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ORIGINAL ARTICLE

Role of dual energy CT with adjusted radiation dose in accurate assessment of electrode position in pediatric cochlear implant ☆

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KEYWORDS

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Abstract *Background and purpose:* Postoperative imaging of cochlear implant needs to provide detailed information on the position of individual electrodes; the aim of this study was to evaluate visualization of individual electrodes and measurement of the electrode–modiolus distance (EMD) using dual energy CT (DECT) – with low radiation dose using virtual monochromatic spectral (VMS) imaging comparing the images quality and radiation dose with those by using multidetector CT (MDCT).

Materials and methods: 25 pediatric patients who underwent cochlear implantation were imaged using DECT (15 patients) and MDCT (10 patients), and the image quality and radiation dose of DECT were compared to those of MDCT. Measurement of EMD was done for 5 electrodes and the results were correlated with neural response telemetry (NRT) and behavioural mapping levels.

Results: A statistically significant difference between the radiation dose of DECT and MDCT was confirmed ($p = 0.002$) without a statistically significant difference in images quality (weighted $K = -0.129$ and PABAK = 0.533).

Statistically significant correlations were found between EMD and NRT threshold, T (threshold) and C (maximum comfortable) levels with $p = <0.01$.

Conclusion: DECT accurately detects the electrode position with low radiation dose which helps in CI fitting.

1. Introduction

Cochlear implantation has become standard management for sever to profoundly deaf children (1). In cochlear implant patients, a large proportion of the success or failure depends on the transfer of stimulating signals from the electrode

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toward the auditory nerve fibers. In a study done by Gijs et al., it was concluded that electrode–modiolus distance is of importance in the stimulation of the auditory nerve fibers (2).

Multidetector computed tomography (MDCT) scanners have led to greatly expanded clinical use of CT. Technologic advances have further improved the volume coverage, resolution, and scanning speed of CT scanners (3). This results in high efficacy of MDCT in the postoperative imaging of CI patients (4,5). Like conventional X-ray, MDCT confirms the intracochlear position of the implant. It also detects malpositioning and kinking (4,6,7). The position of an electrode array as well as the individual electrode contact-to-modiolus distance can be assessed by MDCT (8,9). Unfortunately, these improvements in imaging have also inevitably led to an increase in radiation exposure to the patient (3). This radiation exposure from CT is especially critical in pediatric patients (10).

The main disadvantage of CT in the postoperative assessment of CI was the metallic artifact that may interfere with the visibility of individual electrodes (2,11).

The use of a high peak voltage, high tube charge, narrow collimation and thin sections helps reduce metal-related artifacts (12). However this will lead to increase radiation dose received by the patient (13).

The use of virtual monochromatic spectral (VMS) imaging has been proposed as a mean of reducing beam-hardening metal artifacts (14).

As monochromatic dual-energy CT (DECT) images are generated from projection-space data, they are less affected by beam-hardening artifact (15).

The aim of this study was to evaluate visualization of individual electrodes and measurement of the electrode-modiolus distance (EMD) using dual energy CT (DECT) – with low radiation dose using virtual monochromatic spectral (VMS) imaging comparing the images quality and radiation dose with those by using multidetector CT (MDCT).

2. Materials and methods

This prospective study was performed in full accordance with regulations issued by the local ethics committee.

2.1. Study population

Two groups were included:

Group A (imaged by DECT): 15 children (5 males and 10 females), age range between 23 and 172 months with mean age of 72.68 months (6.1 years).

Group B (imaged by MDCT): 10 children (3 males and 7 females), age range between 15 and 180 months with mean age of 82.8 months (6.9 years).

The inclusion criteria include age less than 18 years with sever to profound SNHL and little or no benefit from optimally fitted hearing aids in terms of access to speech sounds, absence of medical (e.g. the presence of other serious co morbidities) or radiological (e.g. cochlear nerve or labyrinthine aplasia) contraindications to surgery and the presence of family support and help for the implanted child.

The exclusion criteria include patients with malformed cochlea in which the modulus is not properly identified and malpositioning or kink of the CI system.

2.2. NRT measurements

NRT is a system that allows the use of the intracochlear electrodes for both stimulation and recording purposes by applying an electrical pulse on a given electrode and the evoked neural response is measured at a neighboring electrode.

Patients were implanted with the nucleus® CI24RE Freedom cochlear implant from cochlear, Intra operative NRT measurements were conducted on all 22 electrodes, telemetry took place immediately after implantation in the operating room under general anesthesia using the auto-NRT functionality of the software, and values were recorded and then processed by the custom sound 3.2 EP software (Cochlear limited, Lane Cove, NSW and Australia).

2.3. Image acquisition and reconstruction

Written consent was obtained from all parents, and young and noncooperative patients (5 patients in group A and 3 patients in group B) underwent light anesthesia using chloral hydrate oral 5 mg/kg.

Group A Patients were examined on a second-generation 128-slice dual-source CT in dual-energy mode (Somatom Definition Flash, Siemens Healthcare, Forchheim, Germany), with the parameters shown in Table 1.

These parameters were chosen after visual evaluation of multiple post-CI DECT studies done with different imaging parameters prior to this study.

Group B Patients were examined on a 128-slice MDCT (Ingenuity TF PET/CT Philips medical systems, Nederland) with the parameters shown in Table 1.

The radiation dose for each patient was obtained from the radiation dose report.

The images of group A were reconstructed using Syngo.via workstation (Siemens AG, Munchen, Germany), while the images of group B were reconstructed using extended brilliance work space (EBW-NM) 4 (Philips Medical Systems, Nederland), and the reconstruction parameters are shown in Table 1.

Table 1 Imaging & reconstruction parameters of DECT & MDCT.

	DECT	MDCT
Tube voltage	100 kV	120 kV
Tube current	375 mA	208 mA
Beam collimation	2 × 0.5 mm	64 × 0.625 mm
Rotation time	0.5 s	0.5 s
Scan field of view (FOV)	240 mm	200 mm
Reconstruction parameters:		
Section thickness	0.6 mm	
Section interval	0.3 mm	
Filter	Kernel (H70 h) WEDGE_2	

MPR images were created parallel to the basal turn of the cochlea and perpendicular to the modiolus and thus in the plane of the electrode array.

2.4. Image analysis

The quality of the images of the two groups was evaluated by two independent head & neck radiologists with 11 and 13 years of experience and each case was graded into accepted (if the electrode contact was clearly separated from its neighboring contacts), neutral (if electrode contacts could be differentiated at the surface but not in the center) or unaccepted (if an electrode contact could not be distinguished from the previous or following contact) (4) (Fig. 1).

In all patients, the EMD was measured from the center of each electrode to the center of the modiolus (Fig. 2). The EDM of five selected electrodes (Nos. 1, 6, 11, 16 and 22) was measured taking into consideration the electrodes are numbered from 1 (basal) to 22 (apical). The average of both measures of each electrode was taken.

These electrodes were chosen as they span the electrode array and include one or two electrodes from each of the three electrode groups typically used when programming the speech processor with speech bursts: Electrodes 1 and 6 in the basal turn of the cochlea for high frequencies, electrodes 11 and 16 in the midturn of the cochlea for midfrequencies and electrode 22 in the apical turn for low frequencies (see Fig. 3).

Fig. 1 Sagittal oblique view using DECT (A) and axial view using MDCT (B) for post-cochlear implant after adjustment of the window width and level displaying identification of individual electrodes by the two techniques.

Fig. 2 Long axis view DECT. Measurement of the EMD at electrodes 1, 6, 11, 16 and 22.

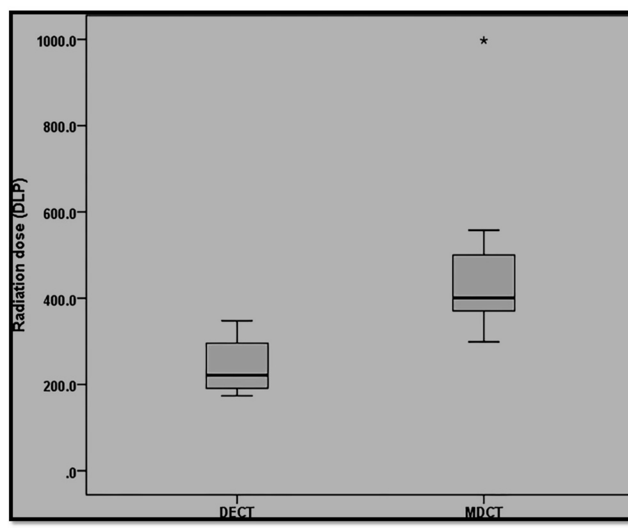

Fig. 3 Box plot showing the radiation dose associated with DECT or MDCT. Box represents the range between the 1st and 3rd quartiles (interquartile range). Line inside the box represents the median (2nd quartile). Error bars extend from the minimum to the maximum value excluding extreme values (asterisks).

2.5. Behavioral mapping

Connection was performed at 21 days postimplantation, children were equipped with the Sprint speech processor and the processor was programmed with Cochlear Corporation's Custom 3.2 EP software.

Behavioral levels, stimulation threshold level (T-level) and maximum comfortable level (C-level) were obtained using tone burst stimulus.

T level is the lowest current level at which a conditioned or an observable behavioral response is obtained while C level is the maximum current level which causes behavioral response of discomfort.

2.6. Collected data and statistical analysis

Data were analyzed using MedCalc© version 14 (MedCalc© Software bvba, Ostend, Belgium) and the DAG Stat spreadsheet.

Skewed numerical data were presented as median (interquartile range) and between-group comparisons were done using the Mann–Whitney test.

Inter-observer and inter-method agreement was assessed by calculation of the weighted kappa statistic (κ) and the prevalence-adjusted and bias-adjusted kappa (PABAK) (16).

3. Results

The results showed that both methods can measure the indentify the individual electrodes and measure their EMD; there was no statistically significant difference in the EMD measured by DECT and MDCT as the p value ranges between 0.676 and 1 for each electrode; also, there is no statistically significant difference between the images quality between DECT and MDCT as both methods have total quality score of 4 with p value of 0.833 with moderate agreement between the two observers with weighted K of −0.111 for DECT cases and −0.098 for MDCT cases. Regarding the radiation dose there is a statistically significant difference between the two methods as the median radiation dose for DECT was 221.7 DLP (187.0–302.1) while that of MDCT was 400.5 DLP (370.8–500.1) with p value of 0.0002.

Analysis of the measures of EMD by DECT showed that it ranges between 1 mm and 6.7 mm (mean 3.5107 mm ± SD 1.51466).

There is a statistically significant correlation between the EMD and the NRT threshold with correlation coefficient $r = 0.684$.

There is a statistically significant strong positive correlation (p value < 0.01) between the EMD and the T-level with correlation coefficient $r = 0.641$ as shown in Table 2.

There is a statistically significant strong positive correlation (p value < 0.01) between the EMD and the C-level with correlation coefficient $r = 0.623$ as shown in Table 3.

The correlation between EMD, threshold level and comfortable level with regression line is summarized in Fig. 4.

Table 2 Correlation between EMD and T-level.

		Electrode modiolus distance	Threshold level
Electrode modiolus distance	Pearson correlation	1	0.641[a]
	Sig. (2-tailed)		0.000
Threshold level	Pearson correlation	0.641[a]	1
	Sig. (2-tailed)	0.000	

[a] Correlation is significant at the 0.01 level (2-tailed).

Table 3 Correlation between EMD and C-level.

		Electrode modiolus distance	Comfortable level
Electrode modiolus distance	Pearson Correlation	1	0.623[a]
	Sig. (2-tailed)		0.000
Comfortable level	Pearson Correlation	0.623[a]	1
	Sig. (2-tailed)	0.000	

[a] Correlation is significant at the 0.01 level (2-tailed).

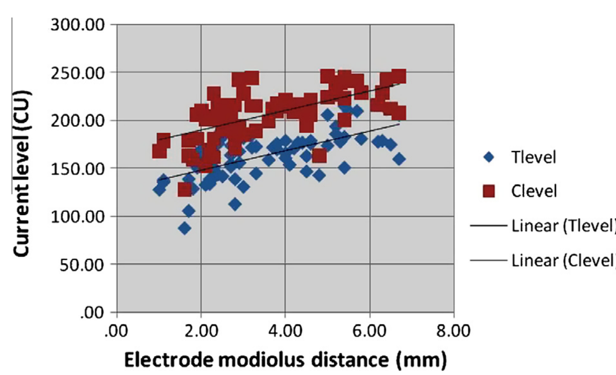

Fig. 4 Correlation between EMD, T-level and C-level.

4. Discussion

MDCT has proven its efficacy in the postoperative imaging of CI patients (4,17). The use of DECT in postoperative evaluation of CI patients has not yet been studied to our knowledge.

The aim of this study was to evaluate whether it is possible to obtain high resolution images of implanted cochlea using DECT by reduction of the metallic artifacts and radiation dose to those critical pediatric patients and to study the correlation between the EMD, the NRT and behavioral mapping levels.

In this study, the radiation dose of DECT was found to be significantly lower than that of MDCT without a significant difference regarding the images quality.

The radiation dose (DLP) of DECT ranged between 187 and 302.1 milligray × centimeter (median = 221.7 milligray × centimeter), while in a study done by Nauer et al. (18), a low dose CT protocol was used for preoperative MDCT imaging of the inner ear in pediatric patients; the radiation dose was found to range between 40 and 49 milligray × centimeter (20), although the radiation dose in our study seems to be higher yet this could be explained by the difference in the study population as our study was concerned by post-CI patients with metallic prosthesis requiring different imaging protocols to overcome the induced artifacts; to our knowledge, no study was done measuring the radiation dose in postoperative CT imaging of pediatric CI patients to correlate its results with ours.

This study revealed that in 25 patients, the electrode arrays were fully inserted and the electrodes could be clearly distinguished in all turns of the cochlea. There was a decrease in the EMD measurements between the selected electrodes and the modiolus from electrode number 1 toward electrode number 22. This is in agreement with cochlear anatomy as the electrode number 1 is in the wide basal turn while the electrode number 22 is in the narrow apical turn.

Verbist et al. (19) described in a case series study using MDCT in vivo imaging of CI on which individual electrodes were distinguished. They conducted their study on Clarion CII cochlear implant with 16 electrodes distributed on 2.5 mm, in comparison with Nucleus freedom device in this study which is characterized by 22 electrodes distributed on 1.5 mm, which means that Clarion CII cochlear implant has less metallic artifact, also their series reports only 3 cases in comparison with this study which was conducted on 25 patients; the usage of higher version DECT machine allowed the authors to overcome the crowding of the 22 electrodes and the metallic artifacts produced and to identify them precisely.

The combination of high image quality and low radiation dose was achieved by the use of low tube voltage, high tube current and low rotation time. This is in agreement with a study done by Tang et al. (20), which revealed that it is possible to reduce radiation dose without degradation of image quality by reducing tube voltage and increasing tube current.

This study revealed a significant positive correlation between NRT threshold and EMD which means that as the EMD increases, the NRT threshold increases.

There was also a significant positive correlation between EMD and T-level and between EMD and C-level. These results support the hypothesis that threshold and comfortable levels would reduce as the distance of the electrode from the modulus decreases, and this is in agreement with the study done by van Wermeskerken et al. (2); yet this study was conducted in only 5 adult patients and investigated only 3 basal electrodes (1, 4 and 7) which represents only the high frequencies in comparison with this study which was conducted in 25 pediatric patients and investigated 5 electrodes (1, 6, 11, 16 and 22) representing different frequencies (high, medium and low).

These results are also in agreement with the study done by Esquia Medina et al. (21) which was conducted on 22 adult patients (25 ears) and showed that cases with greater EMD were associated with poorer short-term hearing performance (6 months after implantation); yet they found no correlation between EMD and hearing outcome at 12 months and the study done by Fischer et al. (22) was conducted on 63 CI with follow-up for 24 weeks and showed that scalar dislocation may require an increase of the necessary stimulus charge but it may not negatively influence the hearing threshold.

Our study still has some limitations; the most important of them are the small study population and short period of follow-up which require future studies including larger number of patients and longer follow-up period of hearing performance to give more accurate results.

5. Conclusion

Dual energy CT scan is a very useful tool in high resolution postimplantation imaging in pediatric patients with CI enabling detection of the individual electrode position inside the cochlea with radiation dose lower than that of multidetector CT.

There is a significant positive correlation between the electrode position and both NRT threshold and behavioral levels; however, more studies are needed to be done in order to be able to use this relation in CI fitting which is a difficult challenge in pediatric patients.

Conflict of interest

The authors declare that there are no conflict of interests.

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