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Research Article

Partial Deafness Cochlear Implantation Improves Voice Quality in Children

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ABSTRACT

Partial Deafness (PD), characterized by normal hearing at low frequencies and deep hypoacusis at high frequencies, causes voice disorders in children. Disturbed acoustic voice parameters in partial deafness children include those, which describe frequency, amplitude, noise and tremor. Apart from partial deafness dysphonia, this hearing this type of impairment causes developmental delays, which need a prompt intervention and rehabilitation.

For many years partial deafness patients, including children, did not receive appropriate help as traditional hearing aids were not effective in improving speech discrimination. Only Partial Deafness Cochlear Implantation (PDCI) became an effective tool that gives patients a chance of restoring hearing at high frequencies and improving speech recognition.

The study was performed to analyze the influence of PDCI on voice quality in children. Voice acoustics and subjective features of voice in a group of 44 prelingual partially deaf children were examined before and after cochlear implantation. The study proved improvement of objective acoustic measures describing changes in frequency, amplitude, presence of noise and tremor. Following objective improvement, perceptual assessment showed better voice, which became less harsh, more sonorous, less asthenic and stronger.

Keywords: Hearing impairment; Implant technology; Medical devices; Hypoacusis; Partial deafness

INTRODUCTION

Hearing impairment affects a growing number of people worldwide, including children. Apart from a distress experienced by patient, hearing deficit is a reason of communication problems and seriously hinders the appropriate development of communication and cognitive abilities in children [1-5]. It was proved by many researchers, that hearing impaired children present delays in development of speech, their vocalizations are less and babbling appears later compared with their healthy peers [6]. Therefore, to enable good development of speech, children with hypoacusis should be subjects for early audiological intervention and further rehabilitation. The methods used mainly depend on depth of impairment. Traditional hearing aids are used in children with hypoacusis of small and moderate degree, whilst cochlear implants became a solution for those with deep hearing impairment or deafness. In contrary to traditional hearing aids which amplify the sounds transferred to the ear, cochlear implants substitute function of damaged cells of organ of Corti and enable transforming mechanical waves into bioelectrical impulses conducted by auditory nerve to hearing areas of temporal area of the brain.

Cochlear implants were introduced to medical use in mid-eighties of twenty century. Implant technology is a subject of constant development and becomes more and more advanced in time. First cochlear implants were single-channel, whilst those used nowadays are modern, technologically advanced multi-channel medical devices. Treatment of deep hearing impairment and deafness with cochlear implantation gives a benefit of coming into world of sound to huge number of children and adults worldwide. Thanks to this modern technology lots of children born deaf were able to develop speech and communication abilities and live a normal living. As cochlear implants developed and became commonly used in medicine, the number of indications for implantation procedure became wider.

A very specific group of children, who suffer from hypoacusis, are those with Partial Deafness (PD). The specificity of this condition is a normal hearing at low frequencies and deep hearing impairment (near deafness) at high frequencies. Partial deafness in children is usually inborn as a result of genetic background, perinatal hypoxia or ototoxic drugs [7].

In contrary to other types of hearing impairments, traditional

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hearing aids, despite sound amplification, do not improve speech discrimination. This is due to physiological phenomena taking place in human cochlea with PD.

Inappropriate loudness recruitment causes perception of sound as excessively loud, thus hearing aids in such condition are not accepted by majority of patients. Deteriorated frequency resolution in PD cochlea, as a result of hair cells damage, causes a spread of stimulation area, and similar tones from neighboring areas overlap one another. Despite hearing the sounds patient is not able to properly discriminate speech. Therefore, hearing aids do not improve speech understanding. The last phenomenon in PD is the presence of dead areas in cochlea. Hair cells in the areas are completely destroyed, thus no stimulation there is present. What happens instead is stimulation of neighboring cells and similar hearing sensations appear for tones of different frequencies. As a result, discrimination of speech is weak is spite of using a hearing aid.

Lack of auditory benefit from hearing aids application caused that patients with partial deafness were for long time devoid of efficient help in improving their hearing ability. Use of cochlear implants in such condition was not possible due to the risk of a damage to healthy hair cells (responsible for low frequencies) while introducing an electrode into cochlea.

A real breakthrough in partial deafness treatment was first worldwide cochlear implantation performed by Henryk Skarżyński of Institute of Physiology and Pathology of Hearing in Warsaw, Poland. This first cochlear implantation in PD adult was performed in 2002. Two years later first cochlear implant was received by PD child (Partial Deafness Cochlear Implantation, PDCI). This became possible thanks to a dedicated electrode design co-designed by Henryk Skarżyński and an innovative approach to cochlea through a round window (round window approach) in a six-step procedure. The PDCI procedure enabled an effective combination of acoustic and electric stimulation (Electro-Acoustic-Stimulation, EAS). The above achievement of Skarzynski gave PD patients a chance to regain hearing in high frequencies and benefit from this in other aspects of their life. Since that time, the list of indications for cochlear implantation became much wider. The idea of PDCI became a ground for implementation partial deafness treatment program in Poland, first such program worldwide [8-12]. In case of children partial deafness cochlear implantation restores chances for voice and speech development, catching up the general development delays and improve communication and cognitive abilities. As PD patients develop voice problems, PDCI is a chance to improve their voice quality [13].

Purpose

The purpose of the study was to examine the influence of partial deafness cochlear implantation on voice quality in children.

MATERIALS AND METHODS

The total study group consisted of 67 subjects: 44 children aged 7-12 years with prelingual partial deafness and 23 children in a control group with normal hearing. The average age of participants was 9.4 years.

The study protocol first included anamnesis and physical examination. Further steps consisted of:

- General otolaryngological examination with a detailed assessment of peripheral speech organ, morphological and functional evaluation of upper respiratory system and larynx.
- Detailed analysis of hearing with use of Pure Tone Audiometry (PTA), Impedance Audiometry (AI), Otoacoustic Emissions Registration (OAE) and Brainstem Evoked Response Audiometry (BERA). Patients fulfilling the criteria of Partial Deafness (PD) were finally recruited to the study group.

The exclusion conditions included:

- Lip, alveolar and palate cleft.
- Secretory otitis media.
- Inborn or acquired structural abnormalities of the larynx.
- Organic or palsy dysphonia.
- Allergies.
- Thyroid diseases.
- Asthma.
- Mental retardation.
- Neurogenerative disorders.

Voice sample recordings were done in a clinical anechoic chamber. Microphone was located 10 cm away from patient`s mouth and the same, standardized, phonetically equilibrate speech samples were used. Acoustic voice parameters analysis was performed with Multi Dimension Voice Program (MDVP) by Kay Elemetrics.

Every patient`s voice was also evaluated subjectively using GRBAS scale (by Hirano,1981). To ensure consistency and reliability voice was subjectively assessed by two independent medical doctors with over 10 years of experience in phoniatrics and audiology. Inter-rater coherence achieved over 90%.

The study protocol was approved by bioethical committee of Institute of Physiology and Pathology of Hearing in Warsaw.

RESULTS

Data analysis showed that changes in acoustic characteristics of voice in PD children were present in most of acoustic parameters. Statistically important changes *versus* control group were mainly seen in parameters describing frequency, amplitude, noise and voice tremor.

As for frequency parameters, statistical changes were noted in average fundamental frequency (F0), which was elevated (290 Hz *vs.* 217 Hz in control group) and variation of fundamental frequency (vF0), which appeared to be decreased (4.12% *vs.* 5.13% in control group).

Statistically important changes of amplitude parameters included variation of amplitude (vAm) showing the increase (20.96% *vs.* 14.71% in control group) and smoothed amplitude perturbation quotient (sAPQ), which was lowered (6.24% *vs.* 7.05% in control group).

Noise parameters were statistically changed mainly when it comes to Noise-to-Harmonic Ratio (NHR) with its decrease (0.15 *vs.* 0.17 in control group) and Soft Phonation Index (SPI) which was lowered in PD children (7.59 *vs.* 9.43 in control group).

Parameter describing frequency modulation, Frequency Tremor Intensity Index (FTRI) was decreased (0.34 *vs.* 0.78 in control group).

Acoustic parameters of voice in children with partial deafness compared to children with normal hearing are presented in (Table 1).

Table 1: Acoustic parameters of voice in children with partial deafness *vs.* control group.

Parameter	Control group	Children with PD	P value
F0 (Hz)	217	290.00*	p<0,05
Jita (μs)	77.66	41.06	p>0,05
Jitt (%)	1.64	1.12	p>0,05
RAP (%)	0.99	0.66	p>0,05
PPQ (%)	1	0.62	p>0,05
sPPQ (%)	1.44	0.95	p>0,05
vF0 (%)	5.13	4.12*	p<0,05
ShdB	0.55	0.38	p>0,05
Shim (%)	6.18	4.96	p>0,05
APQ (%)	4.55	3.6	p>0,05
sAPQ (%)	7.05	6.24*	p<0,05
vAm (%)	14.71	20.96*	p<0,05
SPI	9.43	7.59*	p<0,05
NHR	0.17	0.15*	p<0,05
FTRI	0.78	0.34*	p<0,05

Apart from objective changes in voice also subjective voice evaluation in PD children showed abnormalities compared to the control group. GRBAS evaluation depicted changes in all voice features. In all children: Grade (G) was rated 1 in 31 subject and 2 in 13 subjects, Roughness (R) was rated 1 in 29 subjects and 2 in 15 subjects, Breathiness (B) was rated 1 in 30 subjects and 2 in 14 subjects, Asthenic (A) was rated 1 in all subjects and Strained (S) was rated 1 in 32 subjects and 2 in 12 subjects. Therefore, the voice of most of the children was slightly harsh and breathy, dull and slightly tensed. The spread of GRBAS ratings within the study group before cochlear implantation is presented in (Table 2).

Table 2: Spread of GRBAS ratings in children with partial deafness before PDCI.

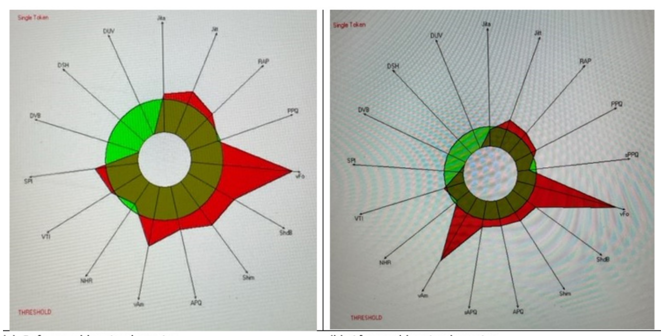
No of patients/GRBAS	0	1	2	3
G	0	31	13	0
R	0	29	15	0
B	0	30	14	0
A	0	44	0	0
S	0	32	12	0

The voice of children was then analyzed objectively and subjectively 9 months after partial deafness cochlear implantation. Statistically important changes were found in relation to: Frequency parameters-decrease of fundamental frequency F0 by 22 Hz and increase of variation of fundamental frequency vF0 by 4,52 (%); amplitude parameters-increase of variation of amplitude vAm by 1,68 (%) and increase of smoothed amplitude perturbation quotient by 3,38 (%); noise parameters-decrease of noise-to-harmonic ratio by 0,03; tremor parameters-increase of frequency tremor intensity index by 0,56. The summary of the changes are presented in (Table 3).

Table 3: Changes in acoustics voice parameters in children with partial deafness after cochlear implantation.

Parameter	Before PDCI	After PDCI	P-value
F0 (Hz)	290	268*	p<0,05
Jitt (%)	1.12	2.21	p>0,05
PPQ (%)	0.62	1.02	p>0,05
sPPQ (%)	0.95	1.16	p>0,05
vF0 (%)	4.12	8.64*	p<0,05
RAP (%)	0.66	1.08	p>0,05
vAm (%)	20.96	22.64*	p<0,05
ShdB (dB)	0.38	0.65	p>0,05
Shim (%)	4.96	6.85	p>0,05
sAPQ (%)	6.24	9.59*	p<0,05
NHR	0.15	0.12*	p<0,05
FTRI	0.34	0.90*	p<0,05

The Figure of voice acoustics before and after PDCI is showed in the MDVP below (Figure 1).



(a). Before cochlear implantation (b). After cochlear implantation

Figure 1: MDVP presentation of average voice parameters in PD children. **Note:** (a) Before cochlear implantation (b) After cochlear implantation.

Subjective assessment of voice after cochlear implantation showed an improvement within GRBAS features. Grade (G) decrease was found in 72% of children, Roughness (R) decreased in 66%, Breathiness (B) showed decrease in 72% of children, Asthenic (A) decreased in 43% and Strained (S) showed decrease in 28% of subjects. The biggest changes were therefore found in features describing grade, roughness and breathy voice, less referred to asthenic and strained voice. In perceptual assessment voice of children became more sonorous and stronger. The spread of GRBAS ratings within the study group after cochlear implantation is presented in (Table 4).

Table 4: Spread of GRBAS ratings in children with partial deafness after PDCI.

No of patients/GRBAS	0	1	2	3
G	30	13	1	0
R	37	6	1	0
B	30	14	0	0
A	18	26	0	0
S	6	32	6	0

In the final step of the study the results achieved in objective and subjective assessment were analyzed for correlation existence. Pearson correlation index "r" was calculated and the analysis revealed that:

a) G strongly correlates with vF0, APQ, sAPQ, vAm

b) R strongly correlates with Jitt, RAP, PPQ, sPPQ, vF0, APQ, sAPQ, NHR and FTRI

c) B correlates with Jitt, RAP, PPQ, sPPQ, vF0, RAP, APQ, sAPQ, vAm and VTI

d) A weakly correlates with VTI

e) S strongly correlates with SPI and FTRI

Correlations summary is presented in below (Table 5).

Table 5: Correlations between objective and subjective features of voice in PD children.

	Pearson R index				
	G	R	B	A	S
vF0 (%)	0.86	-	0.51	-	0.79
Jitt, RAP, PPQ	-	0.83	0.51	-	0.79
APQ, sAPQ, vAm	0.86	0.83	0.51	-	0.79
VTI	-	-	0.51	0.34	-
FTRI	-	0.83	-	-	0.79
NHR	-	0.83	-	-	-

The study showed that G and R correlate with parameters describing changes in frequency and amplitude, B correlates with parameters of frequency, amplitude, tremor and noise, A correlates with parameters of tremor and S correlates with parameters of frequency, amplitude and tremor.

DISCUSSION

It was proved by numerous studies that hearing impairment causes distress and discomfort to patients in many areas of their life. Voice disturbances appear to be one of common problems associated with hearing impairment [14-22].

Lots of studies were conducted worldwide to analyze the influence of hypoacusis and deafness on human voice. Subsequently, many studies were tailored and performed to check how cochlear implantation influences voice characteristics. However, the studies on voice acoustics in partial deafness, as defined by Skarzynski, are very limited, both before and after implantation. In-depth literature analysis shows that out study is the first one to assess voice changes in partial deafness cochlear implanted children.

Changes in voice of children with partial deafness mainly include fundamental frequency (F0, vF0), amplitude (sAPQ, vAm), Noise Parameters-Noise Harmonic Ratio (NHR), and Soft Phonation Index (SPI) and Tremor-Frequency Tremor Intensity Index (FTRI). Subjective analysis of voice features seems to reflect the objective changes as voice is harsh, rough and strained.

Analysis performed in partially deaf children 9 months after PDCI showed a significant improvement of voice quality. Improvements of statistical importance were found in parameters of frequency (F0, vF0), amplitude (vAm, sAPQ), noise (NHR) and tremor (FTRI). Similar effects were found in children implanted due hearing impairments, other than partial deafness [23-29]. Normalization of acoustic parameters of voice in implanted children were also described [30,15]. In the studies, Fundamental frequency (F0) and its variation (vFo) and variation of Amplitude (vAm) decreased, which meant voice stabilization. In most of studies decrease of fundamental frequency after cochlear implantation was observed as well as decrease of jitter, shimmer and Voice Turbulence Index (VTI). Implanted children presented lower nasalence. Similar observations were made by other authors [31,32].

Our study proved that partial deafness cochlear implantation improves voice quality in children. The observation stays in line with many other studies conducted in hearing impaired children, however none of them before was dedicated to children with partial deafness. The results achieved in our study, apart from clinical implications, may be a complementation of our knowledge on different aspects of partial deafness. The summary of changes in voice acoustics after PDCI in children is presented below (Table 6).

Table 6: Changes of acoustic voice parameters in children after PDCI.

Parameter	PD children	
	Before PDCI	After PDCI
Fundamental frequency	F0	F0 (↓)
Parameters describing changes of frequency	vF0	vF0 (↑)
Parameters describing changes of amplitude	vAm, sAPQ	vAm (↑) sAPQ (↑)
Parameters describing changes of noise	NHR	NHR (↓)
Parameters describing changes of tremor	FTRI	FTRI (↑)

CONCLUSION

The results of our study show, that apart from hearing benefits, partial deafness cochlear implantation improves voice quality in children. This innovative approach of partial deafness treatment with cochlear implantation, elaborated and commenced by Henryk Skarżyński, became an effective procedure that improves children`s quality of life in my aspects.

Cochlear implantation in partially deaf children improves acoustic parameters of voice, particularly related to changes of frequency, amplitude, noise and tremor. The study performed 9 months after cochlear implantation proved stabilization of the parameters, which achieve values close to those in children with normal hearing.

Parallelly to objective parameters, voice improvement is also seen in perceptual assessment. GRBAS scale helps to notify a better quality of voice in implanted children. Grade of hoarseness and roughness decrease. Voice after PDCI becomes less breathy, less asthenic and not as strained as prior to implantation.

Changes of acoustic parameters of voice may be a helpful tool to track progress of rehabilitation process of implanted children and to follow up the results of a restored auditory control of voice production. Acoustic analysis of voice may be of a particular practical and objective value in younger kids, in whom the progress of rehabilitation was limited to observational assessment and parents use questionnaires.

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