AMERICAN JOURNAL OF OTOLARYNGOLOGY–HEAD AND NECK MEDICINE AND SURGERY 37 (2016) 162–168

Available online at www.sciencedirect.com

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Hearing loss patterns after cochlear implantation via the round window in an animal model

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ARTICLE INFO

Article history:
Received 8 October 2015

ABSTRACT

Purpose: The mechanism and the type of hearing loss induced by cochlear implants are mostly unknown. Therefore, this study evaluated the impact and type of hearing loss induced by each stage of cochlear implantation surgery in an animal model.
Study design: Original basic research animal study.
Setting: The study was conducted in a tertiary, university-affiliated medical center in accordance with the guidelines of the Institutional Animal Care and Use Committee.
Subjects and methods: Cochlear implant electrode array was inserted via the round window membrane in 17 ears of 9 adult-size fat sand rats. In 7 ears of 5 additional animals round window incision only was performed, followed by patching with a small piece of periosteum (control). Hearing thresholds to air (AC) and bone conduction (BC), clicks, 1 kHz and 6 kHz tone bursts were measured by auditory brainstem evoked potential, before, during each stage of surgery and one week post-operatively. In addition, inner ear histology was performed.
Results: The degree of hearing loss increased significantly from baseline throughout the stages of cochlear implantation surgery and up to one week after ($p < 0.0001$). In both operated groups, the greatest deterioration was noted after round window incision. Overall, threshold shift to air-conduction clicks, reached 61 dB SPL and the bone conduction threshold deteriorated by 19 dB SPL only. Similar losses were found for 1-kHz and 6-kHz frequencies. The hearing loss was not associated with significant changes in inner ear histology.
Conclusions: Hearing loss following cochlear implantation in normal hearing animals is progressive and of mixed type, but mainly conductive. Changes in the inner-ear mechanism are most likely responsible for the conductive hearing loss.

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http://dx.doi.org/10.1016/j.amjoto.2015.12.004
0196-0709/

1. Introduction

Cochlear implantation has become the treatment of choice for patients with profound hearing loss. Findings of remarkable improvement in speech understanding and auditory communication have prompted clinicians to widen the selection criteria to patients with near-normal hearing or with moderate low frequency hearing loss and severe high frequency loss [1] who can be treated with combined acoustic and electrical stimulation. However, while this approach is contingent on the presence of some acoustic hearing, cochlear implantation is itself a risk factor for residual hearing loss. Therefore, several studies have suggested techniques to reduce intracochlear trauma during implantation, including a round-window approach [1–6]. Nevertheless, in a 2008 review study of various cochlear implants (Nucleus Hybrid; Medel Combi +40/−40 M; Nucleus 24 contour advanced) with insertion depths ranging from 6 to 27 mm, substantial acoustic hearing loss was noted in 24% of 253 patients after cochlear implantation, including total hearing loss in 13% [7]. Induction of low and high frequency hearing loss occurred in the majority of patients after implantation of long electrodes [8–11] and even with the use of short basal electrodes [1]. The mechanism responsible for cochlear-implant-induced residual hearing loss is largely unknown. Some studies suggested that it may involve immediate, direct trauma to the cochlear structures [5,12–15] and delayed loss could be due to a host response to the electrode or to introduction of bone dust into the perilymphatic space at the site of insertion [16,17]. However, Roland et al. [18] failed to find significant structural trauma in 30 of 32 temporal bones following insertion of a full-coverage electrode or a 10-mm hybrid electrode. One study found that auditory performance with the implant was unrelated to the percentage or type of structural elements that remained normal [2].

It is also possible that there is a change in the mechanical behavior of the middle or inner ear or both, at each stage of cochlear implant surgery. Even if the cochlear implant electrodes do not directly contact or damage the basilar membrane [19,20], the size of the electrode can affect the volume and geometric shape of the scala tympani, modifying the pressure waves propagated from the stapes to the round window. A deficiency in conduction of acoustic stimuli from the middle ear to the organ of Corti was found to induce almost pure conductive hearing loss [21–23]. On the other hand, a significant impairment in the transduction process in the organ of Corti would lead to an increase in the BC threshold. To date, differentiating between conductive and cochlear hearing loss in patients after cochlear implantation is difficult due to the lack of BC thresholds in addition to the AC threshold measurements [6,12,24]. Therefore, the present study is the first to assess the pattern of hearing loss during and after cochlear implantation using a normal-hearing fat sand rat model, including measurements of both AC and BC thresholds.

2. Materials and methods

2.1. Experimental model

The fat sand rats used in the study were handled and housed according to the standards described by the National Ministry of Health Guidelines for the Care and Use of Laboratory Animals. The study was approved by the Rabin Medical Center Animal Care and Use Committee (approval number 022-b3362-1). The animals were supplied by Harlan Biotech Israel, Ltd. (Rehovot, Israel).

The fat sand rat (*Psammomys obesus*) is a terrestrial mammal of the gerbil subfamily. As in other rodents (rats, guinea pigs, chinchillas), the cochlea, vestibule, and semicircular canals bulge into the bulla cavity and can be easily accessed. The stapedial artery lies between the stapes crura, away from the round window niche. The cochlea consists of 3.25 turns [25]. Similar to other gerbils, the length of the basilar membrane is about 11.7 mm [26], and the cross-section of the scala tympani at the base measures about 0.37 mm^2 [27]. Measurements of ganglion cell density, slope of place frequency along the cochlea, and auditory thresholds have shown that the auditory sensitivity of the fat sand rat range is between 0.1 and 40 kHz with best thresholds at frequencies of 1–4 kHz, similar to best sensitivity in human ears [26,28]. The inner and middle ears of the fat sand rat have been extensively studied in our laboratory [21–23,29] and by others [25,30].

The present study was performed on 9 adult-size, 6-month-old fat sand rats, weighing 225–262 g (average 247.5 g). A total of 17 ears were included, as follows: 12 ears underwent electrode round window insertion and 5 ears underwent incision of the round window membrane only, followed by a patch made of a small piece of periosteum from the bulla, without insertion of the electrode array. The operated cochlea (right/left) in each animal was selected at random.

2.2. Procedure

Animals were anesthetized by intramuscular injection of ketamine 0.75 mg/kg and xylazine 0.5 mg/kg. Additional doses were given as needed. The patency of the tympanic membrane was confirmed by visual inspection and tympanometry.

Core temperature was monitored with a rectal probe and maintained at approximately 37 °C with heating pads. A retroauricular incision was made, and the retroauricular muscles and skin were dissected to expose the bulla. The bulla was opened under a microscope, using a delicate drill, and the round-window niche was drilled open to expose the membrane. To verify the location and mobility of the round window, the stapes was gently mobilized, resulting in movement of a light reflection on the round-window membrane.

The round-window membrane was then incised with a Rosen knife. A soft and flexible electrode array measuring 0.3 mm in diameter (Medel, Innsbruck, Austria) was gently inserted through the incision into the scala tympani, to a depth of 3–5 mm (Fig. 1). A small piece of periosteum from the mastoid bulla was used to fix the implant in the fenestra, as well as to obliterate any gap that could result between the implant and the fenestra wall. This was followed by auditory measurements. In the animals with two operated ears, cochlear implantation was performed in both simultaneously. It is important to note that only the cochlear implant electrode array was inserted, without the receiver and magnet and therefore other changes that could cause middle ear conductive hearing loss (posterior tympanotomy, ossicular