The Acoustic Characteristics of the Voice in Cochlear-Implanted Children: A Longitudinal Study

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Summary: Objective. The purpose of this study was to characterize changes in the voice and vowel articulation of prelingually deaf children after cochlear implantation.

Methods. In this study, the patient group included 30 prelingually deaf children who underwent unilateral cochlear implantation at 4–6 years of age. The control group included normally hearing children of the same age. All deaf children had follow-ups before cochlear implantation and at 1, 3, 6, 12, and 24 months after implantation. The acoustic parameters, aerodynamic parameters, and vowel formants were measured in the patient group and compared with those of the control group.

Results. All acoustic parameters, aerodynamic parameters, and vowel formants differed significantly between normally hearing children and prelingually deaf children. For prelingually deaf children, all of the above parameters gradually decreased after cochlear implantation. Furthermore, the acoustic parameters Jitter and Shimmer were significantly reduced as early as 6 months, whereas the fundamental frequency, the standard deviation of fundamental frequency, estimated subglottal pressure, aF1, iF2, and uF2 were significantly altered 12 months after implantation. However, statistically significant differences in these parameters were not observed between 12 and 24 months after cochlear implantation.

Conclusion. After cochlear implantation, prelingually deaf children established auditory feedback and improved voice control and vowel production.

Key Words: Prelingually deaf children–Acoustic–Aerodynamic–Vowel articulation–Cochlear implant.

INTRODUCTION

Human vocal characteristics are vital to oral communication. After birth, the organs required for pronunciation and articulation constantly change, develop, and mature. The human voice also changes with age.[1–4] For this reason, the acoustic characteristics of the human voice are considered a mirror of human aging. Many studies have reported the influence of anatomic changes in growing children on voice acoustic characteristics.[5–7] The fundamental frequency (F0) is approximately 440 Hz for crying newborns. This frequency decreases during anatomic maturation.[8–10] Tavares et al[2] reported that F0 decreases with age and noted a significant decrease from 275.09 to 222.49 Hz in boys and from 257.14 to 234.09 Hz in girls. The standard deviation of F0 (SDF0) refers to the overall stability of vocal cord vibrations. During early childhood, children have weak control over the stability of vocal cord vibrations. Accordingly, they have a relatively high SDF0, which gradually declines with growth and age. Jitter and Shimmer refer to the regularity of vocal cord vibrations, reflecting the roughness and hoarseness of the voice, respectively. Jitter and Shimmer reflect the variability of pitch and amplitude.[11] In some studies, Jitter and Shimmer did not vary significantly with age.[2] The quality of vowel articulation is easily distinguished by the vowel formant frequencies, which are determined by the shape and size of the articulation tract, particularly for the first (F1) and second (F2) formant frequencies.[11–13] A lower F1 reflects the fact that the tongue is closer to the roof of the mouth. F2 reflects the resonance of the oral cavity and is associated with the front-back placement of the tongue.[12,13]

Auditory feedback is important for the control of respiratory, phonatory, and articulatory functions during speech.[14,15] Because of a lack of auditory control, prelingually deaf children have poor speech perception and production. In a study by Peng et al,[16] Mandarin-speaking, hearing-impaired children showed lower intelligibility compared with children with normal hearing. Hearing-impaired children cannot correct their speech efficiently and accurately. Furthermore, they cannot control their voice stability for the proper perception of pitch, loudness, hoarseness, roughness, and breathiness. The vocal characteristics of deaf children differ considerably from normally hearing children.[17–19] In some studies, deaf people had a higher F0 than normally hearing individuals.[17,18] Moreover, in some studies, deaf people were reported to exhibit inaccurate production of vowel sounds and increased voice intensity.[18,19] Valero et al[18] studied the voice qualities of 62 children with different degrees of profound deafness and found that deaf children showed significant differences in both F0 and in Shimmer compared with normally hearing children. In addition, greater degrees of hearing loss were associated with more pathologic voice quality parameters. In the study by Leder et al,[19] deaf adult males spoke with significantly increased voice intensity than normally hearing males.

With the development of hearing technology, more prelingually deaf children have benefited from hearing aids, particularly multichannel cochlear implants (CI). After cochlear implantation, deaf children enter the world of sound, establish auditory feedback, have speech perception and vocal production abilities, and even have fluent verbal communication. Many studies focused on analyses of voice acoustics of deaf implanted children, but the conclusions did not always agree.

In some studies, the vocal parameters of the implanted children differed considerably from those of normally hearing

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children,[18,20,21] whereas other studies reported values similar to those in the normally hearing children.[12,22–24] Valero Garcia et al[18] studied the influence of the type of auditory prosthesis on the voice quality of deaf children and found that the CI children presented statistically significant differences in vocal parameters compared with those of normally hearing children. However, in the study performed by de Souza et al,[22] there were no significant differences in F0, Jitter, Shimmer, or the noise to harmonics ratio between implanted children and normally hearing children.

Irena Hocevar-Boltezar et al[14] studied the changes in some acoustic parameters in deaf children after cochlear implantation and found that F0 did not significantly decrease after implantation and was even higher 24 months after implantation. However, in other studies, F0 decreased after cochlear implantation.[25,26] Leder et al[26] noted that F0 was one of the earliest voice parameters to approximate normal values after cochlear implantation. Irena Hocevar-Boltezar[14] also concluded that deaf children who received CIs at or before the age of 4 years improved their voice control more rapidly than children who received their implants at older ages. This conclusion was similar to the findings of Seifert et al,[12] who stated that prelingually deaf children who received a CI before the age of 4 years attained better acoustic control. In some studies, early CI use was reported to promote better neuromuscular control of sustained phonation.[23,27,28]

Regarding the voice of deaf children, particularly CI children, numerous investigations have been conducted and were mainly focused on analyzing acoustic parameters. After reviewing the relevant literature, we determined that the conclusions did not always agree. Different assessment technique and evaluation materials have been used in published studies. Importantly, individual diversity was not considered. The age of CI, the duration of CI use, the hearing gain after CI, and the types of cochlear strategies are all important factors influencing voice quality. Few authors mentioned all of the above aspects in their research.

In comparison with other studies, one of the main values of this study is the longitudinal design. To exclude the impact of individual diversity, in this study, 30 hearing-impaired children were followed longitudinally for up to 24 months. In addition, we measured the acoustic parameters and vowel formants, as well as characterized the development of the aerodynamic parameters in CI children.

MATERIALS AND METHODS

Research subjects

Thirty prelingually deaf children (12 boys, 18 girls) were included in the study. The children received a unilateral CI at 4–6 years of age, with a mean age of 5 years and 2 months. All children were implanted with a multichannel CI (Med-El SONATA TI100, Innsbruck, Tyrol, Austria) and fitted by experienced audiologists using the fine structure processing strategy. After implantation, the average pure tone audiograms for 500, 1000, 2000, and 4000 Hz ranged from 23.55 to 47.25 dB. All patients had follow-up visits before cochlear implantation and at 1, 3, 6, 12, 18, and 24 months after implantation. The following were the inclusion criteria: (1) the children exhibited prelingual bilateral severe to profound sensorineural hearing loss, (2) the children did not present intellectual disabilities, H-NLAT test and Griffith test were used to rule out intellectual disabilities, (3) the children did not have flu before the evaluation, (4) Chinese was the native language of all children, all of whom had regular hearing training and speech therapy after implantation, (5) the otolaryngological examination confirmed that the structures of the vocal tract and the oral motor skills were normal in all patients, and (6) the children were able to perform the sustained vowels /a/, /i/, and /u/.

Fifteen normally hearing children between 4 and 6 years of age were included in the control group, with an average age of 5 years and 8 months. The children did not present intellectual disabilities or speech disorders. The otolaryngological examination confirmed that the vocal tract structures and oral motor skills were normal in all children.

Research methods

Acoustic analyses

Voice samples of the long vowel /a/, which was pronounced at a comfortable pitch and intensity for a duration of 3 seconds, were analyzed with *MDVP* software (KayPENTAX, Lincoln Park, NJ, USA). All children were asked to pronounce /a/ three times while in a sitting position into a microphone (SM48-LC, Shure Niles, IL, USA) held at a distance of 10 cm and a 45° angle. All samples were recorded in a quiet, soundproof room. The "middle part" of each sample was used for the analysis. The parameters F0, Jitter, Shimmer, and SDF0 were evaluated for every voice sample.

Vowel formant analyses

Children from each group were asked to pronounce /a/, /i/, and /u/ at a habitual pitch and loudness for a duration of 3 seconds. The samples were analyzed using a Computerized Speech Lab 4300B (KayPENTAX). F1 and F2 frequencies of the three vowels were measured.

Aerodynamic analysis

A phonatory aerodynamic system model 6600 (KayPENTAX) was used for the aerodynamic assessment. Oral cavity catheters were inserted into the children's mouths to a depth of approximately 2.5 cm such that the nozzle was not blocked by the tongue or palate. The children were asked to fasten the mask to their nose and mouth. They were then asked to produce a set of eight /pa/ syllables at a comfortable pitch and loudness. The data were automatically analyzed using the Voicing Efficiency protocol. The values of the subglottal pressure (SGP) were recorded. As many cochlear-implanted children cannot distinguish /pa/ and /ba/ until after 6 months of CI use, the aerodynamic examination was performed 6 months after implantation.

Statistical analyses

SPSS v13.0 (Chicago, IL, USA) software was used to compare the samples. The paired *t* test, Kruskal-Wallis test, and Bonferroni test were used, depending on the samples' characteristics. Probability values less than 0.05 were considered statistically significant.