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Radiation dose reduction in postoperative computed position control of cochlear implant electrodes in lambs – An experimental study

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ABSTRACT

Objective: Cochlear implants (CI) are standard treatment for prelingually deafened children and postlingually deafened adults. Computed tomography (CT) is the standard method for postoperative imaging of the electrode position. CT scans accurately reflect electrode depth and position, which is essential prior to use. However, routine CT examinations expose patients to radiation, which is especially problematic in children. We examined whether new CT protocols could reduce radiation doses while preserving diagnostic accuracy.
Methods: To investigate whether electrode position can be assessed by low-dose CT protocols, a cadaveric lamb model was used because the inner ear morphology is similar to humans. The scans were performed at various volumetric CT dose-indexes CTDIvol)/kV combinations. For each constant CTDIvol the tube voltage was varied (i.e., 80, 100, 120 and 140 kV). This procedure was repeated at different CTDIvol values (21 mGy, 11 mGy, 5.5 mGy, 2.8 mGy and 1.8 mGy). To keep the CTDIvol constant at different tube voltages, the tube current values were adjusted. Independent evaluations of the images were performed by two experienced and blinded neuroradiologists. The criteria diagnostic usefulness, image quality and artifacts (scaled 1–4) were assessed in 14 cochlear-implanted cadaveric lamb heads with variable tube voltages.
Results: Results showed that the standard CT dose could be substantially reduced without sacrificing diagnostic accuracy of electrode position. The assessment of the CI electrode position was feasible in almost all cases up to a CTDIvol of 2–3 mGy. The number of artifacts did not increase for images within this dose range as compared to higher dosages. The extent of the artifacts caused by the implanted metal-containing CI electrode does not depend on the radiation dose and is not perceptibly influenced by changes in the tube voltage.

Summarizing the evaluation of the CI electrode position is possible even at a very low radiation dose.
Conclusions: CT imaging of the temporal bone for postoperative electrode position control of the CI is possible with a very low and significantly radiation dose. The tube current–time product and voltage can be reduced by 50% without increasing artifacts. Low-dose postoperative CT scans are sufficient for localizing the CI electrode.

1. Introduction

Cochlear implantation (CI) has become a highly standardized and safe surgical procedure in the last decades, and CI is now an established treatment for hearing restoration in prelingually deafened children. The indications for CI implantations are constantly expanding, so children with residual hearing and no hearing aid benefit are also eligible CI candidates. Hearing preservation and an atraumatic surgical procedure for the

Abbreviations: CBCT/DVT, cone-beam CT/digital volume tomography; CTDIvol, volumetric CT dose index.

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preservation of cochlear structures are essential in such cases [1]. Postoperative imaging for the determination of CI electrode position is important for three reasons: (1) Electrode malposition in the scala vestibuli has a direct impact on residual hearing and also on hearing outcome; (2) Cochlear malformations might increase the risk for electrode misplacement in other structures such as the vestibule, thus requiring surgical revision; and (3) The number of inserted electrodes determines hearing performance and is essential for the first CI mapping.

Perioperative imaging using conventional transorbital radiographic images of both cochleae (cochlear view) assists surgeons in assessing the implant position after insertion of a CI electrode. As an alternative to conventional radiography, a computer tomography (CT) scan might be ordered, especially in cases with high CI electrode impedances and doubtful neuronal response in telemetry results [2–5]. Some centers that perform CI use integrated intraoperative CT or portable cone-beam CT/digital volume tomography (CBCT/DVT) scanners, however, these machines are not routinely used or even available in current practice. Because conventional radiography provides little information about electrode position [5], the majority of infants receive a postoperative CT scan. CT scans provide details about the cochlea and the distribution of electrodes within the cochlea [2,6,7] and is currently a standard method for quality control after CI surgery.

A temporal bone CT scan is a radiation-intensive investigation [8]; the applied effective dose of a skull CT is about 20 times higher than a conventional anterior–posterior radiography of the skull [9,10]. Optimized low-dose radiation protocols have the potential to reduce radiation exposure significantly without sacrificing validity [11]. Such low-dose protocols were successfully used in computer-assisted endoscopic sinus surgery [12,13].

Children are particularly sensitive to ionizing radiation. Brenner et al. [14] assessed the lifetime cancer mortality risks attributable to pediatric CT radiation. They reported that the estimated lifetime cancer mortality risks attributable to the radiation exposure from a CT examination of a one year old are 1 in 550 for a single abdominal CT, and one in 1500 for a head CT. They claimed that the risks are an order of magnitude higher than for adults, although this is a small increase in cancer mortality over the natural background rate. They reported that of the 600,000 abdominal and head CT examinations performed on American patients less than 15 years of age, approximately 500 might ultimately die from cancer attributable to CT radiation [14]. The use of CT scans in children to deliver cumulative doses of about 50 mGy might almost triple the risk of leukemia and doses of about 60 mGy might triple the risk of brain cancer [15]. Because these cancers are relatively rare, the cumulative absolute risks are small: in the 10 years after the first scan for patients younger than 10 years, one excess case of leukemia and one excess case of brain tumor per 10,000 head CT scans is estimated to occur [15]. Nevertheless, although clinical benefits should outweigh the small absolute risks, it is important to optimize radiation doses from CT scans for this patient population. This can be evaluated by applying question-focused examination protocols and by adjusting the study parameters to each child's physical condition. Use of unit protocols should be avoided [16]. CT protocols adjusted for age and body weight enable reduction of radiation exposure [17]. The dose adjustment in pediatric CT protocols is usually done by lowering the current–time- product (milliampere-second, mAs) [18]; however, reduction of the tube voltage (kilovolts, kV) is also recommended [19,20]. Vock [20] concluded that the required photon energy (kV) for irradiating a child's body is less than in an adult; while the application of 120 kV is reasonable for an average adult, the photon energy required for children ranges from 80 kV to 100 kV. A reduction in the energy of the photon spectrum results in a slight shift of the physical interaction of ionizing radiation from the Compton scattered radiation toward the photon absorption and at the same time leads to increased contrast between tissues of different mean atomic density. Thus, a higher image contrast can be achieved even at reduced tube voltage. On the other hand, reinforced metal artifacts are common at reduced tube voltage.

The objective of this study was to determine experimentally in a young sheep cadaveric model (lamb) to what extent the CT radiation dose may be reduced without affecting the evaluation of the implant electrode position. Secondary objectives were to determine whether the tube voltage affects the image quality and whether a lower tube voltage yields a sufficient image quality.

2. Materials and methods

For this experimental work no permission was required by the Cantonal Ethics Committee or the Cantonal Animal Experimentation Commission; no live animals were studied.

2.1. Anatomical specimen and cochlear implantation in lambs

We used 14 cadaveric lamb temporal bones, which served as a model for an infant skull and inner ear structure. As reported by Seibel et al. [21,22] and Schnabl et al. [23], the morphology of the lamb's inner ear is very similar to that of humans and is appropriate for experimental oto-surgical studies with implantable hearing devices. The authors morphometric studies [21,22] revealed a high degree of similarity in the anatomy of the ear in sheep and in humans. A comparison between sheep anatomy of the temporal bone and that of humans showed that almost all structures of the ear in sheep measure at least 2/3 of the equivalent structures of the human ear, except for the horizontal diameter and the surface of the tympanic membrane.

Six-month-old lambs have a head diameter comparable to children less than 2 years of age [24].

Heads of 14 six-months-old lambs, bred and slaughtered for human consumption, were purchased at the slaughterhouse. We chose lambs instead of adult sheep due to European regulations related to bovine spongiform encephalopathy. Heads were bathed for 2 weeks at the Institute of Pathology of the University of Bern in neutral buffered formalin (4% formaldehyde solution in phosphate buffer, pH 7.4).

Four otologists did a mastoidectomy using surgical metal drills to gain access to the lamb's middle ear. Unlike humans, the mastoid was poorly or incompletely pneumatized. The canal wall was pared away (canal-wall-down mastoidectomy) and the labyrinth block and facial nerve were partially removed in order to gain access to the round window niche. The electrodes were inserted in the cochlea using a standard round window approach.

2.2. Computed tomography

CT scans were performed with an 8-row scanner (LightSpeed Ultra, GE Healthcare, Milwaukee, WI, USA). The standard high-resolution technique for temporal bone CT was applied for all examined lamb heads. The heads were positioned coronal and a helical scan with a field of view of 10 cm was performed. From the resulting data set 0.625 mm thin layers were reconstructed with 68% overlap. Additionally, an edge-lifting kernel ("bone plus") was used. We opted for a coronal position because the resulting head diameter and the inner ear structures were most similar to human infants.

The scans were performed at various volumetric CT dose-indexes (CTDIvol)/kV combinations. For each constant CTDIvol the tube voltage was varied (i.e., 80, 100, 120 and 140 kV). This procedure was repeated at different CTDIvol values (21 mGy, 11 mGy, 5.5 mGy, 2.8 mGy and 1.8 mGy; Table 1). To keep the CTDIvol constant at different tube voltages, the tube current values