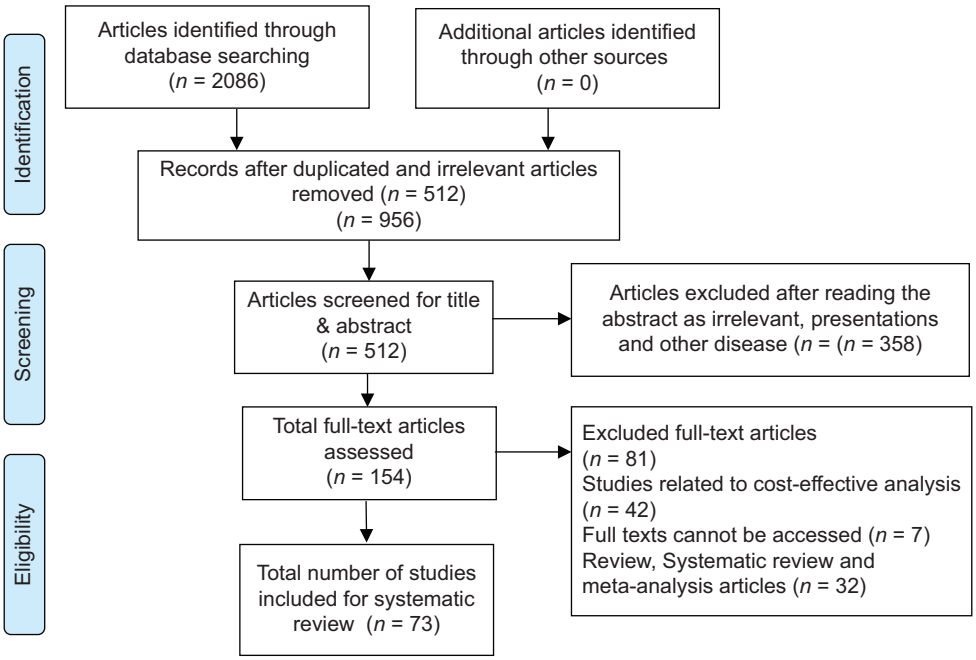

Figure 1: PRISMA flow chart

a total of 991 patients. The summary of the selected articles is represented in Table 1.

Unilateral CI surgery in adult patients

In adult patients with unilateral CI surgery, a total number of 19 articles were selected [Table 1]. All the included studies showed significant improvement in the perceptive abilities, followed by CI surgery. Several studies[17,20,23,27] reported perceptive results in elderly patients were lower when compared to younger patients. A study by Labadie *et al*.[16] obtained no statistically significant differences in the outcomes for both younger and older patients. Adults of all ages experienced improved perception of speech after a unilateral CI as demonstrated by various studies.[19,21,25,28,31] The results of the studies included in the review demonstrated that in the performance of post-CI outcomes in patients, the age is not a determinant factor. In adults patients, the quality of life showed a statistically significant improvement.[18] In contrast, Park *et al*.[24] reported quality of life improved markedly in all age groups, but it was not statistically significant. Roberts *et al*.[27] reported a family history in hearing loss had been related to a trend toward better recognition of speech. Dillon *et al*.[33] reported CI could deliver significant improvements in quality of life in cases of serious unilateral hearing loss (UHL). A different cutoff age was used by various studies. Obviously, these differences in age limit impact outcomes. Recently, Dixon *et al*.[34] reported clinically significant improvement was reported in patients with Tinnitus Handicap Inventory (THI). The most commonly used processing strategies/types of implants are shown in Figure 2.

Unilateral CI versus bimodal stimulation versus bilateral CI in adult patients

A total number of 17 articles were included on unilateral CI versus bimodal stimulation versus bilateral CI in adult patients. When compared to hearing in one CI only, significant improvement in hearing capacity in a silent condition was observed from bilateral CI use demonstrated by eight studies.[38,40,41,43-45,47,48] In a noisy environment, ten studies[36,38-41,43-46,48] observed significant improvement in hearing capacity from bilateral CI uses when compared to hearing in one CI only. Some studies demonstrated a statistically significant result. Seven studies[35,37,41,42,45,47,48] were seen in the localization capacity improvements of the sonorous source using two implants regarding the monaural condition. Two studies[1,46] compared the clinical effectiveness between bilateral and unilateral CIs in adults. The results of both studies demonstrated that the bilateral CI patient group significantly has better outcomes than patients with unilateral CI. The subjective advantages of using unilateral versus bilateral CI, as stated in the APHAB questionnaire, were identified in an analysis by Wackym *et al*.[43] A study by Huinck *et al*.[49] demonstrated both fulfilled conservative criteria, and outside this conservative criterion, patient groups demonstrated a beneficial impact of CI on quality of life. Bilateral CI studies with respect to unilateral CI provide benefits in hearing in quiet conditions and sound localization. However, elevated interindividual variation in the benefits obtained from the second implant is recorded. The

Table 1: Summary of the included studies on adult patients with unilateral CI

Author Name	Study design	Sample size and Age	Follow-up	Type of implant/ processing strategy	Results evaluated	Conclusions/opinions
Labadie *et al*.,[16]	Retrospective study	N 36, Younger 20; Mean age: 46.9 years, Older 16; Mean age: 71.5 years.	NR	Devices: Clarion Multi Strategy	Bisyllable words (CNC) and recognition of sentences (CID) Evaluation of perceptive abilities.	Between the two groups, there was no statistically significant difference in outcomes.
Chatelin *et al*.,[17]	Retrospective study	N 65 Age: > 70 years N 101 Age: < 65 years.	3-6-12 months	Clarion and Nucleus CI Devices	HINT, CNC, and CID verbal perception test	Elderly groups also benefited significantly from the CI procedure, but the results were slightly lower than those achieved by younger patients (statistically significant test CNC)
Orabi *et al*.,[18]	Retrospective study	N 34, Age: 65-80 years	9 and >21 months	Medel C40/Medel C40+/Nucleus CI24 Contour/Nucleus CI22/IC Nucleus CI24.	Audio logical performance tests for isolated words, words in sentences in quiet and noise. Functional outcome measures: expectation profiles, Glasgow Benefit inventory (GBI), Glasgow Health Status Inventory Questionnaire (GHSI), emotional and psychological aspects of quality of life, self-reported measures of the social.	Patient answers to the questionnaire indicated the improved quality of life. In open set auditory tests, when compared to preoperative scores, the postoperative scores showed a significant improvement. They compared the results with those in an implanted adult sample <65 yrs, and there were no statistically significant differences.
Chan *et al*.,[19]	Retrospective study	N 28 (Older adult CI users 14, Age: 56-77 years, Adults 14, Age: 18-53 years)	0 to 6 months, 0 to 12 months, and 0 to 24 months	Not specified	Hong Kong Speech Perception Test Manual. Test of verbal perception.	Similar benefit reported in both patient groups, regardless of age; on implant. Duration of deafness is reportedly more important
Poissant *et al*.,[20]	Clinical study	N 26 (CI users 9, Age: ≥70 years, CI users 8, Age: ≤60 years, HA users 9, Age: ≥70 years,)	NR	Devices: Clarion, Nucleus, Mede	Speech understanding scores in indicators of silence and noise and quality of life (Geriatric Depression Screening Scale, UCLA Loneliness Questionnaire)	There were no statistically significant differences for the three tests between the patients implanted before and after age 70 o. Patients undergoing CI after 70 years of age show an development in depression and loneliness
Noble *et al*.,[21]	Retrospective and Prospective study	N 202 (Retrospective: CI 68, CI+CI 36, and CI+HA 38, Age: < 60 years. Prospective: CI 30, CI+CI 18, and CI+HA 16, Age: > 60 years	Test administered 2 months before CI and >1 year after CI	Not specified	Word recognition, sound field localization test, Speech Spatial and Quality of Hearing Scale (SSQ), Hearing handicap Inventory for the Elderly, Hearing Handicap Questionnaire.	After implantation, all groups of patients show significant benefit. In both patient groups, no statistically significant differences were found o (in terms of age)

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Table 1: Contd...

Author Name	Study design	Sample size and Age	Follow-up	Type of implant/ processing strategy	Results evaluated	Conclusions/opinions
Williamson *et al*.,[22]	Retrospective study	N 28 (Group A 13, Age: 75-89 years), (Group B 15, Age: 65-78 years)	1 year	CI Nucleus devices (n=27), Esprit 3G, Freedom platforms, CI Clarion (n=1).	HINT, CNC, questionnaire for satisfaction. Comparison between results (questionnaire on pre- and post-CI satisfaction and verbal perception).	Scores were significantly better postoperatively in both groups with no significant differences according to age.
Friedland *et al*.,[23]	Case-control retrospective study	N 56 (28 patients Age: ≥ 65 years at CI. And 28 younger implanted pts (control group)	1 year	Not specified	Test of verbal perception: HINT-Q, HINT-N, CNC	Improvement shown in both groups. In HINT-Q and CNC, elderly patients obtain lower results when compare with youngers (statistically significant)
Park *et al*.,[24]	Retrospective study	N 161, (Age: <50, Male 23, Female 38, Age: 51-65 years, Male 19, Female 31, Age: <65, Male 20, Female 30)	2 year	Unilateral multichannel CI	Speech recognition: HINT, Quality of life: HHI	Significant improvement shown in speech recognition (HINT). Quality of life improved markedly in all age groups (HHI) (not statistically significant).
Amoodi *et al*.,[25]	Retrospective study	N 27, 14 male 13 female, Age: 26 to 89 years	12 months	Advanced Bionics Corp, Nucleus-Cochlear, and MedEl AG-Innsbruck	Speech recognition: HINT	Significant postoperative improvement shown in the study group for all outcome measures. Significant improvement of all patients perceived hearing-related disabilities (statistically significant).
Firszt *et al*.,[26]	Pilot Study	N 3, Male, Age: 56,57 and 62.	NR	Nucleus System 5, Frequency-modulated (FM), earphones	Subjective reports, temporal and spectral discrimination and localization of CI	The CI recipients with unilateral deafness obtained open-set speech recognition, improved localization, improved word recognition in noise, and improved perception of their ability to hear (statistically significant)
Roberts *et al*.,[27]	Retrospective study	N 113, (Younger adults: 46, Male 25: Female 21, Age: <65 years, Elder adults: 67, Male 37, Female 30, Age: >65 years)	5 months	Nucleus CI512/ Contour Advance, Cochlear Freedom/ Contour, AB HiRes 90K/HiFocus 1j, AB HiRes 90K/HiFocus Helix	Speech perception ability, CNC, family history of hearing loss on CI performance, history of noise exposure, and duration of hearing loss	Speech perception ability in CI users over 65 years of age was substantially lower than in younger adults. A hearing loss family history has been related to a trend toward better recognition of speech (not statistically significant).
Lachowska *et al*.,[28]	Retrospective study	N 30, (17 males, 13 females), Mean age: 76 years	2.74 years	Sound processor	Audio logical evaluation: Free-field audiometry, pure tone audiometry, and speech audiometry.	All patients have shown hearing benefits after implantation. There were no associations between postimplant results and

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Table 1: Contd...

Author Name	Study design	Sample size and Age	Follow-up	Type of implant/ processing strategy	Results evaluated	Conclusions/opinions
					Speech perception tests	age or preimplant hearing levels and voice audiometry. Age in deafened elderly patients is not a deciding or restricting factor for the success of post-CI outcomes.
Castiglione *et al*.,[29]	Retrospective study	N 30, (16 males and 14 females), Age: 65 to 79 years	NR	Not specified	Speech perception: speech detection threshold (SDT) and Speech recognition threshold (SRT). Threshold evaluation: pure tone average (PTA)	Cochlear implantation is a safe procedure even for the elderly, who can benefit significantly from improvements in hearing threshold and speech perception
Franko- Tobin *et al*.,[30]	Retrospective study	N 35, Mean age: 61.5 years	6 to 12 months	Devices: Med-El, Advanced Bionics, Cochlear	Sentence recognition, phoneme, and postimplantation word. Preoperative unaided pure-tone averages (PTAs), and Consonant Nucleus Consonant (CNC) words and sentence recognition scores were obtained	Asymmetric hearing patients and moderate low frequency hearing loss performed significantly better on speech recognition measures than our patients with severe to deep hearing loss or worse.
Sharpe *et al*.,[31]	Retrospective study	N 96, younger adults: 35 (11 male, 24 female), mean age: 38.3 years, older adults: 61 (33 male, 28 female), mean age: 72.3 years	1 year	Device: Cochlear Americas, MED-EL, Advanced Bionics	Word and sentence recognition: HINT, CNC-W and CNC-P.	All ages adults experience improved perception of speech after an unilateral CI.
Lenarz *et al*.,[32]	Prospective study	N 291 (Male 128, Female 163), Age: 13-81 years	2 months	Nucleus Freedom CI24RE (CA), Nucleus CI422, Nucleus CI512, Nucleus 24, Contour Advance and Nucleus Hybrid-CI24REH.	Health Utilities Index Mark 3 (HUI3) and Speech, Spatial, and Qualities of Hearing Scale (SSQ)	High significant improvements for all outcome indicators were observed. The HUI3 and SSQ showed substantial improvements in health-related quality of life and real-life hearing after group implantation
Dillon *et al*.,[33]	Prospective study	N 20, Age: 23-66 years	1, 3, 6, 9, and 12 months	CROS HA, Trans Ear device and BAHA	Abbreviated Profile of Hearing Aid Benefit (APHAB), and the Tinnitus Handicap Inventor. Speech, Spatial, and Qualities of Hearing Scale (SSQ),	CI can deliver significant improvements in quality of life in cases of serious UHL. At the pre- and postoperative intervals, the UHL cohort reported less perceived difficulties than the conventional CI and EAS cohorts. Each group had a significant advantage in the quality of life at APHAB with CI use.

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Table 1: Contd...

Author Name	Study design	Sample size and Age	Follow-up	Type of implant/ processing strategy	Results evaluated	Conclusions/opinions
Dixon *et al*.,[34]	Retrospective study	N 358, Male 170, Female 188, Mean age: 63.2 years	1 year	Not specified	HINT, Tinnitus Handicap Inventory (THI), 36-Item Short-Form Health Survey (SF-36), a generic measure of health-related quality of life (HRQoL)	Clinically significant improvement was reported in patients with THI. Worse residual hearing and greater baseline hearing and tinnitus disability are associated with higher probabilities of tinnitus improvement. Strong independent predictors of resolution were among adult patients with tinnitus and bilateral severe-to - profound hearing loss, worse residual hearing, and worse preimplant THI score

most commonly used processing strategies/types of implants are shown in Figure 3.

Unilateral CI surgery in pediatric patients

In pediatric patients with unilateral CI surgery, a total number of nine articles were included. Two studies[52,56] reported the improvement of speech recognition of patients in noisy conditions. The improvement of localization ability in children with unilateral CI was demonstrated by two studies.[51,52] A study by Hopyan-Misakyan *et al*.[50] reported right CI children could distinguish facial expressions but not prosody affective speech relative to controls. In the CI-alone condition, Deep *et al*.[57] observed a significant improvement of word recognition scores (WRSs) and also suggested CI in this self-chosen cohort is a viable treatment option for pediatric single-sided deafness (SSD). A longer period of CI use, surgery at a younger age, and better output of auditory voice processing affected success in verbal and receptive oral languages as reported by Scarabello *et al*.[10] The most commonly used processing strategies/types of implants are shown in Figure 4.

Unilateral CI versus bimodal stimulation versus bilateral CI in pediatric patients

A total number of 28 articles were selected on unilateral CI versus bimodal stimulation versus bilateral CI in pediatric patients. All the included studies demonstrated improvement obtained from bilateral CI stimulation as per unilateral CI stimulation except two studies.[59,80] Most of the studies obtained statistically significant results. Two studies[63,65] stated that the findings of the second CI exceeded those reported with the first implanted ear in several of the instances in which the second ear has been implanted at a younger age. Several studies[60,62] reported bilateral CI children with stronger outcomes in sound source localization. A significant improvement was shown in children treated with bilateral CI as reported by several studies.[58,62-64,66,74,81] Four studies[71,76,78,81] reported that the children with bilateral CI showed a significant result when compared to unilateral CI, whereas Escorihuela García *et al*.[80] demonstrated no significant differences between bilateral CI and unilateral CI. When compared to bimodal hearing, the bilateral CI demonstrated a good outcome in verbal perception as indicated through several studies.[58,60] Two studies conducted by Litovsky *et al*.[58,60] demonstrated that the benefits (in noise, sonorous source localization, and verbal perception) resulted from bilateral stimulation in both situations, but the benefits in bilateral CI patients were more apparent. Mok *et al*.[74] reported the benefits of bilateral stimulation while listening in a noisy atmosphere in both groups of patients, but a greater benefit was found in children utilizing bimodal stimulation on the second device. The summary of the included studies in this current review demonstrated that the bilateral CI provides benefits in hearing in a silent environment, sound localization, and hearing in noise compared to unilateral CI. The most commonly used processing strategies/types of implants are shown in Figure 5.

Discussion

CIs are an effective tool for overcoming hearing disabilities.[49,85,86] The key purpose of this current review is to assess the clinical effectiveness of CI surgery in pediatric and adult patients. The included studies on unilateral CI in adults showed significant improvement in the perceptive abilities, followed by CI surgery. Our study findings are similar to the previous systematic review by Gaylor *et al*.,[87] which reported that the

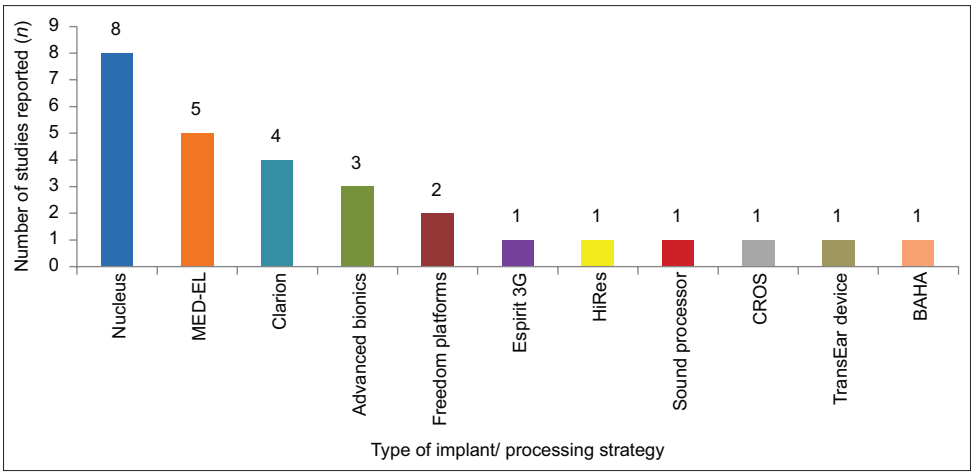

Figure 2: Types of implants/processing strategies used for adult patients with unilateral CI

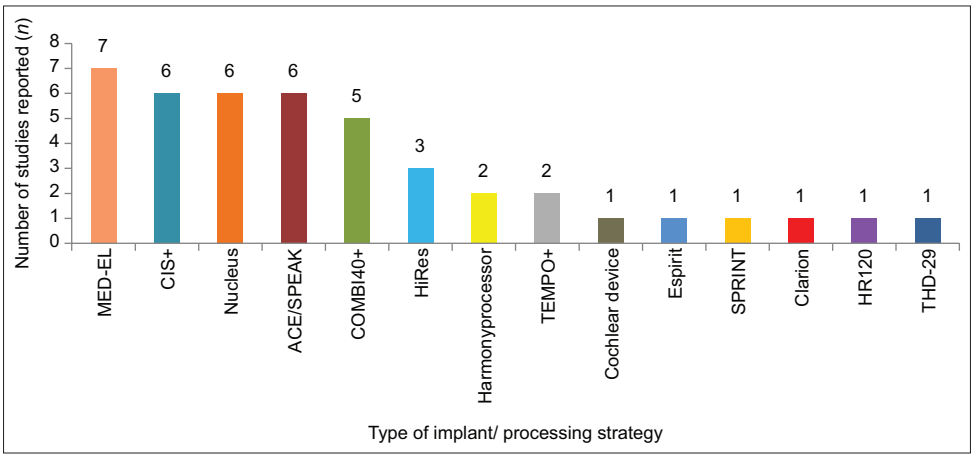

Figure 3: Types of implants/processing strategies used for adult patients with unilateral CI vs bimodal stimulation vs bilateral CI in pediatric patients

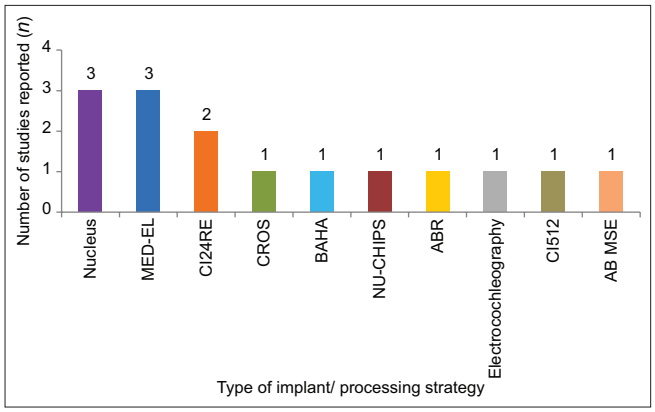

Figure 4: Types of implants/processing strategies used for pediatric patients with unilateral CI

unilateral CI significantly improved the hearing capacity in adult patients. In this study, the perceptive results in elderly patients are lower, when compared to youngers. Similarly, Roberts *et al.*[27] reported perceptions of speech ability were significantly poorer in older age patients compared to the younger adult patients.

The results of the studies included in the review demonstrated that, in the performance of post-CI outcomes in patients, the age is not a determinant factor. Similarly, several studies have found that older people benefit from CI, particularly in terms of quality of life and listening abilities.[16,88,89] Therefore, age is not a determinant or limiting factor in the performance of post-CI outcomes in patients. Likewise, in elderly patients, Lachowska *et al.*[28] confirmed that age is not a restricting factor for the post-CI result. This current systematic review demonstrated that bilateral CI in adult patients provides benefits in hearing in a silent environment, sound localization, and hearing in noise, when compared to unilateral CI. Similarly, a systematic review by Gaylor *et al.*[87] observed the significant improvements in sound localization, followed by bilateral CI in adult patients. This current review demonstrated when compared to unilateral CI, bilateral CI provides in pediatric patients benefits in hearing in a silent environment, sound localization, and hearing in noise. Our study findings are in agreement with the previous systematic review by Forli

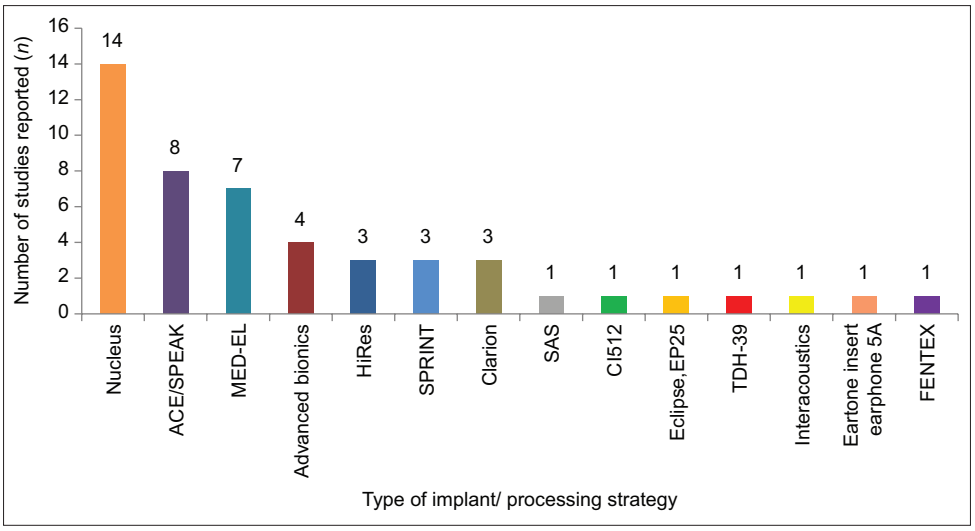

Figure 5: Types of implants/processing strategies used for pediatric patients with unilateral CI vs bimodal stimulation vs bilateral CI

et al.,[14] who reported that bilateral CI provides various advantages in pediatric patients including hearing in noise and quiet environment and sound localization compared to unilateral CI. Additionally, Strom-Roum *et al*.[76] reported bilateral CI showed statistically significant improvement in patients compared to unilateral CI.

The current systematic review has some limitations. The eligible articles included in the present systematic review regarding the clinical efficacy of CI surgery used a wide range of processing strategies and implant types. The variation points revealed that there had been a lack of standardized, universal, and acceptable treatment for the patients with hearing loss problems. The risk of bias assessment was not conducted in this review as the majority of the studies belong to different study designs. Despite these limitations, this updated systematic review provides an evidence-based report on the clinical efficacy of CI surgery in pediatric and adult patients.

Conclusion

Hearing loss is a common problem caused by heredity, disease, ageing, birth complications, and noise. CI has been a standard procedure for people with moderate to serious hearing impairment. People may still be dependent on others without an implant for even simple day-to-day activities. Therefore, CI is a beneficial treatment option for patients with complaints of hearing loss.

Keypoints

- A CI is a neuroprosthetic device which is surgically implanted to provide a modified sense of sound to a person with moderate to profound sensorineural hearing loss.
- Various factors are associated with poor outcomes of CI in patients, including receiving a CI in older age, developmental delay, and abnormal anatomy, specifically cochlea nerve (CN) and hypoplasia/ aplasia.
- Unilateral CI significantly improved the hearing capacity in adult patients.
- Bilateral CI studies with respect to unilateral CI provide benefits in hearing in quiet conditions and sound localization.
- In the performance of post-CI outcomes in patients, the age is not a determinant factor.

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Nil.

Conflicts of interest

There are no conflicts of interest.

References

1. Smulders YE, van Zon A, Stegeman I, Rinia AB, Van Zanten GA, Stokroos RJ, *et al*. Comparison of bilateral and unilateral cochlear implantation in adults. JAMA Otolaryngol Neck Surg 2016;142:249-56.
2. Stevens G, Flaxman S, Brunskill E, Mascarenhas M, Mathers CD, Finucane M. Global and regional hearing impairment prevalence: an analysis of 42 studies in 29 countries. Eur J Public Health 2013;23:146-52.
3. Farinetti A, Ben Gharbia D, Mancini J, Roman S, Nicollas R, Triglia J-M. Cochlear implant complications in 403 patients: Comparative study of adults and children and review of the literature. Eur Ann Otorhinolaryngol Head Neck Dis 2014;131:177-82.
4. National Institute on Deafness and Other Communication Disorders. Cochlear Implants; 2017.
5. Birman CS, Powell HRF, Gibson WPR, Elliott EJ. Cochlear implant outcomes in cochlea nerve aplasia and hypoplasia. Otol Neurotol 2016;37:438-45.
6. Louza J, Klappert CL, Ledderose G, Gürkov R, Krause E. Cochlear implant surgery and the risk of falls in an adult

population. Otol Neurotol 2018;39:e74-9.
7. McRackan TR, Reda FA, Rivas A, Noble JH, Dietrich MS, Dawant BM, *et al*. Comparison of cochlear implant relevant anatomy in children versus adults. Otol Neurotol 2012;33:328-34.
8. Amaral MSA do, Reis ACMB, Massuda ET, Hyppolito MA. Cochlear implant revision surgeries in children. Braz J Otorhinolaryngol 2019;85:290-6.
9. Ikeya J, Kawano A, Nishiyama N, Kawaguchi S, Hagiwara A, Suzuki M. Long-term complications after cochlear implantation. Auris Nasus Larynx 2013;40:525-9.
10. Scarabello EM, Lamônica DAC, Morettin-Zupelari M, Tanamati LF, Campos PD, Alvarenga KF, *et al*. Language evaluation in children with pre-lingual hearing loss and cochlear implant. Braz J Otorhinolaryngol 2020;86:91-8.
11. Gao Z, Wang S, Yang H, Feng G, Shang Y, Wang B, *et al*. Simultaneous bilateral cochlear implantation in children aged 12–18 months is safe and can be performed using standard cochlear implant surgical techniques. Eur Arch Otorhinolaryngol 2020;277:2193-7.
12. Cesur S, Derinsu U. Temporal processing and speech perception performance in postlingual adult users of cochlear implants. J Am Acad Audiol 2020;31:129-36.
13. Berrettini S, Baggiani A, Bruschini L, Cassandro E, Cuda D, Filipo R, *et al*. Systematic review of the literature on the clinical effectiveness of the cochlear implant procedure in adult patients. Acta Otorhinolaryngol Ital 2011;31:299-310.
14. Forli F, Arslan E, Bellelli S, Burdo S, Mancini P, Martini A, *et al*. Systematic review of the literature on the clinical effectiveness of the cochlear implant procedure in paediatric patients. Acta Otorhinolaryngol Ital 2011;31:281-98.
15. Moher D, Shamseer L, Clarke M, Ghersi D, Liberati A, Petticrew M, *et al*. Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. Syst Rev 2015;4:1.
16. Labadie RF, Carrasco VN, Gilmer CH, Pillsbury HC. Cochlear implant performance in senior citizens. Otolaryngol Neck Surg 2000;123:419-24.
17. Chatelin V, Kim EJ, Driscoll C, Larky J, Polite C, Price L, *et al*. Cochlear implant outcomes in the elderly. Otol Neurotol 2004;25:298-301.
18. Orabi AA, Mawman D, Al-Zoubi F, Saeed SR, Ramsden RT. Cochlear implant outcomes and quality of life in the elderly: Manchester experience over 13 years1. Clin Otolaryngol 2006;31:116-22.
19. Chan V, Tong M, Yue V, Wong T, Leung E, Yuen K, *et al*. Performance of older adult cochlear implant users in Hong Kong. Ear Hear 2007;28(Supplement):52S-5S.
20. Poissant SF, Beaudoin F, Huang J, Brodsky J, Lee DJ. Impact of cochlear implantation on speech understanding, depression, and loneliness in the elderly. J Otolaryngol Head Neck Surg 2008;37:488-94.
21. Noble W, Tyler RS, Dunn CC, Bhullar N. Younger- and older-age adults with unilateral and bilateral cochlear implants. Otol Neurotol 2009;30:921-9.
22. Williamson RA, Pytynia K, Oghalai JS, Vrabec JT. Auditory performance after cochlear implantation in late septuagenarians and octogenarians. Otol Neurotol 2009;30:916-20.
23. Friedland DR, Runge-Samuelson C, Baig H, Jensen J. Case-control analysis of cochlear implant performance in elderly patients. Arch Otolaryngol Neck Surg 2010;136:432-8.
24. Park E, Shipp DB, Chen JM, Nedzelski JM, Lin VYW. Postlingually deaf adults of all ages derive equal benefits from unilateral multichannel cochlear implant. J Am Acad Audiol 2011;22:637-43.
25. Amoodi HA, Mick PT, Shipp DB, Friesen LM, Nedzelski JM, Chen JM, *et al*. Results with cochlear implantation in adults with speech recognition scores exceeding current criteria. Otol Neurotol 2012;33:6-12.
26. Firszt JB, Holden LK, Reeder RM, Waltzman SB, Arndt S. Auditory abilities after cochlear implantation in adults with unilateral deafness. Otol Neurotol 2012;33:1339-46.
27. Roberts DS, Lin HW, Herrmann BS, Lee DJ. Differential cochlear implant outcomes in older adults. Laryngoscope 2013;123:1952-6.
28. Lachowska M, Pastuszka A, Glinka P, Niemczyk K. Benefits of cochlear implantation in deafened adults. Audiol Neurotol 2014;19:40-4.
29. Castiglione A, Benatti A, Girasoli L, Caserta E, Montino S, Pagliaro M, *et al*. Cochlear implantation outcomes in older adults. Hear Balanc Commun 2015;13:86-8.
30. Franko-Tobin E, Camilon PR, Camposeo E, Holcomb MA, Meyer TA. Outcomes of cochlear implantation in adults with asymmetric hearing loss. Otol Neurotol 2015;36:409-15.
31. Sharpe RA, Camposeo EL, Muzaffar WK, Holcomb MA, Dubno JR, Meyer TA. Effects of age and implanted ear on speech recognition in adults with unilateral cochlear implants. Audiol Neurotol 2016;21:223-30.
32. Lenarz T, Muller L, Czerniejewska-Wolska H, Vallés Varela H, Orús Dotú C, Durko M, *et al*. Patient-related benefits for adults with cochlear implantation: A multicultural longitudinal observational study. Audiol Neurotol 2017;22:61-73.
33. Dillon MT, Buss E, Rooth MA, King ER, Deres EJ, Buchman CA, *et al*. Effect of cochlear implantation on quality of life in adults with unilateral hearing loss. Audiol Neurotol 2017;22:259-71.
34. Dixon PR, Crowson M, Shipp D, Smilsky K, Lin VY, Le T, *et al*. Predicting Reduced Tinnitus Burden After Cochlear Implantation in Adults. Otol Neurotol 2020;41:196-201.
35. Nopp P, Schleich P, D'Haese P. Sound localization in bilateral users of MED-EL COMBI 40/40+cochlear implants. Ear Hear 2004;25:205-14.
36. Schleich P, Nopp P, D'Haese P. Head shadow, squelch, and summation effects in bilateral users of the MED-EL COMBI 40/40+ cochlear implant. Ear Hear 2004;25:197-204.
37. Verschuur CA, Lutman ME, Ramsden R, Greenham P, O'Driscoll M. Auditory localization abilities in bilateral cochlear implant recipients. Otol Neurotol 2005;26:965-71.
38. Ramsden R, Greenham P, O'Driscoll M, Mawman D, Proops D, Craddock L, *et al*. Evaluation of bilaterally implanted adult subjects with the nucleus 24 cochlear implant system. Otol Neurotol 2005;26:988-98.
39. Ricketts TA, Grantham DW, Ashmead DH, Haynes DS, Labadie RF. Speech recognition for unilateral and bilateral cochlear implant modes in the presence of uncorrelated noise sources. Ear Hear 2006;27:763-73.
40. Litovsky R, Parkinson A, Arcaroli J, Sammeth C. Simultaneous bilateral cochlear implantation in adults: A multicenter clinical study. Ear Hear 2006;27:714-31.
41. Tyler RS, Dunn CC, Witt SA, Noble WG. Speech perception and localization with adults with bilateral sequential cochlear implants. Ear Hear 2007;28(Supplement):86S-90S.
42. Neuman AC, Haravon A, Sislian N, Waltzman SB. Sound-direction identification with bilateral cochlear implants. Ear Hear 2007;28:73-82.
43. Wackym PA, Runge-Samuelson CL, Firszt JB, Alkaf FM, Burg LS. More challenging speech-perception tasks demonstrate

binaural benefit in bilateral cochlear implant users. Ear Hear 2007;28(Supplement):80S-5S.
44. Eapen RJ, Buss E, Adunka MC, Pillsbury HC, Buchman CA. Hearing-in-noise benefits after bilateral simultaneous cochlear implantation continue to improve 4 years after implantation. Otol Neurotol 2009;30:153-9.
45. Mosnier I, Sterkers O, Bebear J-P, Godey B, Robier A, Deguine O, *et al*. Speech performance and sound localization in a complex noisy environment in bilaterally implanted adult patients. Audiol Neurotol 2009;14:106-14.
46. Dunn CC, Noble W, Tyler RS, Kordus M, Gantz BJ, Ji H. Bilateral and unilateral cochlear implant users compared on speech perception in noise. Ear Hear 2010;31:296-8.
47. Reeder RM, Firszt JB, Holden LK, Strube MJ. A longitudinal study in adults with sequential bilateral cochlear implants: Time course for individual ear and bilateral performance. J Speech Lang Hear Res 2014;57:1108-26.
48. Kraaijenga VJC, Ramakers GGJ, Smulders YE, van Zon A, Stegeman I, Smit AL, *et al*. Objective and subjective measures of simultaneous vs sequential bilateral cochlear implants in adults. JAMA Otolaryngol Neck Surg 2017;143:881-90. Erratum in: JAMA Otolaryngol Head Neck Surg 2017;143:960.
49. Huinck WJ, Mylanus EAM, Snik AFM. Expanding unilateral cochlear implantation criteria for adults with bilateral acquired severe sensorineural hearing loss. Eur Arch Otorhinolaryngol 2019;276:1313-20.
50. Hopyan-Misakyan TM, Gordon KA, Dennis M, Papsin BC. Recognition of affective speech prosody and facial affect in deaf children with unilateral right cochlear implants. Child Neuropsychol 2009;15:136-46.
51. Hassepass F, Aschendorff A, Wesarg T, Kröger S, Laszig R, Beck RL, *et al*. Unilateral deafness in children: audiologic and subjective assessment of hearing ability after cochlear implantation. Otol Neurotol. 2013;34:53-60.
52. Távora-Vieira D, Rajan GP. Cochlear implantation in children with congenital and noncongenital unilateral deafness. Otol Neurotol 2015;36:235-9.
53. Távora-Vieira D, Rajan GP. Cochlear implantation in children with congenital unilateral deafness: Mid-term follow-up outcomes. Eur Ann Otorhinolaryngol Head Neck Dis 2016;133:S12-4.
54. Sadadcharam M, Warner L, Henderson L, Brown N, Bruce IA. Unilateral cochlear implantation in children with a potentially useable contralateral ear. Cochlear Implants Int 2016;17(Suppl 1):55-8.
55. Beck RL, Aschendorff A, Hassepaß F, Wesarg T, Kröger S, Jakob TF, et al. Cochlear Implantation in Children With Congenital Unilateral Deafness: A Case Series. Otol Neurotol. 2017;38:e570-6.
56. Thomas JP, Neumann K, Dazert S, Voelter C. Cochlear implantation in children with congenital single-sided deafness. Otol Neurotol 2017;38:496-503.
57. Deep NL, Gordon SA, Shapiro WH, Waltzman SB, Roland JT Jr, Friedmann DR. Cochlear Implantation in Children with Single-Sided Deafness. Laryngoscope 2021;131:E271-7.
58. Litovsky RY, Johnstone PM, Godar S, Agrawal S, Parkinson A, Peters R, *et al*. Bilateral cochlear implants in children: Localization acuity measured with minimum audible angle. Ear Hear 2006;27:43-59.
59. Schafer EC, Thibodeau LM. Speech recognition in noise in children with cochlear implants while listening in bilateral, bimodal, and FM-system arrangements. Am J Audiol 2006;15:114-26.
60. Litovsky RY, Johnstone PM, Godar SP. Benefits of bilateral cochlear implants and/or hearing aids in children. Int J Audiol 2006;45(suppl 1):78-91.
61. Scherf F, van Deun L, van Wieringen A, Wouters J, Desloovere C, Dhooge I, *et al*. Hearing benefits of second-side cochlear implantation in two groups of children. Int J Pediatr Otorhinolaryngol 2007;71:1855-63.
62. Beijen J-W, Snik AFM, Mylanus EAM. Sound localization ability of young children with bilateral cochlear implants. Otol Neurotol 2007;28:479-85.
63. Wolfe J, Baker S, Caraway T, Kasulis H, Mears A, Smith J, *et al*. 1-Year postactivation results for sequentially implanted bilateral cochlear implant users. Otol Neurotol 2007;28:589-96.
64. Galvin KL, Mok M, Dowell RC. Perceptual benefit and functional outcomes for children using sequential bilateral cochlear implants. Ear Hear 2007;28:470-82.
65. Peters BR, Litovsky R, Parkinson A, Lake J. Importance of age and postimplantation experience on speech perception measures in children with sequential bilateral cochlear implants. Otol Neurotol 2007;28:649-57, S1-2.
66. Zeitler DM, Kessler MA, Terushkin V, Roland TJ Jr, Svirsky MA, Lalwani AK, *et al*. Speech perception benefits of sequential bilateral cochlear implantation in children and adults: A retrospective analysis. Otol Neurotol 2008;29:314-25.
67. Galvin KL, Mok M, Dowell RC, Briggs RJ. Speech detection and localization results and clinical outcomes for children receiving sequential bilateral cochlear implants before four years of age. Int J Audiol 2008;47:636-46.
68. Scherf F, Van Deun L, van Wieringen A, Wouters J, Desloovere C, Dhooge I, *et al*. Subjective benefits of sequential bilateral cochlear implantation in young children after 18 months of implant use. ORL J Otorhinolaryngol Relat Spec 2009;71:112-21.
69. Gordon KA, Papsin BC. Benefits of short interimplant delays in children receiving bilateral cochlear implants. Otol Neurotol 2009;30:319-31.
70. Scherf F, Van Deun L, van Wieringen A, Wouters J, Desloovere C, Dhooge I, *et al*. Three-year postimplantation auditory outcomes in children with sequential bilateral cochlear implantation. Ann Otol Rhinol Laryngol 2009;118:336-44.
71. Lovett RES, Kitterick PT, Hewitt CE, Summerfield AQ. Bilateral or unilateral cochlear implantation for deaf children: An observational study. Arch Dis Child 2010;95:107-12.
72. Galvin KL, Hughes KC, Mok M. Can adolescents and young adults with prelingual hearing loss benefit from a second, sequential cochlear implant? Int J Audiol 2010;49:368-77.
73. Van Deun L, van Wieringen A, Scherf F, Deggouj N, Desloovere C, Offeciers FE, *et al*. Earlier intervention leads to better sound localization in children with bilateral cochlear implants. Audiol Neurootol 2010;15:7-17.
74. Mok M, Galvin KL, Dowell RC, McKay CM. Speech perception benefit for children with a cochlear implant and a hearing aid in opposite ears and children with bilateral cochlear implants. Audiol Neurotol 2010;15:44-56.
75. Eustaquio ME, Berryhill W, Wolfe JA, Saunders JE. Balance in children with bilateral cochlear implants. Otol Neurotol 2011;32:424-7.
76. Strøm-Roum H, Laurent C, Wie OB. Comparison of bilateral and unilateral cochlear implants in children with sequential surgery. Int J Pediatr Otorhinolaryngol 2012;76:95-9.
77. Grieco-Calub TM, Litovsky RY. Spatial acuity in 2-to-3-year-old children with normal acoustic hearing, unilateral cochlear implants, and bilateral cochlear implants. Ear Hear 2012;33:561-72.
78. Boons T, Brokx JP, Frijns JH, Peeraer L, Philips B, Vermeulen A, *et al*. Effect of pediatric bilateral cochlear implantation on language development. Arch Pediatr Adolesc

Med 2012;166:28 34.
79. Marsella P, Giannantonio S, Scorpecci A, Pianesi F, Micardi M, Resca A. Role of bimodal stimulation for auditory perceptual skills development in children with a unilateral cochlear implant. Ter Arkh 2005;35:442-8.
80. Escorihuela García V, Pitarch Ribas MI, Llópez Carratalá I, Latorre Monteagudo E, Morant Ventura A, Marco Algarra J. Comparative study between unilateral and bilateral cochlear implantation in children of 1 and 2 years of age. Acta Otorrinolaringol (English Ed. 2016;67:148-55.
81. Jacobs E, Langereis MC, Frijns JH, Free RH, Goedegebure A, Smits C, *et al*. Benefits of simultaneous bilateral cochlear implantation on verbal reasoning skills in prelingually deaf children. Res Dev Disabil 2016;58:104-13.
82. Bianchin G, Tribi L, Formigoni P, Russo C, Polizzi V. Sequential pediatric bilateral cochlear implantation: The effect of time interval between implants. Int J Pediatr Otorhinolaryngol 2017;102:10-4.
83. Dhondt CMC, Swinnen FKR, Dhooge IJM. Bilateral cochlear implantation or bimodal listening in the paediatric population: Retrospective analysis of decisive criteria. Int J Pediatr Otorhinolaryngol 2018;104:170-7.
84. Nassiri AM, Yawn RJ, Brown CL, O'Malley MR, Bennett ML, Labadie RF, *et al*. Unilateral versus bilateral cochlear implantation in children with auditory neuropathy spectrum disorder (ANSD). Otol Neurotol 2018;39:e810-6.
85. Geers AE. Predictors of reading skill development in children with early cochlear implantation. Ear Hear 2003;24:59S-68S.
86. Nikolopoulos TP, Lloyd H, Starczewski H, Gallaway C. Using SNAP Dragons to monitor narrative abilities in young deaf children following cochlear implantation. Int J Pediatr Otorhinolaryngol 2003;67:535-41.
87. Gaylor JM, Raman G, Chung M, Lee J, Rao M, Lau J, *et al*. Cochlear implantation in adults: A systematic review and meta-analysis. JAMA Otolaryngol Neck Surg 2013;139:265-72.
88. Vermeire K, Brokx JPL, Wuyts FL, Cochet E, Hofkens A, Van de Heyning PH. Quality-of-life benefit from cochlear implantation in the elderly. Otol Neurotol 2005;26:188-95.
89. Pasanisi E, Bacciu A, Vincenti V, Guida M, Barbot A, Berghenti MT, *et al*. Speech recognition in elderly cochlear implant recipients. Clin Otolaryngol Allied Sci 2003;28:154-7.