Evidence-based Speech-Language Pathology and Audiology
Fonoaudiologia Baseada em Evidências

Systematic analysis of the benefits of cochlear implants on voice production

Análise sistemática dos benefícios do uso do implante coclear na produção vocal

Ana Cristina Coelho[1]
Alcione Ghedini Brasolotto[2]
Maria Cecília Bevilacqua[2]

Keywords

Voice
Voice quality
Voice disorders
Hearing disorders
Cochlear implantation

ABSTRACT

Purpose: To perform a systematic analysis of the research regarding vocal characteristics of hearing impaired children or adults with cochlear implants. **Research strategy:** A literature search was conducted in the databases Web of Science, Bireme, and Universidade de São Paulo's and CAPES' thesis and dissertations databases using the keywords voice, voice quality, and cochlear implantation, and their respective correspondents in Brazilian Portuguese. **Selection criteria:** The selection criteria included: title consistent with the purpose of this review; participants necessarily being children or adults with severe to profound pre-lingual or post-lingual hearing loss using cochlear implants; and data regarding participants' performance on perception and/or acoustic analysis of the voice. **Results:** Twenty seven papers were classified according to the levels of evidence and quality indicators recommended by the American Speech-Language-Hearing Association (ASHA). The designs of the studies were considered of low and medium levels of evidence. Six papers were classified as IIb, 20 as III, and one as IV. **Conclusion:** The voice of hearing impaired children and adults with cochlear implants has been little studied. There is not an effective number of studies with high evidence levels which precisely show the effects of the cochlear implantation on the quality of voice of these individuals.

Descritores

Voz
Qualidade da voz
Distúrbios da voz
Transtornos da audição
Implante coclear

RESUMO

Objetivo: Realizar uma revisão sistemática de pesquisas relacionadas às características vocais de crianças ou adultos com deficiência auditiva usuários de implante coclear. **Estratégias de pesquisa:** Foi realizada uma busca com os descritores voz, qualidade da voz e implante coclear, e seus respectivos correspondentes na língua inglesa, nas bases de dados *Web of Science,* Bireme, portal de teses e dissertações da USP e banco de teses e dissertações da CAPES. **Critérios de seleção:** Os critérios adotados incluíram título condizente com a proposta deste estudo, casuística necessariamente englobando crianças ou adultos com deficiência auditiva de grau severo a profundo, pré ou pós-linguais, usuários de implante coclear e que tenham passado por análise perceptivo-auditiva e/ou acústica da qualidade vocal. **Resultados:** Vinte e sete trabalhos foram classificados seguindo-se os níveis de evidências e indicadores de qualidade empregados pela *American Speech-Language-Hearing Association* (ASHA). Os desenhos dos trabalhos analisados foram considerados de média e baixa evidência científica. Seis trabalhos foram classificados como nível de evidência IIb, 20 como III, e um como IV. **Conclusão:** A qualidade vocal da criança ou adulto com deficiência auditiva usuário de implante coclear tem sido estudada em pequena escala. Não há um número efetivo de estudos com alto índice de evidência que demonstrem com precisão os efeitos do implante coclear na qualidade vocal desses indivíduos.

Correspondence address:
Ana Cristina Coelho
Faculdade de Odontologia de Bauru, Clínica de Fonoaudiologia
Al. Dr. Octávio Pinheiro Brisolla, 09/75, Vl. Altinópolis, Bauru (SP), Brasil, CEP: 17012-901.
E-mail: anacrisccoelho@yahoo.com.br

Received: 3/5/2012

Accepted: 7/17/2012

Study performed at the Graduate Program in Speech-Language Pathology and Audiology, Bauru School of Dentistry, Universidade de São Paulo – USP – Bauru (SP), Brazil.
(1) Graduate Program (Master's degree) in Speech-Language Pathology and Audiology, Bauru School of Dentistry, Universidade de São Paulo – USP – Bauru (SP), Brazil.
(2) Department of Speech-Language Pathology and Audiology, Bauru School of Dentistry, Universidade de São Paulo – USP – Bauru (SP), Brazil.
Conflict of interests: None

INTRODUCTION

The main focus of the speech-language pathologist's work with individuals who are deaf and hard of hearing does not always include voice production. However, the vocal alteration can represent a very negative impact, interfering on speech intelligibility and decisively compromising social integration[1].

The cochlear implant (CI) provides global benefits on hearing perception, and consequently on expressive and receptive language, including improved vocal quality. It results on the optimization of speech perception, and therefore on the verbal communication of its users. Hence, the CI is known to be one of the most promising and effective technologies to remedy hearing loss[2,3].

Extensive literature shows that the cochlear implant, in addition to all the hearing benefits, brings also great advantages for voice production. The most reported findings are improved noise and perturbation measures[4-7], phonatory control[4-7], fundamental frequency[5,8], roughness and strain[9], and pitch[10]. However, some studies did not find significant changes on the voice production of individuals who are deaf and hard of hearing and use cochlear implants[11-13].

A literature review directed to the methodological aspects of these papers may help to understand these results, and serve as a guideline to what needs to be better explored. The present investigation is a systematic review, which consists on the application of scientific strategies that aim the critical evaluation and synthesis of a large number of studies on a given topic. Its relevance is the ability to condense and summarize results of several studies, producing different quantitative and qualitative indicators on the topic researched[14-16].

OBJECTIVE

The purpose of this study was to perform a systematic review of researches related to the vocal characteristics of children and adults who are deaf or hard of hearing and use cochlear implants.

RESEARCH STRATEGY

To perform this systematic review, we followed the concepts of the online course promoted by the Brazilian Cochrane Center and by the Laboratory of Distance Learning – LED-DIS of the Department of Health Informatics of Universidade Federal de São Paulo/Escola Paulista de Medicina, available at http://www.virtual.epm.br/cursos/valida.php. The literature review was based on the question "What are the effects of cochlear implants on the voice of individuals who use this device?"

To search for studies, we used three key-words from the Health Science Descriptors (DeCS) and four key-words from the Medical Subject Heading Terms (MeSH). The DeCS terms used were "*voz"* (voice), "*qualidade da voz"* (quality of voice) and "*implante coclear"* (cochlear implant). The MeSH terms were "voice", "voice quality", "cochlear implant" and "cochlear implantation". We used different combinations of these terms (Chart 1), with the connector "AND".

Chart 1. Combination of the DeCS and MeSH descriptors used in the bibliographic search

DeCS descriptors	MeSH descriptors
Voz and *Implante coclear*	Voice and Cochlear implants
Voice and Cochlear implantation	Voice and Cochlear implantation
Qualidade da voz and *Implante coclear*	Voice quality and Cochlear implants
Quality of voice and Cochlear implantation	Voice quality and Cochlear implantation

The bibliographic research (Table 1) was performed in the databases Web of Science (www.isiknowledge.com); Bireme – Virtual Health Library - BVS (www.bireme.br), comprising the databases LILACS, MEDLINE, Cochrane Library, SciELO and IBECS; Digital library of theses and dissertations of the Universidade de São Paulo (http://www.teses.usp.br/); and CAPES's digital library of theses and dissertations (www.capes.gov.br/servicos/banco-de-teses). There was no restriction regarding the publication year.

SELECTION CRITERIA

A pre-selection of all the publications/studies whose title seemed to be related to the question proposed in this systematic review was performed. To be analyzed, the study should

Table 1. Number of publications found per database according to the descriptor

Descriptors	BVS (Lilacs, Medline, SciELO, Cochrane Library, IBECS)	Web of Science	USP Database	CAPES Database	Total
Voz and *Implante coclear*	35	-	2	0	37
Qualidade da voz and *Implante coclear*	19	-	0	0	19
Quality of voice and Cochlear implantation	42	-	0	0	42
Voice and Cochlear implantation	76	605	0	0	681
Voice quality and Cochlear implantation	-	362	-	-	362
Voice and Cochlear implants	-	964	-	-	964
Voice quality and Cochlear implants	-	566	-	-	566

necessarily include children or adults with severe to profound hearing loss, pre- or post-lingual, using cochlear implants. Another selection criterion was the performance of auditory-perceptual and/or acoustic analysis of the voice of the CI users.

We excluded duplicated publications (85), publications whose full texts were not found (13), whose language was not Portuguese or English (15) and whose content did not correspond to the purpose of this review (2354). At the end of the search, 27 relevant publications remained for the systematic review, which included a letter to the editor and two master's thesis. The others referred to published studies, 2 performed in Brazil and 22 in other countries.

DATA ANALYSIS

All the publications were analyzed and classified following the levels of evidence employed by ASHA in 2004, adapted from the Scottish Intercollegiate Guideline (Chart 2). Moreover, the studies were analyzed based on a proposal[16,17] of eight quality indicators to evaluate studies, which include: the study design, blinding, sampling/allocation, group/participant comparability, outcomes, significance, precision and intention to treat.

Chart 2. Levels of evidence (ASHA, 2004)

Level	Description
Ia	Well-designed meta-analysis of more than one randomized controlled trial
Ib	Well-designed randomized controlled study
IIa	Well-designed controlled study without randomization
IIb	Well-designed quasi-experimental study
III	Well-designed non-experimental studies, i.e., correlational and case studies
IV	Expert committee report, consensus conference, clinical experience of respected authorities

RESULTS

Regarding the levels of evidence, six studies were classified as IIb, 20 as III, and 1 as IV. The designs of the studies found were considered of good and lower scientific levels, although it is important to consider that non-experimental studies have great value for understanding a certain subject.

Regarding the quality indicators, 23% of the studies are quasi-experimental and 77% are non-experimental; 66.67% present groups that are comparable and adequately described; 70.78% present valid and reliable outcomes; in 85%, the confidence interval is calculable and the p-value is reported; there are evidence of randomization and blinded assessors in 29.62% of the publications. The intention to treat[6,7] was not considered, since this indicator applies only for controlled trials.

The heterogeneity of the methods used in the studies makes it difficult to understand how the use of cochlear implants can benefit the vocal quality of individuals who are deaf and hard of hearing. The results of the studies are diverse and often controversial (Chart 4). In many cases, the importance of understanding the voice of the individual with a CI is not clear.

Although all the studies unanimously report that the use of the CI provide some benefit for voice production, the reports of these benefits are inconsistent. Factors such as the advantages provided by the CI for voice production, improving oral communication and how these advantages can help in a therapeutic process, or even how they can be considered as one of the many criteria to decide which device will be used, are not well described.

Chart 3. List of the studies by title, authors, year, description and level of evidence

Title	Authors	Year	Description	LE
Clarion cochlear implant: short-term effects on voice parameters	Monini, Banci, Barbara, Argiro and Filipo[18]	1997	Non-experimental study	III
Effect of cochlear implantation on nasality in post-lingually deafened adults	Langereis, Dejonckere, van Olphen and Smoorenburg[19]	1997	Non-experimental study	III
Effect of cochlear implantation on voice fundamental frequency in post-lingually deafened adults	Langereis, Bosman, van Olphen and Smoorenburg[20]	1998	Non-experimental study	III
Evaluation of cochlear implanted children's voices	Perrin, Berger-Vachon, Topouzkhanian, Truy and Morgon[21]	1999	Non-experimental study	III
A case study of the speech, language and vocal skills of a set of monozygous twin girls: one twin with a cochlear implant	Bell, Hickson, Woodyatt and Dornan[22]	2001	Non-experimental study	III
Changes of voice and articulation in children with cochlear implants	Seifert, Oswald, Bruns, Vischer, Kompis and Haeusler[23]	2002	Non-experimental study	III
Changes in vowel quality after cochlear implantation	Schenk, Baumgartner and Hamzavi[24]	2003	Non-experimental study	III
Comparison of overall intelligibility, articulation, resonance and voice characteristics between children using cochlear implants and those using bilateral hearing AIDS: a pilot study	Van Lierde, Vinck, Baudonck, De Vel and Dhooge[25]	2005	Quasi-experimental study	IIb

Chart 3. continuation

Title	Authors	Year	Description	LE
Acoustic analysis of the voice in pediatric cochlear implant recipients: a longitudinal study	Campisi, Low, Papsin, Mount R, Cohen-Kerem and Harrison[5]	2005	Non-experimental study	III
The influence of cochlear implantation on some voice parameters	Hocevar-Boltezar, Vatovec, Gros and Zargi[4]	2005	Non-experimental study	III
Acoustic and perceptual appraisal of speech production in pediatric cochlear implant users	Poissant, Peters and Robb[11]	2006	Non-experimental study	III
Change of phonation control after cochlear implantation	Hocevar-Boltezar, Radsel, Vatovec, Geczy, Cernelc, Gros, Zupancic, Battelino, Lavrencak and Zargi[26]	2006	Quasi-experimental study	III
Multidimensional voice program analysis in profoundly deaf children: quantifying frequency and amplitude control	Campisi, Low, Papsin, Mount and Harrison[10]	2006	Non-experimental study	III
Voice and pronunciation of cochlear implant speakers	Horga and Liker[9]	2006	Non-experimental study	III
Voice analysis in pediatric cochlear implant recipients	Campisi[27]	2006	Clinical experience of respected authorities	IV
Prosody and voice characteristics of children with cochlear implants	Lenden and Flipsen Jr[28]	2007	Non-experimental study	III
Acoustic voice analysis of prelingually deaf adults before and after cochlear implantation	Evans and Deliyski[8]	2007	Non-experimental study	III
Relationship between voice and speech perception in children with cochlear implants	Coelho, Bevilacqua, Oliveira and Behlau[1]	2009	Non-experimental study	III
Vocal singing by prelingually-deafened children with cochlear implants	Xu, Zhou, Chen, Li, Scultz and Zhao[29]	2009	Non-experimental study	III
Acoustic analysis of voice in cochlear implant recipients with post-meningitic hearing loss	Allegro, Papsin, Harrinson and Campisi[30]	2009	Non-experimental study	III
Abnormal voicing in children using cochlear implants	Holler, Campisi, Allegro and Chadha[31]	2010	Non-experimental study	III
The influence of the auditory prosthesis type on deaf children's voice quality	Valero, Rovira and Sanvicens[12]	2010	Quasi-experimental study	IIb
Voice analysis of deaf before and after cochlear implantation	Ubrig-Zancanella[6]	2010	Quasi-experimental study	IIb
Objective vocal quality in children using cochlear implants: a multiparameter approach	Baudonk, D'haeseller; Dhooge and Van Lierde[13]	2011	Quasi-experimental study	IIb
Voice analysis of postlingually deaf adults pre- and postcochlear implantation	Ubrig, Goffi-Gomez; Weber; Menezes and Nmer[7]	2011	Quasi-experimental study	IIb
Classification of voice disorder in children with cochlear implantation and hearing aid using multiple classifier fusion	Mahmoudi, Rahati, Ghasemi Asadpour and Tayarani[32]	2011	Non-experimental study	III
Effect of different speech processors coding strategies on the voice of children with cochlear implants	Coelho[33]	2011	Quasi-experimental study	IIb

Note: LE = level of evidence

We noticed predominant use of Kay Elemetrics' softwares (48.14%) in case of acoustic analysis of the voice signal as a part of the methodology. Eight studies (29.62%) involved auditory-perceptual evaluation of the voice, all with evidence of randomized samples and blinded raters. One study considered the different types of cochlear implants in the evaluated population.

CONCLUSION

With this review, it was possible to observe that the quality of voice of children and adults who are deaf and hard of hearing and use cochlear implants has been studied on a small scale. There is not an effective number of studies with high levels of evidence that demonstrate precisely the effects of the cochlear

Chart 4. List of the publications by title, population, objectives and outcomes

Title	Population	Objectives	Outcomes
Clarion cochlear implant: short-term effects on voice parameters[18]	6 adults and 3 children with CI	Evaluate the phonatory control immediately after the activation of Clarion implants	The participants showed a lowering of voice intonation, a better control of voice intensity and a reduction of the nasal quality
Effect of cochlear implantation on nasality in postlingually deafened adults[19]	21 adults with CI	Access the nasality before the CI and after 3 and 12 months of use	The use of CI significantly improved nasality
Effect of cochlear implantation on voice fundamental frequency in post-lingually deafened adults[20]	20 adults with CI	Evaluate the fundamental frequency before, 3 months and 12 months after implantation	Mostly, the F_0 values were reduced, reaching normative ranges. However, the authors found large interindividual variability
Evaluation of cochlear implanted children's voices[21]	4 children with CI and 4 normal hearing children	Compare the voice of CI children with the voice of corresponding normal children	The authors found differences only on vowel duration
A case study of the speech, language and vocal skills of a set of monozygous twin girls: one twin with a cochlear implant[22]	1 child with CI and 1 normal hearing child	Compare the communication skills of a set of monozygous twins: one with CI and the other with normal hearing	The analysis of the voice of the implanted twin indicated abnormalities in all the acoustic and perceptual parameters in comparison to the other
Changes of voice and articulation in children with cochlear implants[23]	20 children with CI	Investigate the fundamental frequency and formants of children with CI in comparison to normal hearing children	The authors found that the children who received a CI before their fourth birthday attain better acoustic control of speech, with normal F_0 and improved vowel articulation
Changes in vowel quality after cochlear implantation[24]	10 adults with CI	Investigate F_0 and formants of adults using CI	The authors found improvement of the parameters after 3 and 12 months of implantation
Comparison of the overall intelligibility, articulation, resonance and voice characteristics between children using cochlear implants and those using bilateral hearing AIDS: a pilot study[25]	9 children with CI and 6 children with hearing aids	Compare the oral communication of children with CI and conventional hearing aids	The authors found differences only in the articulation, which is better for users of CI
Acoustic analysis of the voice in pediatric cochlear implant recipients: a longitudinal study[5]	21 children with CI	Evaluate acoustic features of children with CI	The authors did not find differences on the F_0 and on the control of frequency, however the control of amplitude was restored
The influence of cochlear implantation on some voice parameters[4]	31 children with CI	Investigate changes in some voice parameters after cochlear implantation	The F_0 did not change significantly. However, jitter and shimmer improved as early as 6 months after the implantation and the noise-to-harmonic ration improved 2 years after the implantation in children who had received the CI before reaching four years of age
Acoustic and perceptual appraisal of speech production in pediatric cochlear implant users[11]	6 children with CI	Examine chances in voice production immediately following a disruption in auditory feedback provided by the CI	The authors observed changes in the F_0, formants and vowel articulation, which are better with the implant on
Change of phonation control after cochlear implantation[26]	29 children and 11 adults with CI	Access the influence of the use of CI on some voice parameters	The parameters analyzed were significantly more deviated in children, however they presented greater improvement of these parameters then the adults after using the implant
Multidimensional voice program analysis in profoundly deaf children: quantifying frequency and amplitude control[10]	21 children and teenagers with CI	Characterize the vocal profile of children with CI from an acoustic point of view	The authors found values of F_0, jitter, shimmer, and formants within normative measures. Amplitude and frequency variability were high

Chart 4. continuation

Title	Population	Objectives	Outcomes
Voice and pronunciation of cochlear implant speakers[9]	10 children with hearing aids, 10 children with CI and 10 normal hearing children	Compare vocal features of normal hearing children with users of CI and conventional hearing aids	The vocal features of the CI users were closer to the normal hearing children's, mainly regarding asthenia and breathiness
Voice analysis in pediatric cochlear implant recipients[27]	-	-	-
Prosody and voice characteristics of children with cochlear implants[28]	6 children with CI	Describe vocal and prosodic characteristics of children with CI	The authors found alterations in speech rate, intonation, loudness and resonance
Acoustic voice analysis of prelingually deaf adults before and after cochlear implantation[8]	3 adults with CI and 3 normal hearing adults	Explore changes of voice and speech pre and postimplantation over 6 months	There was great variability among the participants, but the most striking features were reduction of the f_0 and better resonance
Relationship between voice and speech perception in children with cochlear implants[1]	25 children with CI	To relate the speech perception abilities with the vocal characteristics of children with CI	The authors found that the better the speech recognition, the better frequency control, intensity, overall severity and resonance
Vocal singing by prelingually-deafened children with cochlear implants[29]	7 children with CI and 14 normal hearing children	Evaluate the vocal control of children with CI during singing in comparison to normal hearing children	The children with CI did not have difficulties with rhythm, but presented poor control of the frequency
Acoustic analysis of voice in cochlear implant recipients with post-meningitic hearing loss[30]	10 children with CI	Investigate the relationship between duration of auditory deprivation and the control of voice production in post-menigitic children	The long-term control of frequency was within normal limits for subjects with a period of auditory deprivation of less than four months. Measures of long-term amplitude was normal for all participants, except those with cochlear ossification
Abnormal voicing in children using cochlear implants[31]	27 children with bilateral CI	Measure acoustic voice outcomes in children with bilateral CI and to compare these with established norms	The children presented poor control of long-term amplitude and long-term frequency perturbation
The influence of the auditory prosthesis type on deaf children's voice quality[12]	54 normal hearing children, 35 with hearing aids and 35 with CI	Compare the vocal quality of children with CI, hearing aids and normal hearing	The groups with hearing impairment presented altered values of F_0 and shimmer. The group with digital hearing aids presented better values of F_0, jitter and shimmer in relation to the group with analogue hearing aids and the group with CI
Voice analysis of deaf before and after cochlear implantation[6]	40 adults with CI and 12 with hearing aids	Verify if there are changes in vocal parameters after cochlear implantation, without specific vocal rehabilitation	The authors found statistically significant reduction in overall severity, strain, loudness, instability, F_0 and F_0 variability. The hearing aid users showed no statistically significant changes in most of the parameters
Objective vocal quality in children using cochlear implants: a multiparameter approach[13]	36 children with CI, 25 with hearing aids and 25 with normal hearing	Determine the objective vocal quality in users of CI and compare it with hearing aid users and normal hearing children	The authors found dysphonia severity index close to normality in CI users. The children with CI presented mild roughness, strain, high pitch and increased loudness in comparison to the normal hearing children. No differences were found regarding the acoustic measures between the groups
Voice analysis of postlingually deaf adults pre- and postcochlear implantation[7]	40 adults with CI and 12 with hearing aids	Longitudinally investigate whether the use of CI changes perceptual and acoustic parameters in adults, comparing them with users of hearing aids	Opposite to the hearing aid users, the users of CI presented significant improvement of the overall severity, strain, loudness and instability

Chart 4. continuation

Title	Population	Objectives	Outcomes
Classification of voice disorder in children with cochlear implantation and hearing aid using multiple classifier fusion[32]	18 children with CI or hearing aids and 12 normal hearing children	Develop and evaluate automated classification of voice disorders in children with cochlear implantation and hearing aids	The protocol rated these children's voices over time with nonlinear analysis, and demonstrated improvement of voice parameters with the hearing devices
Effect of different speech processors coding strategies on the voice of children with cochlear implants[33]	50 children with CI and 25 with normal hearing	Compare the voices of children who use different speech coding strategies among themselves and with normal hearing children	Users of the strategy Advanced Combination Encoder presented vocal features closer to the voices of normal hearing children

implant on the quality of voice of children and adults who are deaf and hard of hearing.

To improve the quality of the studies regarding scientific evidence, the studies must be carefully designed, with a significant number of participants, according the possibilities of the centers in which they are performed. Moreover, a methodology based on the quality indicators proposed by ASHA should be adopted in future studies about the theme.

AKLOWLEDGEMENTS

The authors would like to thank the São Paulo Research Foundation (FAPESP), for the financial support, process nº. 2008/07948-1.

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