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# Bilateral cochlear implantation or bimodal listening in the paediatric population: Retrospective analysis of decisive criteria

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ABSTRACT

*Introduction:* In children with bilateral severe to profound hearing loss, bilateral hearing can be achieved by either bimodal stimulation (CIHA) or bilateral cochlear implantation (BICI). The aim of this study was to analyse the audiologic test protocol that is currently applied to make decisions regarding the bilateral hearing modality in the paediatric population.
*Methods:* Pre- and postoperative audiologic test results of 21 CIHA, 19 sequential BICI and 12 simultaneous BICI children were examined retrospectively.
*Results:* Deciding between either simultaneous BICI or unilateral implantation was mainly based on the infant's preoperative Auditory Brainstem Response thresholds. Evolution from CIHA to sequential BICI was mainly based on the audiometric test results in the contralateral (hearing aid) ear after unilateral cochlear implantation. Preoperative audiometric thresholds in the hearing aid ear were significantly better in CIHA versus sequential BICI children ($p < 0.001$ and $p = 0.001$ in unaided and aided condition, respectively). Decisive values obtained in the hearing aid ear in favour of BICI were: An average hearing threshold measured at 0.5, 1, 2 and 4 kHz of at least 93 dB HL without, and at least 52 dB HL with hearing aid together with a 40% aided speech recognition score and a 70% aided score on the phoneme discrimination subtest of the Auditory Speech Sounds Evaluation test battery.
*Conclusions:* Although pure tone audiometry offers no information about bimodal benefit, it remains the most obvious audiometric evaluation in the decision process on the mode of bilateral stimulation in the paediatric population. A theoretical test protocol for adequate evaluation of bimodal benefit in the paediatric population is proposed.

## 1. Introduction

Nowadays, cochlear implantation (CI) is the golden standard in auditory rehabilitation for patients with bilateral severe to profound sensorineural hearing loss. Compared to the rehabilitation with acoustic hearing aids, a CI is more often provided unilaterally [1,2]. However, compared to monaural stimulation, bilateral stimulation results in more natural hearing, reduced listening effort and improved quality of life [3,4]. Providing auditory input in both ears is expected to improve speech perception in noise by a combination of the head shadow effect, binaural summation and binaural squelch. The head shadow effect is a bilateral effect, requiring two functional ears. Binaural summation and binaural squelch presume the central auditory system to combine the auditory cues from both ears. In addition, interaural time and level differences available through bilateral auditory stimulation support spatial hearing and sound source localisation in the horizontal plane [5–7]. Stimulation of both ears also prevents neural degeneration resulting from auditory deprivation [8]. Bilateral hearing seems to be of particular importance in children, as research has proved that unilateral hearing loss may be accompanied by behavioural problems, academic difficulties and delays in speech and language development [9,10].

In patients with bilateral severe to profound hearing loss, bilateral hearing may be achieved by either bilateral cochlear implantation (BICI) or bimodal stimulation. BICI has the advantage that the ear with the best postoperative performance is certainly stimulated electrically [2,3,11,12]. However, the outcome is restricted by the limitations in speech processing strategies of the devices. After all, the electric auditory CI signals predominantly comprise spectral envelope information, whereas the temporal fine structure of sound is discarded. This spectral envelope encoding is sufficient for speech perception in quiet, but for more demanding speech understanding situations the temporal information adds value [13–15].

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In bimodal stimulation, electric and acoustic hearing are combined using a CI in one ear and appealing to the residual acoustic hearing in the other ear, if necessary amplified with a hearing aid [6,12,16]. This approach includes three major advantages. First, there is no need for a second surgery. Therefore, supplementary costs are avoided and risks concerning both anaesthetics and potential vestibular damage are reduced [2,11,12]. Secondly, the contralateral ear remains intact so that it can be engaged for possible new treatments for hearing loss in the future such as stem cell therapy and hair cell regeneration [1,2,12,16]. Finally, in bimodal stimulation, the high-frequency electric hearing is complemented by the low-frequency acoustic input in the contralateral ear, which comprises spectro-temporal information that is lacking in the electric signal [11,16–18]. This is especially beneficial for segregating voice sources, perceiving voicing information in consonants and perception of sound quality, melody and music [17–20]. However, bimodal stimulation is only a valuable alternative in patients with functional residual hearing [2,6,12,16].

Both bimodal stimulation and BICI are considered effective approaches to provide bilateral hearing, since the majority of recent studies agree that no significant differences in speech perception, language development and localisation ability are found between bimodally stimulated patients and BICI users [16,17,21–24]. However, their speech perception in noise and localisation abilities remain poor compared to bilateral normal hearing listeners. The two devices, being a hearing aid and a CI or two CIs, function independently and are not aligned in terms of timing and intensity of the signal presentation, which hampers the central processing of auditory input arriving in both ears. Therefore, the benefit of bilateral compared to monaural stimulation in both bimodal and BICI listeners on speech perception in noise and localisation tasks is principally attributed to the head shadow effect, and the real benefit of binaural processing of acoustic cues is questioned [25].

In young children with bilateral profound hearing loss due to meningitis and in patients with Usher syndrome, BICI is advocated [2–4,12]. Apart from these exceptions, BICI only seems to be considered if the use of a contralateral hearing aid results in insufficient bimodal benefit [2,6,12,17]. The question remains how to determine this bimodal benefit, especially in young children, and to define what is considered sufficient in this regard. As no worldwide standard criteria are currently available concerning BICI candidacy, most CI centres are inclined to appeal to the unilateral candidacy criteria, using, for example, pure tone audiometry [1,4]. This method is of questionable validity because the expectations of unilateral CI cannot be compared to the desirable outcome of bilateral hearing [1].

The aim of this retrospective study was (a) to evaluate the audiologic test protocol that is currently applied in deciding between bimodal stimulation and BICI in the paediatric CI population in our centre and (b) to determine which factors and audiologic test results are influencing the decision.

## 2. Materials and methods

### 2.1. Subjects

From September 1997 until the start of this retrospective study in October 2016, 276 patients have been implanted and followed at the department of Otorhinolaryngology in the Ghent University Hospital. Only patients younger than 12 years of age on the 9th of December 2009 were included in this study, since from that date onwards BICI is reimbursed to patients up to 12 years of age in Belgium. Additionally, patients needed to be stimulated bilaterally, i.e. with BICI or bimodally, from a young age onwards, i.e. before the age of 18 months.

Fifty-two paediatric patients met these inclusion criteria and were divided into three groups. The first group (CIHA) consisted of 21 bimodal listeners (12 males; 9 females) with a mean age of 10.1 years (SD: 4.1). The mean age of implantation was 4.3 years (SD: 3.0). The 19 (9 males; 10 females) sequential BICI users (Seq BICI) switched from bimodal to BICI condition and had a mean age of 9.6 years (SD: 3.7). They received the first implant at a mean age of 3.3 years (SD: 3.0) and the second at a mean age of 5.6 years (SD: 3.5) The third group consisted of 12 children (8 males; 4 females) with a mean age of 3.1 years (SD: 1.6) who received CIs in both ears simultaneously (Sim BICI) at a mean age of 1.0 years (SD: 0.4). The aetiology of the hearing loss is summarised in Table 1. Occurrence of multiple disorders (psychomotor or cognitive retardation, delayed speech and language development, vestibular, respiratory, cardiac, feeding, muscle tension and/or visual disorders) was reported in nine Seq BICI patients, seven CIHA patients, and three Sim BICI patients and showed no statistically significant difference between subject groups ($p > 0.05$, Fisher's exact test). All included patients signed an informed consent form. The study design was approved by the Ghent University Hospital Medical Ethical Committee.

**Table 1**
Aetiology of hearing loss in the three subject groups.

| | Total $n = 52$ | | CIHA $n = 21$ | | Seq BICI $n = 19$ | | Sim BICI $n = 12$ | |
|---|---|---|---|---|---|---|---|---|
| | % | (*n*) | % | (*n*) | % | (*n*) | % | (*n*) |
| cCMV | 23 | (12) | 10 | (2) | 42 | (8) | 17 | (2) |
| Cx26 | 17 | (9) | 14 | (3) | 5 | (1) | 42 | (5) |
| Bilateral EVA | 8 | (4) | 14 | (3) | 5 | (1) | – | |
| Meningitis | 8 | (4) | 5 | (1) | – | | 25 | (3) |
| AN/AD | 8 | (4) | 10 | (2) | 11 | (2) | – | |
| Premature hypoxia | 2 | (1) | – | | 5 | (1) | – | |
| Cochlear nerve hypoplasia | 2 | (1) | – | | 5 | (1) | – | |
| Unknown - familial | 10 | (5) | 19 | (4) | 5 | (1) | – | |
| Unknown | 23 | (12) | 29 | (6) | 21 | (4) | 17 | (2) |

CIHA = bimodal listeners; Seq BICI = children with sequential bilateral cochlear implantation; Sim BICI = children with bilateral simultaneous cochlear implantation; cCMV = congenital cytomegalovirus infection; Cx26 = connexin 26 gene mutation; EVA = enlarged vestibular aqueduct; AN/AD = auditory neuropathy/auditory dyssynchrony.

### 2.2. Audiologic tests

#### 2.2.1. Middle ear evaluation

In order to preclude temporary middle ear pathologies (e.g. middle ear effusion, tympanic membrane perforation), middle ear status was examined by micro-otoscopy every six months. Tympanometry (TympStar, Grason Stadler Inc., MN, USA) was performed before every audiologic measurement. High-frequency tympanometry (1000 Hz) was used in infants younger than nine months of age. From the age of three months, a 226 Hz probe stimulus was applied.

#### 2.2.2. Auditory Brainstem Response (ABR)

Hearing thresholds were determined objectively by means of ABR testing. Wave V thresholds were examined using the Eclipse EP25 (software Otoaccess version 1.2.1, Interacoustics, Assens, Denmark) using insert phones calibrated according to ISO-389 reference values (E-A-RTONE Insert Earphone 3A ABR, 3M Company, Indianapolis, IN, USA). In clinical practice, besides click stimuli, toneburst stimuli are commonly used. In this database only thresholds using click stimuli were included as these provide a general overview of the child's hearing status. Assessment and interpretation of the measurements was performed by an audiologist out of a fixed team of four audiologists with at least five years of experience in the neonatal and paediatric audiologic diagnostics.

#### 2.2.3. Subjective hearing evaluation

Subjective hearing evaluation included pure tone audiometry, speech audiometry and phoneme discrimination. These tests were performed in the same double-walled sound-attenuated audiometric