Chapter

Effect of Cochlear Implantation on Voice Quality in Patients with Hearing Impairment

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Abstract

Hearing impairment is a cause of many problems suffered by a patient. Apart from hearing problems also voice problems develop as a result. Already in deaf newborns, clear signs of voice disturbances appear soon after birth. Development of voice is delayed, babbling appears later and speech development depends on the time and kind of medical intervention. The reason of voice abnormalities in hearing impaired individuals is abnormal hearing control over voice production. Therefore, audio-logical intervention enabling better control, is an important factor for hearing and voice quality improvement. This chapter summarizes up-to-date knowledge on the influence of hearing aids and cochlear implants on voice quality of hearing impaired patients. Both literature studies and authors’ own research show that the use of cochlear implants is the most effective tool of improving hearing and voice of people with hypoacusis. Cochlear implantation brings better results compared to hearing aids and the time of implantation plays a key role.

Keywords: hearing impairment, voice quality, voice disorders, cochlear implant, partial deafness, acoustic voice analysis

1. Introduction

In newborns, voice appears as a reflex immediately after birth. It continues to develop during further stages of life and, together with the onset of speech, voice becomes a useful tool for interpersonal communication. Numerous studies have demonstrated how voice production is strictly controlled by both the central nervous system and the auditory system. This means that a disorder in either of these control systems can lead to abnormalities in voice quality and changes in its acoustic structure.

Individuals deprived of full hearing suffer many problems in their social, professional, and personal lives. Prolonged hearing deprivation, particularly in children, results in problems such as loss of voice control, which is evident as dysphonia of different degrees.

Compared to healthy children, hearing-impaired children are no different in terms of their larynx. However, differences do become apparent in the first few years of life, with the degree depending on various factors, such as type and depth of hearing
impairment and the method and success of rehabilitation. The type of voice disorder in poorly hearing or deaf children is usually classed as functional [1].

In infants with hearing impairment, changes can be seen in voice development within a matter of months. The voice is typically higher pitched, shows greater fluctuations in frequency, and is less constant in volume. In the first few months of life, intrinsic motivation is the major stimulus for vocalization (i.e., no external sound stimulus is needed), but later on there is a greater reliance on hearing [2, 3]. Analysis of the vocalizations of hearing-impaired children only a few months old brings out the differences compared to normally hearing children. In the first year of life, hearing-impaired children show a delay in canonical babbling, usually of 4–6 months, whereas children with normal hearing produce many more canonical syllables [4–6]. The delay depends on the severity of the hearing impairment [7, 8].

Apart from the quality of vocalization, hearing impairment can also affect the number of vocalization episodes, with hearing impaired or deaf children producing significantly less vocalizations than their healthy peers [9, 10]. The deleterious effect of hearing impairment depends strongly on its severity. For deaf children, the number of vocalizations is significantly less than in children with only partial hearing impairment, and in both groups the number of vocalizations is substantially lower than in normally hearing peers [11]. At later stages of development (i.e., 16–24 months), the transition from babbling to words is also delayed among hearing-impaired children. Later on, as speech develops, hearing-impaired children show delays or more limited use of syllables containing consonants, incorrect vowel articulation, and a smaller vocabulary [12].

Compared to normally hearing people, the voice of hearing-impaired individuals is, in general, marked by an increase in average fundamental frequency (F0), an increase in the variation of fundamental frequency (vF0), an increase in the variation of amplitude (vAm), and a decrease in phonation time [13–16]. These factors suggest that the hearing impaired have difficulty in controlling long-term frequency and amplitude during phonation. Perceptively, this difficulty manifests as vocal instability that can take the form of tremor, poor modulation, and elevated pitch. Those voice features fall into the category of ‘audiogenic dysphonia.’ In addition, the speech of hearing-impaired individuals is also marked by patterns of poor articulation, or ‘audiogenic dyslalia.’ Taken together, voice quality depends on the effective functioning of the auditory organs and adequate performance of the respiratory tract. With a functional level of hearing, it is possible to have correct voice range development, an ability to modulate voice intensity, and achievement of normal acoustic voice parameters. In brief, appropriate hearing allows normal speech and prosody to develop.

Among hearing-impaired individuals, changes in the acoustic structure of voice are seen at every developmental stage. The changes are primarily related to voice frequency. In particular, deaf and partially deaf individuals use a narrower range of frequencies in their voice and tend to have less control over pitch [17–21]. The voice of a hearing-impaired child is frequently dull, fluctuating, and harsh, and is accompanied by high muscle tension; it is often breathy, toneless, weak, monotonous, and devoid of melody. It appears that hearing impairments interfere with how the pitch, volume, rhythm, and timbre of the voice is regulated [22–24].

Other studies have demonstrated that individuals with hearing disorders often exhibit abnormalities of voice resonance – evident as nasalance [25–27] – so that voice and speech becomes nasal, dull, and rather dark. Most researchers consider that nasalance reflects inadequate central nervous system control of the velopharyngeal muscles due to a lack of auditory input [25, 28, 29]. Another potential factor in
causing nasalence is a slower rate of speech [30–32]. Perceptive and acoustic examinations reveal elevated nasal resonance, even when electromyography (EMG) of the palatal muscles remains normal [33].

These studies suggest that a lack of auditory-derived control produces abnormal voice characteristics, evident as changes in aerodynamic parameters. The changes come about from poor coordination between the internal and external muscles of the larynx, and are seen as abnormalities the way antagonistic muscles develop and release tension. Comparisons of normal and hearing-impaired individuals have revealed statistically significant differences in the vital capacity of the lungs (VC), maximum sustained phonation time (MSPT), and fast adduction–abduction rate (FAAR). In particular, they show lower VC, shorter MSPT, and smaller FAAR compared to normally hearing individuals. There is also a somewhat smaller peak expiratory flow (PEF), although this difference does not reach statistical significance [34, 35].

Research on the mechanisms of respiration and chest mobility suggest that, among deaf and poorly hearing individuals, there may be abnormalities in the coordination of chest and abdominal movements. In particular, such people tend to initiate phonation using an incorrect volume of air in the lungs (either too large or too small). The mean volume of air (per syllable) is double that of normally hearing subjects. Deaf or hearing impaired individuals therefore tend to speak fewer syllables per breath, which leads to awkward breaks to breathe in at grammatically inappropriate moments [36].

2. Cochlear implantation and voice quality

Early intervention, either with hearing aids or cochlear implantation, is crucial to enable patients to receive appropriate hearing. Better auditory control of the voice will help improve the patient’s voice quality. The option of whether to use a hearing aid or a cochlear implant depends on the degree of hearing impairment. Regardless of the choice, numerous studies have shown that the earlier the intervention is performed, the better are the results in terms of hearing and voice improvement.

In this context, one relevant study was conducted in the Institute of Physiology and Pathology of Hearing in Warsaw, Poland, on a group of 83 Polish school children aged 7–12 years [37]. The aim of the study was to compare the quality of the voice after using hearing aids or cochlear implants. Acoustic voice analysis was performed for each individual, and the linguistic material was a prolonged [a] vowel. The criterion for including a patient in the study was profound prelingual, sensorineural hypoacusis. The study group was divided into four subgroups according to their hearing and use of hearing devices: there were 20 children without any type of hearing device (HL), 20 children who used hearing aids (HA), 20 children with cochlear implants (CI), and 23 normal-hearing children, of the same age, who had no voice disorders (control group, NH). The children who used hearing aids or cochlear implants had undergone hearing rehabilitation 6 months previously.

After audiological intervention and rehabilitation, statistically important changes were observed in several acoustic voice parameters. The group of hearing-impaired children (HL) had the highest average fundamental frequency F0. In the hearing aid group (HA), testing performed 6 months after a hearing aid was fitted showed there was a slight decrease in the average F0 value. However, in the CI group, there was a much greater decrease in F0. The study also showed a significant decrease in the number of fundamental frequency periods (pitch periods, PER) in the hearing-impaired
children compared to the control group. In the HA group, some improvements in PER were observed, but in the CI group, the improvements occurred much faster. At the same time, slight decreases in smoothed amplitude perturbation quotient (sAPQ) were observed in the HL and HA groups, indicating that amplitude control stabilized quite quickly. The highest average peak amplitude variation (vAm) was found in the HL group, and the lowest in the control group (NH). Values of vAm in the HL group reached values almost twice those of vAm in the control group. These significantly lower vAm values after use of hearing aids and cochlear implants indicate that the patients had better auditory control of the voice. Noise-to-harmonic ratio (NHR) decreased in the HL and HA groups, whereas a significant increase was noted in the CI group. The soft phonation index (SPI) was found to be lower in the HA and CI groups, but higher in the CI group. F0 tremor intensity index (FTRI) in the HL group was almost twice that of the control group. In the HA and CI groups there was a significant decrease in FTRI, but it was even greater in the CI group. This reflected an observed decrease of voice tremor in the patients.

The conclusion of the study was that long-term hearing deprivation, whether minor or substantial, affects the acoustic structure of children’s voices. Significant changes were found in fundamental frequency (F0), highest fundamental frequency (Fhi), variability of fundamental frequency (vF0), number of periods of fundamental frequency (PER), amplitude perturbation quotient (sAPQ), variability of amplitude (vAm), noise-to-harmonic ratio (NHR), soft phonation index (SPI), and frequency tremor index (FTRI). The implication is that patients with a profound level of hearing impairment develop long-term problems in the control of voice frequency and amplitude. Acoustic analysis confirms that the use of hearing rehabilitation devices significantly improves most acoustic voice parameters. The improvements reflect improved auditory control of voice frequency and amplitude, and a decrease in noise components and voice tremor. In particular, significantly better voice results have been seen in children who have received cochlear implants [37].

Similar results were obtained by Campisi et al. [17] who conducted acoustic voice analysis of 21 children before and 6 months after cochlear implantation. Before cochlear implantation elevated levels of F0, vF0, and vAm were observed. After cochlear implantation, vF0 tended towards normal and there was a marked decrease in vAm, bringing more stability to voice.

In a study by Evans and Deliyski [14], patients before cochlear implantation presented abnormalities in F0, jitter, shimmer, NHR, VTI, SPI, vAm, and vF0. After cochlear implantation they noted a decrease in F0 for all subjects. After implantation the voice was more stable, while jitter, shimmer, and VTI were markedly less. After cochlear implantation all subjects had much lower nasality. Similar findings were noted by Fletcher et al. [29].

In another study of 31 children aged 2–3 years with prelingual deafness who received cochlear implants, Hocevar-Boltezar et al. [38] reported substantial improvements in jitter and shimmer 6 months after implantation and after 24 months there was a noticeable improvement in NHR. It was clear that cochlear implants improved the patients’ ability to control the pitch and loudness of their voice. These findings were confirmed by Holler et al. [15].

Kishon-Rabin et al. [39] described the effects of cochlear implantation on voice in a group of post-lingually deaf patients. They noted a decrease of F0 after 1, 6, and 24 months from implantation. They also found that voice quality improved more if the intervention was undertaken earlier.
Szkicielowska et al. [40] compared acoustic voice parameters before and after a CI in two groups of 40 children aged 3–7 and 7–12 years. After implantation, both groups received intensive rehabilitation and the voice parameters were then measured 6 months later. Most parameters improved and they correlated with better subjective voice quality. MPT was longer and voice range was wider. The main improvement of objective voice parameters were seen in Jitt, RAP, PPQ, SPPQ, VFo, ShdB, Shim, APQ, SAPQ, vAm, DUV, NUV, FTRI, and ATRI. In general, implantation followed by intensive rehabilitation allowed better control of voice frequency and amplitude, less tremor, and fewer voice breaks.

Kosztyła-Hojna et al. [41] examined voice and speech quality before and after cochlear implantation in two groups of patients: one with prelingual deafness and the other with post-lingual deafness. All patients had features of functional dysphonia, with a slight prevalence of hyperfunction in the prelingually deaf patients and hypo-function in the post-lingually deaf ones. After the CI, the quality of voice and speech in both groups improved. Improvements were mainly seen in parameters describing changes in amplitude and frequency.

Another study by Kosztyła-Hojna et al. [42] examined 21 adults with prelingual or post-lingual deafness. Before receiving a CI, the subjects showed a disturbed motorial function of the articulation organs and errors in articulation of vowels and consonants. After the CI, there was a substantial improvement in articulation, the voice became more stable, the scope of words was larger, and prosody improved [43].

3. Voice quality in partial deafness

Partial deafness (PD) is characterized by normal hearing thresholds at low frequencies and much poorer hearing thresholds (almost deaf) at high frequencies. In an audiogram this is seen as a hearing threshold curve that drops sharply at high frequencies. It is mainly seen in elderly patients, but may also affect individuals exposed to noise, take certain medications, or have a genetic predisposition. In contrast to other types of hearing impairment, the use of amplifying hearing aids in PD is constrained due to three physiological factors. The first factor is an abnormal loudness perception (recruitment), which makes the patient hear sounds louder than they really are. The second is poorer frequency resolution, which means that sound stimulation covers a larger group of hearing cells (there is an overlap of stimulus frequencies), and this leads to difficulty in the patient’s sound discrimination. The third phenomenon is distortion caused by “dead areas” in the cochlea, where hearing cells are completely destroyed. In these areas, sounds cannot be perceived at all and so sounds have to be picked up by neighboring cells. Stimulation therefore covers broad areas and slightly different tones are perceived by the patient as the same. Together, these three factors mean that standard hearing aids giving unsatisfactory results for PD patients.

PD patients have therefore been left struggling to overcome their deficit. The use of cochlear implants in PD treatment has for many years been circumscribed due to the risk of damaging remaining hair cells, and hearing, while introducing an electrode into the cochlea. An important landmark in PD treatment was a novel type of cochlear implantation for this kind of dysfunction. This was done in an adult PD patient by Skarżyński and colleagues in 2002 [44], and 2 years later in a partially deaf child [45]. Success of the operation was possible thanks to the use of specially designed electrodes and a novel round window approach to the cochlea. In this way, electrical and acoustic stimulation were combined (so-called Electro-Acoustic-Stimulation, EAS),
and offered a way for PD patients to receive improved hearing. Skarżyński's achievement began a systematic Partial Deafness Treatment Program in Poland, the first such program worldwide [44–49].

Like other hearing impairments, PD leads to voice abnormalities. However, the literature on the voice of PD patients before and after a CI is quite limited. The first study was done in the Institute of Physiology and Pathology of Hearing in Warsaw, Poland, by Myszel and Szkiełkowska [50]. They recruited 147 individuals, one group of 67 children aged 7–12 years and another of 80 adults. In one aspect, the voice of school-aged children was analyzed: 44 had prelingual partial deafness and 23 had normal hearing (a control group). As a second aspect, 80 adults were examined: 25 with bilateral postlingual partial deafness (13 females and 12 males) and 55 with normal hearing (28 females and 27 males, a control group). The average age of the partially deaf adults was 49.2 years and the average length of time they had had PD was 19.1 years. Voice parameters of both PD children and PD adults were tested 9 months after cochlear implantation.

All subjects were selected so as to exclude pre-existing conditions (palatal, alveolar, and lip clefts; inborn and acquired malformations of the larynx; paralytic dysphonia; allergy; gastro-esophageal reflux; thyroid disease; asthma; chronic obstructive pulmonary disease; mental or neurogenerative disorder; or delayed psychomotor development). Objective acoustic analysis of the voice was done with the Kay Elemetrics Multi Dimension Voice Program, and subjective analysis was done on the Hirano GRBAS scale.

Individuals were patients of the World Hearing Center of the Institute of Physiology and Pathology of Hearing in Kajetany, Warsaw, from 2014 to 2021. Every individual underwent a detailed anamnesis, otolaryngological examination, and hearing assessment. Hearing assessments included the use of pure tone audiometry, impedance audiometry, otoacoustic emissions, and brainstem evoked response audiometry, ensuring that patients fulfilled the PD criteria as described by Skarzynski [51].

Data analysis showed that, compared to normal hearing, PD in children leads to abnormalities in acoustic structure of the voice. The abnormalities involved most of the voice parameters, but the most important changes were in frequency, amplitude, noise, and voice tremor (F0, vF0, vAm, sAPQ, NHR, SPI, FTRI). In all the examined children, subjective assessment with GRBAS showed grade of hoarseness G1 or G2, roughness R1 or R2, breathy voice B1 or B2, and strain S1 or S2.

For the adults, the most statistically important changes involved the parameters describing frequency, amplitude, subharmonics, noise, voice breaks, and tremor (vF0, Jita, APQ, sAPQ, RAP, vAm, Shim, PPQ, Shim, DUV, NHR). However, no statistical changes were observed in F0, SPI, or VTI. Adults displayed grade of hoarseness G1 or G2, roughness R1 or R2, breathy voice B1, asthenic A1 or A2, and strain S1 or S2. The voice of all PD patients appeared to be slightly harsh, rough, breathy, or asthenic.

Both children and adults were examined 9 months after cochlear implantation. In children, the biggest improvement in voice parameters was observed in frequency, amplitude, noise, and tremor. Normal values were seen in F0, vF0, vAm, sAPQ, NHR, and FTRI. In adults, statistically significant improvements were observed in parameters describing frequency, amplitude, noise, voice irregularities, and subharmonics; normal parameters were seen in vF0, vAm, sAPQ, Shim, NHR, DUV, DSH, and NSH.

In subjective assessment, the voice of PD patients also improved after receiving a CI, especially in grade, roughness, and breathiness. The improvements made their voices less harsh, less breathy, and less asthenic. Apart from the perceptive
improvement, strong correlations were observed between the voice quality assessed subjectively and acoustic voice parameters: G (grade) correlated with vF0 and Shim; R (roughness) correlated with DSH and NSH; B (breathiness) correlated with NSH and NHR; and A (asthenic) correlated with DUV. A weak correlation was observed between S (strain) and both DUV and NHR.

It was concluded that PD leads to voice abnormalities both in children and adults. In both groups statistically significant changes involved parameters describing frequency, amplitude, and presence of noise. The number of years of hearing deprivation was an important factor in determining changes in the voice. In adult PD patients, voice abnormalities affected a wider range of acoustic parameters.

In both children and adults, it is clear that there is a strong correlation between acoustic voice parameters and subjective features. Importantly, cochlear implantation in PD patients strongly improves the voice, normalizing its acoustic structure and subjective character.

4. Summary

Hearing impairment leads to disruption of auditory control of the voice via the central nervous system, creating voice disorders classified as dysphonia. The degree of dysphonia depends on when the hearing loss began (prelingual or post-lingual), its duration, and its severity.

Children born with hearing impairment do start to develop a voice, but its development is delayed compared to healthy children and further development into good speech requires audiological intervention.

Patients with hearing impairment develop voice disorders of a functional type, and these are evident both in perceptual assessments as well as in objective examinations (i.e. acoustic voice parameters). The changes are mostly seen in terms of amplitude, frequency, tremor, and noise. The voice of hearing-impaired patients is usually rough, breathy, asthenic, and strained. Some patients develop nasality. Apart from a different voice characteristic in hearing-impaired patients, there are also morphological changes of the larynx, articulatory organs, and changes in chest biomechanics.

Numerous studies conducted worldwide have demonstrated that, depending on the severity of the hearing loss, the use of hearing aids or cochlear implants improves hearing ability. After regaining auditory control, the voice quality improves in all types of hearing impairment, both in children and in adults. Research shows that, in general, cochlear implants are more effective and improve voice quality faster than hearing aids. The voice of children with cochlear implants is better as soon as a few months after intervention, and the improvement continues progressively. Objective parameters describing changes in amplitude and frequency steadily improve, and tremor and noise decrease or disappear. Perceptive assessment shows the voice becoming less harsh, more stable, and less dull.

Studies performed in the Institute of Physiology and Pathology of Hearing in Warsaw have provided data on voice quality in partial deafness before and after cochlear implantation. The results show that both children and adults with partial deafness develop dysphonia of different degrees, although the number of altered acoustic parameters is higher in adults than in children. After cochlear implantation, however, the voice quality of both children and adults improves, and this is reflected in both objective and subjective assessments.
5. Conclusions

Contemporary medicine gives more and more treatment opportunities for different groups of patients, including those who suffer congenital or acquired hearing impairment. Cochlear implantation is now a treatment of choice for patients with deafness or hypoacusis (including partial deafness), giving them a chance to regain hearing and improve quality of living.

Problems faced by hearing impaired people are seen in many areas of life, including communication, professional life, mental conditions and self-esteem. Voice disorders resulting from hearing impairment is one of the factors underlying patients distress.

Therefore, the procedure of cochlear implantation by enabling better hearing and voice quality improvement, helps to improve patients’ comfort and life quality in many aspects.

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