

# The voice of the hearing impaired: a literature review

## A voz do deficiente auditivo: revisão bibliográfica

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Eliana Maria Gradim Fabron\*

Yasmin Sakimoto Garcia\*

Eliane Maria Carrit Delgado-Pinheiro\*

### Abstract

**Introduction** Hearing loss can affect aspects related to voice, due to changes in vocal control caused by reduced or absent auditory feedback. **Objective:** To present a review on the voice of the hearing impaired over the last 12 years. **Methods** The literature was conducted on articles available at the Lilacs, Scielo and Pubmed / Medline databases with the following keywords: voice, hearing impairment, voice quality, deafness, hearing aids and cochlear implants, and words in the English language during the period from 2003 to 2015. **Results** the terms used in the study were crosswise and present in 829 articles. From this total, 157 articles were relevant to the study. By the inclusion and exclusion criteria, 26 articles were selected. From the ones selected for this review, 13 address the cochlear implant issue; seven deal with the use of cochlear implant and the hearing aid (HA) in the same study; four refer exclusively to the topic and two showed data on hearing impaired participants without electronic device. **Conclusion** The results show the prevalence of studies associated with the vocal quality of cochlear implant users, emphasizing different aspects, such as onset of hearing loss, the time of sensory deprivation and rehabilitation approach, among others, as important factors for the development of acoustic feedback necessary for monitoring voice. They also emphasize the good results obtained by cochlear implant users, in regards to the vocal aspects.

**Keywords:** Cochlear Implantation; Hearing Aids; Hearing Loss; Voice Quality

\*Universidade Estadual Paulista - UNESP - Marília - SP - Brasil

**Authors' contributions:** EMGF Participation in the design, the acquisition, interpretation and analysis of data, as well as writing and critical review of the work. YSG Participation in the acquisition, interpretation and analysis of the data, as well as in the writing of the work. EMCDP Participation in the interpretation and analysis of data, as well as writing and critical review of the work.

**Correspondence address:** Eliana Maria Gradim Fabron - elianaf@marilia.unesp.br

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## Resumo

**Introdução** A deficiência auditiva pode afetar os aspectos relacionados à voz, devido a alterações no controle vocal ocasionado pelo feedback auditivo reduzido ou ausente. **Objetivo** Apresentar uma revisão bibliográfica sobre a voz do deficiente auditivo, ao longo dos últimos 12 anos. **Método** O levantamento bibliográfico foi realizado em artigos disponíveis nas bases de dados Lilacs, Scielo e Pubmed/Medline, com as seguintes palavras-chave: voz, deficiência auditiva, qualidade vocal, surdez, auxiliares de audição e implante coclear, e as palavras respectivas da língua inglesa, durante o período de 2003 a 2015. **Resultados** Os termos foram utilizados de forma cruzada, sendo registrados 829 artigos. Desse total, 157 artigos eram pertinentes ao estudo. Pelos critérios de inclusão e exclusão foram selecionados 26 artigos. Destes selecionados para a presente revisão, 13 abordam o tema implante coclear; sete tratam do uso de implante coclear e do aparelho de amplificação sonora individual (AASI), no mesmo estudo; quatro se referem exclusivamente ao tema AASI e dois apresentam dados sobre participantes deficientes auditivos sem dispositivo eletrônico. **Conclusão** Os resultados demonstram a prevalência de estudos associados à qualidade vocal de usuários de implante coclear, enfatizando diferentes aspectos, como início da perda auditiva, o tempo de privação sensorial e a abordagem de reabilitação, entre outros, como importantes fatores para o desenvolvimento do feedback acústico necessário para o monitoramento da voz. Destacam também os resultados satisfatórios obtidos por usuários de implante coclear, quanto aos aspectos vocais.

**Palavras-chave:** Implante Coclear; Auxiliares de Audição; Perda Auditiva; Qualidade Vocal

## Resumen

**Introducción:** La deficiencia auditiva puede afectar a los aspectos relacionados a la voz, debido a alteraciones en el control vocal ocasionado por el feedback auditivo reducido o ausente. **Objetivo:** Presentar una revisión bibliográfica sobre la voz del deficiente auditivo en los últimos 12 años. **Método:** El análisis bibliográfico fue realizado en artículos disponibles en las bases de datos Lilacs, Scielo y Pubmed/Medline, con las siguientes palabras-clave: voz, deficiencia auditiva, calidad vocal, sordera, auxiliares de audición e implante coclear (IC), y las palabras respectivas de la lengua inglesa, durante el período de 2003 a 2015. **Resultados:** Los términos fueron utilizados de manera cruzada, siendo registrados 829 artículos. De ese total, 157 artículos eran pertinentes al estudio. Por los criterios de inclusión y exclusión fueron seleccionados 26 artículos. De estos seleccionados para la presente revisión, 13 abordan el tema implante coclear; siete tratan del uso de implante coclear y del aparato de amplificación sonora individual (AASI), en el mismo estudio; cuatro se refieren exclusivamente al tema AASI y dos presentan datos sobre participantes deficientes auditivos sin dispositivo electrónico. **Conclusión:** Los resultados demuestran la prevalencia de estudios asociados a la calidad vocal de usuarios de implante coclear, enfatizando diferentes aspectos, como inicio de la pérdida auditiva, el tiempo de privación sensorial y el abordaje de rehabilitación, entre otros, como importantes factores para el desarrollo del feedback acústico necesario para el monitoreo de la voz. Destacan también los resultados satisfactorios obtenidos por usuarios de implante coclear, con relación a los aspectos vocales.

**Palabras clave:** Implantación Coclear; Audifonos; Pérdida Auditiva; Calidad de la Voz

## Introduction

Hearing impairment may manifest as partial or total hearing loss, which may be congenital or acquired, altering the ability to understand speech due to sensory deprivation. Thus, the presence of hearing loss may affect oral communication develop-

ment not only in reception, but also in expression, namely in aspects related to speech and voice<sup>1</sup>.

There are three processes involved in phonation: the production of the glottal sound by the vibration of the vocal folds which react to passage of expiratory air, the resonance and the articulation of the sound that occurs in the articulators. The anatomical structures and the physiological processes

involved in phonation are preserved in the hearing impaired. However, the absence or reduction of acoustic feedback may result in alterations in the vocal quality of the hearing impaired.

Individuals with no hearing alterations feature feedback suitable for voice control and monitoring, considering the parameters of duration, fundamental frequency (F0) and the formants necessary for vowel production. However, individuals with alterations in the auditory system, especially in cases in which hearing loss is classified as severe to profound, may present an increase in the average f0 and not hear their own voice due to the absence of auditory feedback<sup>2</sup>.

Vocal characteristics may vary according to the degree of hearing loss, the type of electronic device used, the age of the adaption to the hearing aid (HA) or activation of the cochlear implant (CI), as well as depending on whether the period in which the hearing loss occurred was prelingual or post-lingual<sup>3</sup>.

There are various alterations that may be present in the vocal production of the hearing impaired, mainly: hoarseness, breathiness, high pitch, monotony, roughness, tension, abrupt vocal attack, excessive variation of loudness, unpleasant quality, vocal fatigue, altered breathing pattern, absence of rhythm, decreased power, reduced tonal range, resonance imbalance, and even unintelligible speech<sup>4</sup>. In addition, the hearing-impaired child may present nasality due to the posteriorized position of the tongue caused by the laryngeal tension, interfering with the resonance quality<sup>5</sup>.

Electronic devices such as the HA and the CI enable access to speech sounds, thus allowing the development of auditory function, oral communication, and improvements in the production process of the voice in hearing impaired individuals<sup>6</sup>. Studies were developed with the goal of comparing the vocal characteristics of hearing-impaired children who use a HA and CI<sup>7,8</sup>.

With the technological advances in hearing aids and the emergence of cochlear implant, it was observed that hearing-impaired children and adolescents are able to have a balanced voice production due to the auditory feedback provided by these electronic devices<sup>1,4</sup>.

The aspects linked to the vocal quality of hearing-impaired individuals have been of great interest to speech therapists who work in the areas of voice and educational audiology. The biblio-

graphical research allows one to search scientific literature studies that indicate the modifications of the vocal standard for the hearing impaired over the years with the technological advancement.

The objective of this study was to conduct a bibliographical research on the voice of the hearing impaired over the past 12 years.

## Methods

Bibliographical research was conducted on the voice of the hearing impaired in articles from journals, both national and international, available in the databases for the period between 2003 and 2015. Only the studies that met the established criteria were included.

### Search Criteria

#### - Databases

The search for articles was conducted in specialized journals, both national and international, in the databases *Lilacs*, *SciELO*, and *Pubmed/Medline*. The research was performed in stages, the first of which was the survey of articles in the referred databases, specifically in each base.

#### - Criteria for inclusion and exclusion

The criteria for inclusion of the articles were: studies that addressed the voice of the hearing impaired with prelingual or post-lingual loss, studies with individuals that use a Hearing Aid or have a Cochlear Implant and articles written in Portuguese and in English. The criteria for exclusion were: studies that were associated with hearing loss in the elderly, aspects exclusively on speech and syndromes, and bibliographical review articles.

#### - Descriptors and selection of articles

The keywords selected for the survey of articles were determined from a search of the Health Science Descriptors. The following keywords were chosen: voice, vocal quality, hearing loss, deafness, cochlear implant and hearing aids, both in English and Portuguese.

The keywords were organized, combining a keyword from the area of voice with another from the area of hearing, as for example: voice x hearing loss; voice x deafness; voice x cochlear implant; voice x hearing aids; vocal quality x hearing loss; vocal quality x deafness; vocal quality x cochlear implant and vocal quality x hearing aids, both in

English and Portuguese. In this phase, two researchers analyzed the summaries of each of the articles to see if there was any relation to the topic of interest.

In the organization of the data, the number of articles that resulted from each crossed term was counted. The articles that repeated in relation to the previous survey and which new articles were related to the present study were measured.

#### - Classification of the articles

After the selection and inclusion of articles, it was possible to delimit the subjects in which the same would be classified for the final analysis, namely:

- Cochlear implant: in this category all the studies that described any type of CI, with or without specifications (model, speech processor and processing strategies) were grouped together;
- HA: all studies of hearing aid users were grouped together;
- CI and HA: studies of those using CI and Hearing Aids were grouped together;
- Other studies in which articles on individuals with hearing impairment with no specification on the type of electronic device were then grouped together.

After classification, the data were organized according to the date of publication, the authors, the casuistry, the objectives and the results.

## Results

From the search conducted in the databases *Scielo*, *Lilacs*, and *Pubmed/Medline* 829 articles were discovered. Of the total articles, 45 were found in the databases of *Scielo*, 39 from *Lilacs*, and 745 from *Pubmed/Medline*. From this total, the summaries were read and 157 articles pertinent to the present study were selected. Nine articles were discarded as they did not meet the inclusion

criteria, as well as 25 articles that did not make the full texts available, thus resulting in 123 articles. It is worth mentioning that 97 articles repeated between the databases.

After the analysis of the articles, 26 texts relating to the topic covered in this study were selected. Of the 26 articles selected for this review, 13 addressed the topic of cochlear implant, 7 dealt with the use of the cochlear implant and hearing aids in the same study, 4 referred exclusively to the Hearing Aid and 2 presented data on hearing-impaired participants with no electronic device.

Some articles showed the results of the analysis of vocal quality and the prosodic resources used in the speech of the hearing impaired. However, in this study we will only discuss the results related to the vocal quality.

The articles that address the voice of one who has a cochlear implant are presented in Chart 1. It can be observed that in this modality, 4 articles did not specify the type of CI, while 9 specified the model.

Chart 2 refers to the studies whose topic was related to the voice of those using hearing aids, both bilateral and unilateral; however, these studies did not specify the model of the device.

Chart 3 organized the articles that studied the vocal quality of those using hearing aids and CI, making comparisons among themselves or comparing the results of the study with those of individuals with normal hearing. From these articles, 3 made no specification of the implant or the hearing aid used. One article specifies the type of hearing aid, but not the CI. Another identifies the type of CI but not the hearing aid, whereas the last two specify the models of CI and the type of rehabilitation with the hearing aid.

Chart 4 groups the studies in which there were no specifications of using a hearing aid or CI.

**Chart 1.** Studies that address the use of cochlear implants

Cochlear Implant	Year	Authors	Casuistry	Objectives	Results
CI – Not specified (n=4)	2014	Hsu, Fang, Lee, Tsou, Chen, Wu <sup>9</sup>	Thirty-five prelingual hearing-impaired children using a CI were selected from the cochlear implant center at the Chang Gung Memorial Hospital (17 males and 18 females between 8 and 12.3 years old). All of them received implants between 1.4 and 6.7 years old and had been using the CI for more than 2 years.	Compare the differences in the vocal quality between hearing-impaired children using a CI that speak Mandarin and their peers with normal hearing. In addition, understand which parameters of CI use may predict unfavorable results for the voice.	In this study it can be observed that inadequate post-operative rehabilitation may hinder the normalization of voice quality of implant patients. A multidimensional analysis can accurately evaluate the voice of children with implant. The authors draw attention to the necessity of carrying out different forms of validation of this type of analysis, including data from other languages and other institutions.
	2012	Souza, Bevilacqua, Brasolotto Coelho <sup>10</sup>	Thirty-six children with severe to profound bilateral sensorineural hearing loss from 3 years and 3 months to 5 years and 9 months, and 25 normal-hearing children between 3 years and 11 months and 6 years and 6 months	Compare perceptual and acoustic parameters of vocal aspects in children using CI and those of normal-hearing children	The data showed that the vocal parameters analyzed in the voices of children with CI, in the most part are similar to the parameters of normal-hearing children.
	2011	Ubrig, Goffi-Gomez, Weber, Menezes, Nemr, Tsuji e Tsuji <sup>11</sup>	The Experimental Group (EG) consisting of 20 males (27 to 60 years old) and 20 females (23 to 60 years old) with post-lingual hearing loss that received CI. The Control Group (CG) with the same characteristics of the EG consisting of 6 males (21 to 52 years old) and 6 females (31 to 56 years old) who were in the evaluation process to receive CI.	Verify whether the CI, with no specific vocal rehabilitation, is associated with changes in the perceptual and acoustic vocal parameters in adults with severe to profound post-lingual deafness.	In the EG the perceptual-auditory assessment showed a significant reduction in the overall degree of vocal alteration, in the tension, loudness, and instability, after 6 to 9 months using the CI. In the vocal acoustic analysis there was significant reduction of f0 in the males and improved variation of f0 in both sexes. The CG did not present the same improvement in the vocal quality when comparing the values between the first and second evaluation.
	2010	Holler, Campisi, Allegro, Chadha, Harrison, Papsin, Gordon <sup>12</sup>	Twenty-seven children (17 boys and 10 girls) from 3 to 15 years old, using bilateral CI, with implantation time varying from 0.3 to 9.8 years, with use of the second implant at an average of 1.3 years.	Analyze acoustic measures of the voice in children with bilateral cochlear implant and compare them with normative data from literature, as well as determine whether these acoustic measures were influenced by the time of use of the implant and age of implantation.	Children with bilateral CI presented varied results of acoustic parameter analysis, but overall, with alterations. However, the vocal control improved with increased time of auditory experience, and there was a positive relationship between the pitch and time of exposure to sound.
CI multichannel (n=1)	2006	Lenden, Flipsen Jr <sup>13</sup>	Six children (5 girls and 1 boy) with severe to profound prelingual hearing loss using CI	Analyze prosody and voice characteristics in children with CI.	The children presented difficulties regarding vocal tension, resonance, speech velocity, intensity and laryngeal quality, but there was no difficulty with phrasing and pitch. The findings suggest that the prosody and the vocal characteristics of spontaneous speech of children with CI have smaller alterations than those historically described in children with profound hearing impairment.

Cochlear Implant	Year	Authors	Casuistry	Objectives	Results
CI multichannel Nucleus 24-16 children Med El C40+- 13 children and Nucleus 24 - 2 adults e Med El C40 +- 9 adults (n=1)	2006	Hocevar-Boltezar, Radsel, Vatovec, Geczy Cernelc, Gros, Zupancic, Battelino, Lavrencak, Zargi <sup>3</sup>	Twenty-nine children (14 girls and 15 boys) with prelingual loss and 11 adults (6 men and 5 women) with profound post-lingual hearing loss.	Evaluate the influence of acquired auditory control in some vocal parameters in hearing-impaired children and adults after use of CI	Children with prelingual hearing impairment displayed greater values of jitter, shimmer, f0 variation, and amplitude variation in relation to adults with post-lingual hearing impairment, before and after the implant. The f0 value did not vary after implantation in both hearing-impaired groups. The children presented greater phonation control after a period of 6 to 12 months of implantation. Unlike in adults, there was no significant improvement in any of the parameters studied.
CI Nucleus 24 - 9 subjects and Nucleus 22 - 1 subject (n=1)	2010	Allegro, Papsin, Harrison, Campisi <sup>14</sup>	Ten people (7 girls and 3 boys) with a mean age of 7.2 years.	Evaluate the critical period between the beginning of sensorineural hearing loss and the placement of the CI in relation to normal voice production in children with post-meningitis hearing impairment.	The f0, the short and long term amplitude and frequency variation was within the limits of normalcy for individuals with an auditory deprivation period less than 4 months. The amplitude variation was not within the standard for those with cochlear ossification. It can be concluded that the factors that interfere in the results presented were: absence of cochlear ossification, early resumption to hearing, residual hearing with Hearing Aid and therapeutic process.
CI Nucleus 24 (n=2)	2011	Hassan, Malki, Mesallam, Farahat, Bukhari, Murry <sup>15</sup>	Thirty-five adults with post-lingual hearing loss with a mean age of 36, divided into 2 groups: A = 17 people (10 men and 7 women) with 6 years or less of hearing loss, and B= 18 people (11 men and 7 women) with more than 6 years of loss. The 2 groups were sub-divided into individuals that participated or not in post-operative rehabilitation programs.	Study the effect of the CI following post-operative rehabilitation in individuals with post-lingual hearing loss with different duration times of loss.	There was significant difference in the vocal parameters of individuals with implants in relation to the normal data from MDVP - Multidimensional Voice Program. The results from group B were inferior to those from group A, the sooner the placement of the CI, better the performance in vocal quality. The authors stated that speech and hearing therapy may improve the quality of life of these patients.
	2009	Coelho, Bevilacqua, Oliveira, Behlau <sup>4</sup>	Twenty-five children using CI ages between 5 and 10 years old.	Relate the speech perception skills with vocal characteristics in children with CI.	Children with better perception of speech sound present smaller deviations from vocal quality observed by perceptual-auditory assessment.





Cochlear Implant	Year	Authors	Casuistry	Objectives	Results
Unilateral, multi channel CI (n=2)	2012	An, Kim, Chung <sup>16</sup>	Twelve children with prelingual loss (9 boys and 3 girls) with unilateral CI.	Investigate the relationship between acoustic analysis and speech intelligibility before and after CI.	Ten children had a high degree of speech intelligibility before and after CI, so that hearing did not influence the voice analysis in the preoperative phase. There was a significant positive correlation between the values of preoperative shimmer and speech intelligibility after 12 months of CI use. The same occurred with the value of jitter; however, it was not statistically significant.
	2005	Hocevar-Boltezar, Vatovec, Gros, Zargi <sup>17</sup>	Thirty-one children (16 boys and 15 girls) with prelingual hearing loss, where 15 received implantation before the age of 4 and 16 after.	Investigate the alterations in some of the voice parameters in deaf children after the cochlear implant.	After the CI, the value of f0 did not change significantly, however, the values for jitter and shimmer improved the earlier the implantation (up to 6 months). The noise-to-harmonics ratio improved 24 months after CI. In children who received implant after the age of 4, the f0 changed after 12 months of the implantation and the shimmer after 24 months. The best conditions occurred in children with implantation before the age of 4.
CI Nucleus 24 contour and Contour Advance (n=1)	2005	Campisi, Low, Papsin, Mount, Cohen-Kerem, Harrison <sup>18</sup>	Twenty-one children with severe to profound hearing loss (15 prelingual and 6 post-lingual).	Characterize vocal abnormalities in deaf children and the effect in restoring auditory feedback with the cochlear implant.	The activation of the CI between 2 and 6 months did not produce alteration in the f0. In profound hearing-impaired children, the most altered acoustic parameters were the values of frequency and amplitude variations; however, there was a normalization of amplitude control. The results indicate that after implantation, additional rehabilitation is necessary.
CI Nucleus 22 (n=1)	2003	Higgins, McCleary, Carney, Schulte <sup>19</sup>	Seven prelingual hearing-impaired children who were submitted to CI, ages between 5 and 10 years. The children initially used the Mini-Speech processor; 5 of the 7 children updated the processor to Spectra and all the children received early education with Total Communication.	The proposals of this study were: 1 – Describe physiological characteristics of speech in prelingual hearing-impaired children before and after CI. 2 – Determine whether articulation deviations and phonatory behavior in children with CI persist even though, in the long run, they used the CI and participated in aural rehabilitation. 3 – Determine whether there is a development of other phon-articulatory deviations after the implantation.	Values of Intraoral pressure, voice onset time, and f0 were studied. Children with implants after 5 years old and who used Total Communication displayed variances in speech and voice, before and after CI. Such deviations persisted for many years after the cochlear implant.

**Chart 2.** Studies that address the use of Individual Hearing Aid

Hearing Aid	Year	Authors	Casuality	Objectives	Results
Uni or bilateral (n=3)	2013	Lee, Liu, Lee <sup>20</sup>	Sixteen participants (9 men and 7 women) with severe to profound prelingual hearing loss, with ages from 16 to 36 years. The periods of initial hearing loss were all before the age of 3 and all participants used Hearing Aids.	Investigate the responses to auditory-verbal feedback of f0 with amplification in severe to profound prelingual hearing loss, using the power spectral analysis of f0 contours of sustained vowels.	The results showed that the increased vocal intensity and amplification significantly improved the vocal control for f0, reducing low frequency fluctuations (low energy frequency, 0.2 to 3 Hz) in the spectrum of f0.
	2008	Lopes, Oliveira, Cárnio <sup>21</sup>	Eighteen participants using Hearing Aids, from 12 to 17 years old and severe to profound bilateral sensorineural hearing loss acquired up to 12 months.	Evaluate the voice of deaf individuals after the application of therapeutic procedure with visual feedback	The statistically significant results demonstrated that there was a reduction of the modal and maximum fundamental frequency, reduction of the jitter and shimmer, and an increase of phonation times after therapeutic procedure.
	2006	Campisi, Low, Papsin <sup>22</sup>	Twenty-one individuals (9 men, 12 women) between 3.5 and 18 years of age, with severe to profound sensorineural hearing impairment, candidates for cochlear implant, with no history of voice or disorders of the larynx.	Characterize the vocal profile of individuals waiting for CI, by means of acoustic assessment.	Values for f0, jitter and shimmer are within the limits of normality, as well as the formants F1, F2 and F3 in most of the individuals. There was no significant increase in the f0 and amplitude variations. The results of auditory deprivation are responsible for the lack of control of the long-term measurement of the frequency and amplitude variation in the phonation of the sustained vowel.
Binaural Multichannel/Digital Hearing Aid (n=1)	2013	Das, Chatterjee, Kumar <sup>23</sup>	Twenty children aged between 5 and 10 years, with a mean age of 8, divided into two groups: children with normal hearing and children using Hearing Aids. The hearing-impaired group was consisted in children with profound bilateral sensorineural hearing loss using binaural multichannel digital hearing aids.	Compare the aerodynamic parameters of the larynx in normal-hearing children and hearing-impaired children using Hearing Aids, paired by age.	There was significant difference in the vital capacity and in the maximum phonation time. The variation of abduction and adduction movement of the vocal folds and the value of the peak flow were similar between the two groups.



**Chart 3.** Articles that address the use of cochlear implants and Hearing Aids

CI and Hearing Aid	Year	Authors	Casuistry	Objectives	Results
CI and Hearing Aid not specified (n=3)	2013	Souza <sup>8</sup>	Eighteen children (12 girls and 6 boys) ages 5 to 7 years old.	Compare vocal parameters of F0, F1 and F2 in children using CI, Hearing Aids and normal-hearing children.	In comparing the three groups, all of the parameters analyzed showed significant differences. In the comparison between the CI group and the normal-hearing children, there was a difference in the values of the F1 variable of the vowel [a] of the syllable [pa]. These results showed that the acoustic parameters of children with CI are close to those of normal-hearing children.
	2011	Mahmoudi, Rahati, Ghasemi, Asadpour, Tayarani, Rajati <sup>24</sup>	Thirty children, ages between 3 and 6 years, 18 using CI or Hearing Aid (6 capable of emitting spontaneous and imitative words, 6 emitting spontaneous words and imitating short sentences, 6 emitting spontaneous words and arbitrary sentences and 12 children with normal hearing.	Develop and evaluate a classification for vocal disorders in children using CI and Hearing Aid	The method studied, Multiple Classifier Fusion, proved to be capable to offer a good assessment of the children as well as the study showed the best form of analysis for this classification. The data also indicated that the greater the use of CI and Hearing Aid, the better the speech of the children. The older children presented greater control of the phonetic characteristics of their voice, due to a more sophisticated speech system.
	2006	Horga, Liker <sup>7</sup>	Thirty children divided into three groups: Control Group, those with CI, and children with profound hearing loss using hearing aid, paired by age.	Analyze speech and voice characteristics and compare between the groups: with Hearing Aid, with CI and those with normal hearing.	It was understood that vocal quality and pronunciation of those with CI was better than those with profound hearing loss using Hearing Aid.
Analogic and digital Hearing Aid, CI not specified. (n=1)	2010	Garcia, Rovira, Sanvicens <sup>25</sup>	Fifty-four normal-hearing children from the control group and 62 children (35 girls and 27 boys) aged 3.10 and 10.9 years, with profound sensorineural hearing loss. Twenty children used binaural analogic Hearing Aids; 15 used binaural digital Hearing Aids and 26 used unilateral CI and 1 used bilateral CI.	Evaluate the voice of children with hearing impairment and compare the voice of hearing children based on the acoustic analysis measurements found in literature.	The experimental group showed changes in vocal quality mainly in F0 and shimmer, however, those with digital Hearing Aids, CI and analogic Hearing Aids presented characteristics different from one another. Those with digital Hearing Aid and CI presented better vocal quality when compared to those using analogic Hearing Aids. There was a correlation between the degree of hearing loss with the analyzed parameters of vocal quality. Greater the hearing loss, greater the vocal alteration.
Multi channel CI and Hearing Aid not specified (n=1)	2011	Baudonck D'haeseleer, Dhooge, Lierde <sup>26</sup>	Sixty-one moderate to profound prelingual hearing-impaired children; 36 of them (16 boys and 20 girls) had CI and 25 (15 boys, 10 girls) used Hearing Aids, with a mean age of 9 years. The control group consisted of 25 children with normal hearing.	Determine the vocal quality in children with CI and compare the vocal quality measurements of children with CI and children using Hearing Aids and normal-hearing children paired by age.	The children with CI had a result in the Dysphonia Severity Index (DSI) very close to normality. In the perceptual assessment of the voice by the GRBASI scale, there was a subtle presence of roughness and tension and a higher level of pitch and intensity. There was no significant difference in the comparison of the vocal parameters between the three groups of children.

CI and Hearing Aid	Year	Authors	Casuistry	Objectives	Results
Bilateral Hearing Aid, Unilateral CI (19 Nucleus/1 Clarion) (n=1)	2013	Lopez, Moundain, Bretèque, Serraféro, Trotter, Barkat-Defradas <sup>27</sup>	Seventy-eight children between the ages of 5 and 13 years, divided into groups: normal hearing with 38 children (18 girls and 20 boys); 20 children using Hearing Aid (9 girls and 11 boys) and 20 children (6 girls and 14 boys) with CI, paired by age.	Compare the obtained measurements in the acoustic assessment, in the aerodynamics assessment and the perceptual-auditory assessment between the groups studied.	Some acoustic parameters differ significantly among the three groups, while others are similar between children with CI and normal hearing. In the aerodynamics parameters assessment, the children with CI had measurements similar to normal-hearing children. In the perceptual-auditory assessment, the data of the children with CI were within the levels of alteration between 0 and 1 on the GRBAS scale. It was concluded that the CI provides better acoustic parameters than the Hearing Aid. Glottic efficiency increases according to the chronological age and the time of use of the CI.
Bilateral Hearing Aid, Unilateral CI (16 Med-El/11 Cochlear/10 Advanced Bionics) (n=1)	2013	Mao, Zhang, Nutter, Zhang, Zhou, Liu, Xu <sup>28</sup>	Thirty-seven prelingual hearing impaired children with unilateral CI, 31 prelingual hearing impaired using Hearing Aid, and 37 normal-hearing children.	Investigate the singing vocal performance in hearing-impaired children with CI and Hearing Aid, as well as assess the relationship between demographic factors of these children and their ability to sing.	Children with CI and Hearing Aid, when compared to normal-hearing children, showed a significantly worse performance in the evaluations associated with the variations of pitch and measures of rhythm. There were no differences between those with CI and Hearing Aids, except for the standard deviation for the intervals between musical notes. The precision to sing was correlated with the time of use of these devices.

**Chart 4.** Studies on the hearing impaired with no specification of the use of Hearing Aid or CI

Other	Year	Authors	Casuistry	Objectives	Results
Profound Hearing loss (n=1)	2011	Dehgan, Scherer <sup>29</sup>	Fifteen boys with profound sensorineural hearing loss, bilateral, and 15 boys with normal hearing, paired by age.	Compare vocal acoustic parameters of boys with profound hearing loss with their peers with normal hearing.	Data showed that boys with hearing impairment present significantly higher values in the measurements of F0, jitter and shimmer, and lower values in noise-to-harmonics ratio, when compared to those with normal hearing.
Severe prelingual hearing loss (n=1)	2004	Lejska <sup>30</sup>	Thirty-five adults (20 men and 15 women) with a mean age of 33 years, with profound prelingual hearing loss and 35 more people in a control group (15 men and 20 women) with a mean age of 39.	The objective was to verify the influence of hearing the human voice, comparing the voice of individuals with hearing impairment to individuals with normal hearing.	The field measurements, dynamics of variation of pitch and intensity are reduced in the hearing impaired. The authors stated that the hearing impaired are not able to maintain the continuous emission of the frequency range.

## Discussion

The studies that researched the vocal quality in children with CI presented diversified results, because different methodologies and analysis of several factors were involved.

It was shown that the use of CI promotes the vocal quality in children because the acoustic parameters analysis and data from perceptual-auditory assessment pointed to their resemblance to the voice of normal hearing children<sup>10,13-14</sup>. The vocal quality of children with CI, however, will depend on factors such as the age in which received the implant<sup>14</sup>, “lifetime of hearing”<sup>12,14</sup>, and the participation in hearing rehabilitation programs<sup>9,18</sup>.

The most studied acoustic parameters analysis, the f0, Jitter, Shimmer and noise-to-harmonics ratio, were related to the time of auditory deprivation, to the “lifetime of hearing”, to the speech intelligibility and to the form of rehabilitation. The f0 was described within normal parameters<sup>10,13-14,17</sup>, especially in children with auditory deprivation of less than four months<sup>14</sup>, however, it did not suffer changes in the period between 2 and 6 months from activation of the CI<sup>18</sup>. The other parameters demonstrated better results in children with early use of the CI<sup>14,17</sup>, use of the CI between 12 and 24 months<sup>16-17</sup> and is related to better speech intelligibility of the child<sup>4,16</sup>. The conditions that did not favor the vocal quality in children were determined by the late age of implantation of the CI<sup>17,19</sup>, showing that initiating the use of this device at 5 years of age is unfavorable<sup>19</sup>. In several studies, the importance of hearing rehabilitation was emphasized<sup>9, 14,18-19</sup>.

Other factors featured in the vocal quality of children with CI are related to the absence of cochlear ossification, the early resumption of hearing, the residual hearing with a hearing aid and the therapeutic process<sup>14</sup>.

In relation to the post-lingual hearing impaired with a CI, two studies were found<sup>11,15</sup>. The perceptual-auditory assessment showed that CI in adults with no specific rehabilitation for the voice provided a positive impact on the vocal quality. The f0 decreased among men and varied in comparison with the findings in women<sup>11</sup>. Results from the acoustic evaluation showed that the results of those with CI were worse than the normal data of the Multi-Dimensional Voice Program (MDVP), however, it did show that those that experienced sensory deprivation less than 6 years achieved

better results. In addition, the authors stated that speech and hearing therapy can improve the quality of life of these patients<sup>15</sup>.

One study that assessed the vocal quality in post-lingual hearing-impaired adults and prelingual hearing-impaired children, both with CI, showed that the children exhibited greater values of jitter, shimmer, f0 variation and amplitude variation in relation to the adults, both before and after implantation. The measure of f0 did not vary after the implantation in both groups. However, the children managed a greater control of phonation after the period of 6 and 12 months of the implant. Unlike in adults, there was no significant improvement in any of the parameters studied<sup>3</sup>.

The studies that examined the vocal quality in those with HA involved participants above 5 years of age<sup>20,23</sup>. In general, the results of these studies demonstrated that sound amplification positively impacts the control of vocal quality, being able to reduce and improve control of the f0 and balance the measures of jitter and shimmer<sup>20-22</sup>. However, research involving the measures of dynamic respiratory pointed out significant differences in the values of vital capacity and maximum phonation times, when compared to normal hearing children<sup>23</sup>.

Some studies were conducted in order to compare the vocal quality between hearing impaired with HA and those with CI. Seven articles on this topic were selected, whose results revealed that the vocal quality of individuals with CI, in addition to being similar to individuals with normal hearing<sup>8,26-27</sup>, it is better in relation to the vocal quality of those using a HA<sup>7-8,27</sup>. Hearing-impaired children with more sophisticated speech development presented more appropriate vocal characteristics<sup>24</sup>. When the results of the voice assessments of the hearing impaired with CI, Digital Hearing Aid and analogic Hearing Aid were compared, it was shown that those using analogic Hearing Aid obtained the worst results<sup>25</sup>.

One study whose objective was to investigate the performance of children with CI and HA in activities that involved singing, as well as assess the relationship between the demographic factors of these hearing-impaired children and their ability to sing, showed that children with both CI and HA presented inferior performance in all vocal evaluations performed when compared to normal hearing children. Though it was observed that the longer the use of the devices, the better the ability to sing<sup>28</sup>.

One article analyzed the vocal quality of the hearing impaired that did not use any electronic device, such as the HA or the CI, and it pointed out that the vocal quality of these individuals was significantly altered in regards to jitter, shimmer and fundamental frequency compared to the vocal quality of individuals with normal hearing<sup>28</sup>. Another study, which did not specify the use of electronic device in hearing-impaired adults, assessed the vocal quality of these participants through a dynamic field of voice software and compared it with their normal hearing peers, concluding that the field of the hearing impaired is reduced<sup>30</sup>.

## Conclusion

This study presents a bibliographic review on the voice of the hearing impaired in the period between 2003 and 2015. The results of this literature review show that the majority of studies found and analyzed focused on the voice quality of hearing-impaired individuals with cochlear implant. The studies about the vocal parameters of those using Hearing Aids were conducted on a much smaller scale than those related to the voice and use of CI.

After analyzing the selected articles, it is possible to see that factors such as an early age diagnose of hearing impairment, the beginning of hearing loss (prelingual or post-lingual), therapeutic process with emphasis in hearing rehabilitation, hearing device used (Hearing Aid or CI), age of intervention and duration of rehabilitation interfere with the voice quality of the hearing impaired, since all these aspects are of extreme importance in the development of the acoustic feedback necessary in monitoring the voice.

The studies have shown the impact of auditory sensory deprivation in the characteristics of the voice in adults and children, affirming that the greater the degree of hearing loss, greater the vocal alterations; however, the technological development for access and the perception of speech sounds enable vocal improvement in children and adults with severe hearing loss.

The articles chosen in the period of 12 years revealed that the cochlear implant was an important advancement, providing better conditions for the development of auditory function and, consequently, that of oral communication of the hearing impaired, enabling vocal characteristics that favor speech intelligibility.

Further studies that analyze the technological evolution of the electronic devices to access speech sounds and the impact on the vocal quality of hearing-impaired children and adults is essential, since it will be an important factor in hearing rehabilitation.

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