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Cone-beam computed tomography in children with cochlear implants: The effect of electrode array position on ECAP

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ABSTRACT

Objectives: To assess the feasibility of using cone-beam computed tomography (CBCT) in young children with cochlear implants (CIs) and study the effect of intracochlear position on electrophysiological and behavioral measurements.

Methods: A total of 40 children with either unilateral or bilateral cochlear implants were prospectively included in the study. Electrode placement and insertion angles were studied in 55 Cochlear® implants (16 straight arrays and 39 perimodiolar arrays), using either CBCT or X-ray imaging. CBCT or X-ray imaging were scheduled when the children were leaving the recovery room. We recorded intraoperative and postoperative neural response telemetry threshold (T-NRT) values, intraoperative and postoperative electrode impedance values, as well as behavioral T (threshold) and C (comfort) levels on electrodes 1, 5, 10, 15 and 20.

Results: CBCT imaging was feasible without any sedation in 24 children (60%). Accidental scala vestibuli insertion was observed in 3 out of 24 implants as assessed by CBCT. The mean insertion angle was 339.7°±35.8°. The use of a perimodiolar array led to higher angles of insertion, lower postoperative T-NRT, as well as decreased behavioral T and C levels. We found no significant effect of either electrode array position or angle of insertion on electrophysiological data.

Conclusion: CBCT appears to be a reliable tool for anatomical assessment of young children with CIs. Intracochlear position had no significant effect on the electrically evoked compound action potential (ECAP) threshold. Our CBCT protocol must be improved to increase the rate of successful investigations.

1. Introduction

A cochlear implant provides hearing by direct electrical stimulation of the auditory nerve endings. By means of various imaging techniques, the position of the electrode array within the cochlea can be determined. Vestibular electrode insertion, tip folding, and angle of insertion (insertion depth) can be evaluated by conventional cochlear view (X-ray) or high-resolution CT (computed tomography). The position of each electrode within the cochlea (array in scala tympani (ST) or scala vestibuli (SV)) can be only determined using high-resolution CT, but this method often provides multiple metal artefacts. More recently, the cone-beam computed tomography 31 (CBCT) imaging technique has been validated in adults as a valuable tool to assess post cochlear implantation of electrodes [5,16,22], with the advantages of less irradiation than a high resolution CT [6,21]. Furthermore, less sensitivity to metal artefacts [11,14] has been found using CBCT, allowing an easier identification of electrode placement in either the ST or the SV. Due to the CBCT imaging process, the CBCT exam duration is longer than the high-resolution CT exam duration, which can be a limitation for using CBCT in young children [14].

Several studies in adults with cochlear implants (CIs) have measured the effect of electrode array position on both the electrically evoked compound action potential (ECAP) threshold and neural response telemetry threshold (T-NRT) and shown higher T-

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NRT values if the electrodes are placed in the scala vestibuli [17,18,20,25]. The type of electrode array also influences the ECAP values with better responses for a perimodiolar array, which is in closer proximity to the modiolus and auditory neurons [9,19,23]. Moreover, the type of electrode array can also influence the rate of dislocation from scala tympani to scala vestibuli [1–3].

To our knowledge, no study has evaluated the feasibility of CBCT imaging in children with CIs less than 5 years old, specifically examining electrode position and its influence on electrophysiological measurements.

2. Materials and methods

2.1. Participants

A total of 40 children with either unilateral or bilateral cochlear implants (20 boys, mean age = 3.5 years old ±1.1) were included in this prospective study (Table 1). All subjects had received a Nucleus® cochlear implant (Cochlear®) between 2011 and 2015. The mean age at first implantation was 1.7 years old (±0.8) (mean age at second implantation was 1.9 years old (±0.7)) (see values in Table 2). Among the 55 Nucleus® cochlear implants (Cochlear®) of the cohort, there were 16 straight arrays (25% CI422 and 4% CI24RE ST) and 39 perimodiolar arrays (71% CI512 and CI24RE CA) (see distribution in Fig. 1). A cochleostomy and a round window approach was performed in 69% and in 31% of cases respectively.

2.2. Imaging techniques

Two imaging techniques were used to assess intracochlear position of the electrode array:

1 CBCT imaging was performed using the same machine (5G NewTom, NewTom, Verona, Italy, serial number 5912006, 200 × 25-mm flat panel detector, 650 mm from the radiation source, tube voltage 110 kV, with a 19-mA charge at the terminals). The X-ray tube rotated through a 360° rotation, and total image acquisition took 40 s. Total filtrations were 2 mm, with a pitch at 125 μm, corresponding to a field view of 8 × 8 cm diameter high resolution (HiRes). Image reconstruction in 125 μm isometric voxels was obtained on axial, sagittal and coronal planes, using the NNT software provided by NewTom.

Table 1
Description of the cohort.

N participants	40
N boys	20
N girls	20
Developmental age (y)	3.5 ± 1.1
Total N CI	55
N RE implants	30
N LE implants	25
N unilaterally implanted	25
N bilaterally implanted	15

N = number; CI = cochlear implant; = standard deviation; y = years; RE = right ear; LE = left ear.

Table 2
Age at implantation.

	1st CI	2nd CI
Implantation age (y)	1.7 ± 0.8	1.9 ± 0.7
N CI under 2 y	29	8
N CI over 2 y	11	7

N = number; CI = cochlear implant; = standard deviation; y = years.

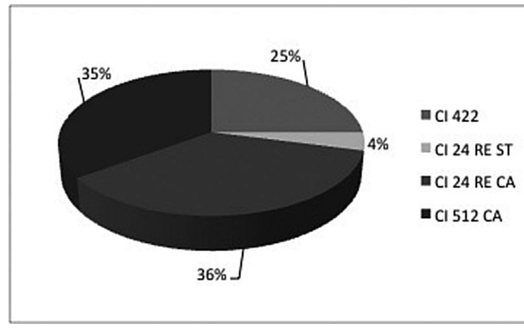

Fig. 1. Type of electrode arrays (%): straight (CI 422 and CI 24 RE ST) and perimodiolar arrays (CI 24 RE CA and. CI 512 CA). CI = cochlear implant; ST = straight array; CA = contour advance. The study cohort consisted of 71% perimodiolar electrode arrays and 29% straight arrays.

The CBCT imaging was scheduled when the child left the recovery room after surgery.

2 If CBCT was unfeasible (no participation of the child), an X-ray analysis was carried out with a Definium 8000 general electric medical systems machine (GEMS, serial number 2UA552065T). The voltage was set at 85 kV with a 400 mA charge. The image acquisition distance was 1 m. A single cranial radiographic image was taken on a frontal plan in accordance to the recommendations of Xu [29].

2.3. Imaging analysis

For cases when CBCT was possible, a “cochlear view” reconstruction [4,15] was carried out. The insertion angle was determined according to the technique described in several studies [7,13,26] inspired by Xu [29]. A reference point was placed through the center of the modiolus, representing a 0° reference angle starting at the level of the helicotrema. The *x*-axis went towards the round window of the cochlea and the *y*-axis towards the distal extremity of the electrode array. The basal turn angle was assumed to be 360°. The insertion depth angle was deduced by adding or subtracting the calculated angle to 360°. The intracochlear electrode position was evaluated with regard to scala tympani, scala vestibuli, and a dislocation from one scala to the other. Two ENT experts performed a double-blind analysis of the imaging similar to other studies [7,10] to limit inter-individual variability, and followed the consensual method [13,26].

For cases when CBCT was not possible, only insertion angle data were collected according to Xu recommendations [29].

2.4. Intraoperative recordings

Intraoperative measurements were taken during the implantation surgery using Custom Sound™ Cochlear® software, which recorded all T-NRT and electrode impedance values. For T-NRT, we determined a linear regression of the growth function, corresponding to a stimulation level for ECAP amplitude referring to zero [12]. For all electrodes, impedance values were collected using the MP1+2 stimulation mode. Electrodes 1, 5, 10, 15 and 20 (E1, E5, E10, E15, and E20) were selected from the base towards the apex of the cochlea for final analysis.

2.5. Postoperative recordings

At least one month after cochlear implant activation, postoperative T-NRT (mV) and electrode impedances (kΩ) were recorded during the fitting sessions, with the Custom Sound™ Cochlear® software on electrodes 1, 5, 10, 15 and 20.