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Cochlear Implant Impedance Fluctuation in Ménière's Disease: A Case Study

Celene McNeill and Kate Eykamp

Healthy Hearing and Balance Care, Sydney, NSW, Australia

Objective: To contribute to the understanding of hearing fluctuation in Ménière's disease (MD) by disseminating a case study of a cochlear implanted ear with ongoing fluctuation of electrode impedances with episodic tinnitus and no associated vestibular symptoms.
Study Design: Retrospective case review.
Setting: Tertiary referral audiology clinic.
Patient: Man, born in 1936, with a total hearing loss in the right ear because of Mumps at age 8 years and a fluctuating progressive hearing loss in the left ear because of Ménière's disease since age 63 years.
Intervention: Sequential bilateral cochlear implantation right ear in August 2002 and left ear in March 2006.
Main Outcome Measure: Impedance measurements of implanted intracochlear electrodes via common ground stimulation using proprietor programming software.
Results: Electrode impedances in the MD showed significant ongoing variation since implantation, whereas the contralateral non-MD ear remained stable over a period of 9 years.
Conclusion: Electrode impedances in the ear with MD showed a variation pattern similar to that found in the hearing fluctuation characteristic of the disease. These findings raise the possibility that the same physiological mechanisms of hearing fluctuation may be responsible for intracochlear electrode impedance changes. We hypothesize that impedance fluctuation is because of changes in the permeability of the blood–labyrinth barrier because of cyclic immune activity in the inner ear which alters the electrical resistance between scala tympani and blood. **Key Words:** Cochlear implant—Electrode impedance—Hearing fluctuation—Impedance fluctuation—Ménière's disease—Tinnitus.
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Hearing fluctuation is a characteristic of Ménière's disease (MD) well documented in the literature (1). Despite hearing fluctuation, studies have shown that hearing aids are beneficial to alleviate hearing loss (2,3) but as the disease progresses they become less effective and many patients become eligible for cochlear implant (CI). Studies have shown that CI can successfully rehabilitate hearing in patients with MD who meet the audiological criteria for candidacy (4–7).

Interestingly, there have been reports that some patients continue to experience hearing fluctuation after receiving a CI in the MD ear (4–6). Graham and Dickins (8) were the first authors to report fluctuation of electrical thresholds in ears with MD and CI. Lustig et al. (4) also reported hearing fluctuation in patients with MD post-CI, noting that some patients experienced alterations in implant performance in association with fluctuations in vestibular symptoms over a follow-up period of 1 to 5 years. Two other studies recently reported hearing fluctuation in patients with MD post-CI, with incidence ranging from 33 to 55% depending on sample size (N = 13, 8) and follow-up period (3.5–2 yr) (5,6). CI remapping was sufficient to restore speech perception and hearing (5,6). Neuburger et al. (9) reported 16 patients with 18 affected ears in whom impedance increases were clearly demonstrated without any sign of previous inflammation.

Endolymphatic hydrops is widely accepted as the underlying cause and physiology of hearing fluctuation remains poorly understood. A clear explanation of the mechanisms of these fluctuations would be invaluable to our understanding of MD.

This Study

This article reviews a unique case study of a patient with bilateral cochlear implants who presented significant electric hearing fluctuation in the ear affected with MD comparing to the contralateral non-MD ear.

METHODS

Patient consent was sought and granted before writing this case study.

The patient was implanted with a Cochlear Nucleus CI24CS in August 2002 in the right ear after 50 years of total hearing loss attributed to mumps. The left ear was diagnosed with MD in 2001 and was implanted with a Cochlear Nucleus CI24RECA

Address correspondence and reprint requests to Dr. Celene McNeill, Ph.D., Healthy Hearing and Balance Care, 1/1204 Newland Street, Bondi Junction, NSW 2022, Australia;
E-mail: celene@healthyhearing.com.au

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in March 2006 after fluctuating hearing loss progressed to severe levels. Both cochlear implants were the ''contour'' design of different generations. The CI24CS was the first generation and the soft tip of the CI24RECA is the only difference between the two electrodes. Both implants have 22 tonal topic intracochlear electrodes, with electrode 1 being the most basal (high frequencies) and 22 the most apical (low frequencies).

At the time of this review the patient had 37 visits to the clinic after receiving the second implant in 2006. During each visit the patient's experience was noted including subjective report of hearing, speech intelligibility, hyperacusis, tinnitus, and vestibular symptoms; electrode impedances were measured in each ear; and implant was remapped if required. The authors found that simple remapping of the implant was able to address impedance fluctuation and perceived distortion in speech perception and hearing though the implant. Mapping was conducted by subjectively measuring threshold (T) and comfortable (C) levels and balancing each electrode for equal loudness perception. Since the initial maps, electrodes 1 and 2 were disabled in right ear and electrode 1 in left ear because of nonauditory percept.

Thirty-eight measurements were recorded from 20 active intracochlear electrodes from the right CI (non-MD) using Custom Sound Cochlear Ltd proprietor software as shown in Figure 1A and 50 measurements from 21 active electrodes from the left CI (MD) as shown in Figure 1B. It should be noted that the left CI had more than one measurement within one session. These results were exported into an Excel spread sheet for analysis.

For the purposes of our analysis, common ground mode impedance measurements were used and results obtained before

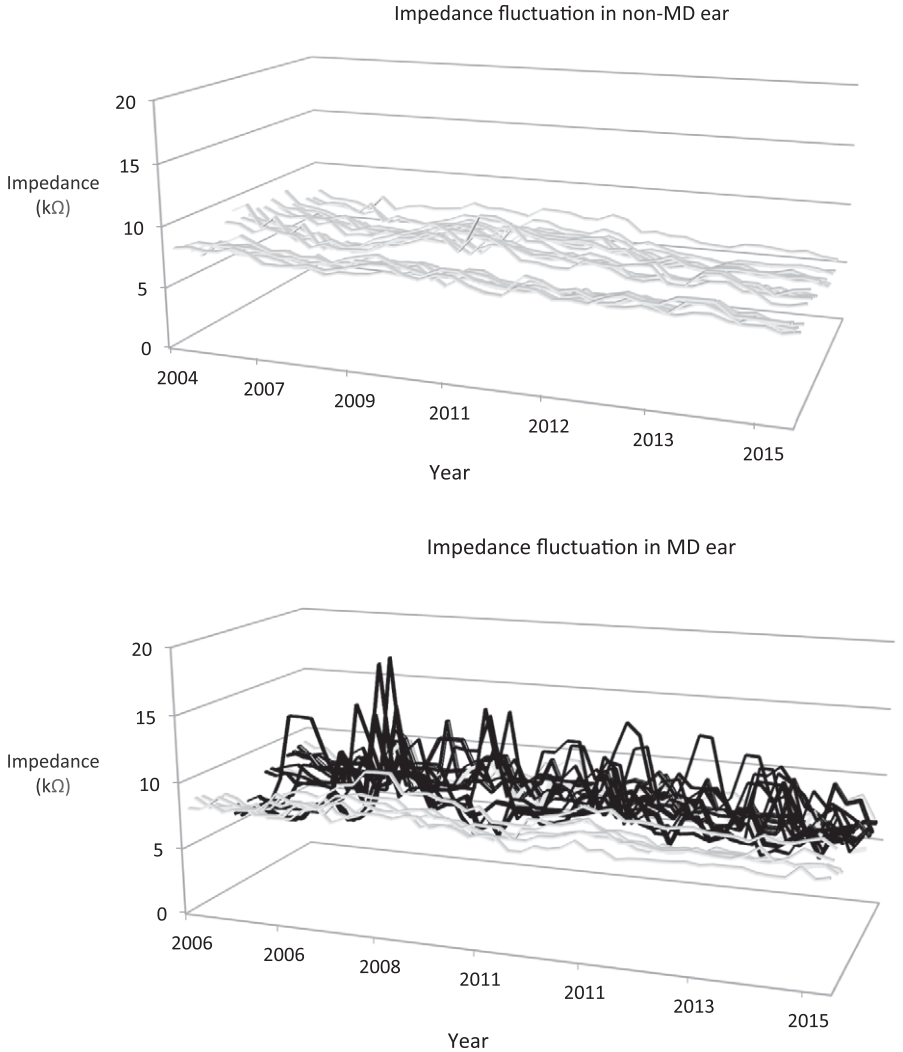

FIG. 1. *A*, Impedance measurements in kΩ of the 20 active intracochlear electrodes in the non-MD ear over time. Each line represents one electrode. At the front of the graph is electrode 3, which is the most basal and at the back is electrode 22, which is the most apical. *B*, Impedance measurements in kΩ of the 21 active intracochlear electrodes in the MD ear over time. Each line represents one electrode. At the front of the graph is electrode 2, which is the most basal and at the back is electrode 22 which is the most apical. Black lines represent electrode impedance fluctuation >3 kΩ between measures; gray lines represent fluctuation <3 kΩ between measures. MD indicates Ménière's disease.

TABLE 1. *Mann–Whitney test results*

Variability	Right CI Non-MD	Left CI MD	*Z* Value	Significance (2-Tailed)
Standard Deviation	0.65	1.21	−2.95	0.003*
Variance	0.46	1.75	−2.91	0.004*

MD indicates Ménière's disease.
*Statistically significant ($P < 0.01$).

6 weeks post-switch-on were excluded, as unstable impedances are expected during this initial period. Impedances of electrodes 1 and 2 of the right ear and electrode 1 of the left ear were also excluded from analysis as they were not enabled in the maps.

Statistical Analysis

Descriptive statistics were obtained using Microsoft Excel. Figures and graphs were created to explore the variability between ears as well as within and across electrodes over time. Mann–Whitney test was performed to quantify the variability (standard deviation, variance) between ears using SPSS.

RESULTS

The pattern of impedance fluctuation over time was clearly different between the two ears. Figure 1A depicts the results of the non-MD ear, which shows that all electrodes fluctuated less than 3 kΩ between measurements. Figure 1B depicts the results for the MD ear showing electrodes 9, 10, 11, 12, 13, 14, 15, 16, 18, 19, 20, and 22 which fluctuated more than 3 kΩ between measurements (represented by black lines) and the remaining electrodes which fluctuated less than 3 kΩ (represented by gray lines).

Mann–Whitney test confirmed a statistically significant difference in the variability of impedance measurements between ears (Table 1).

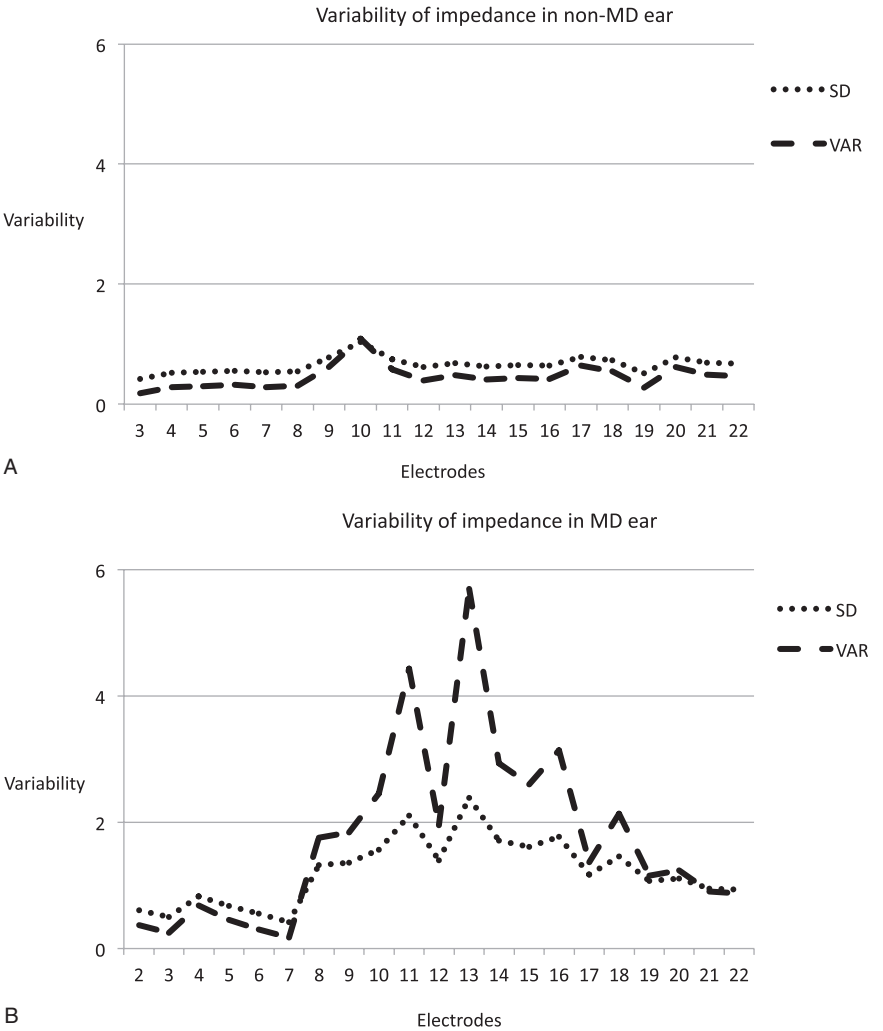

FIG. 2. *A*, Variability of impedance measurements at each electrode in the non-MD ear. Dotted line represents standard deviation (SD) of measurements from mean within each electrode, and dashed line represents variance (VAR) or spread of measurements within each electrode. *B*, Variability of impedance measurements at each electrode in the MD ear. Dotted line represents standard deviation (SD) of impedance measurements from mean within each electrode, and dashed line represents variance (VAR) or spread of measurements within each electrode. MD indicates Ménière's disease.

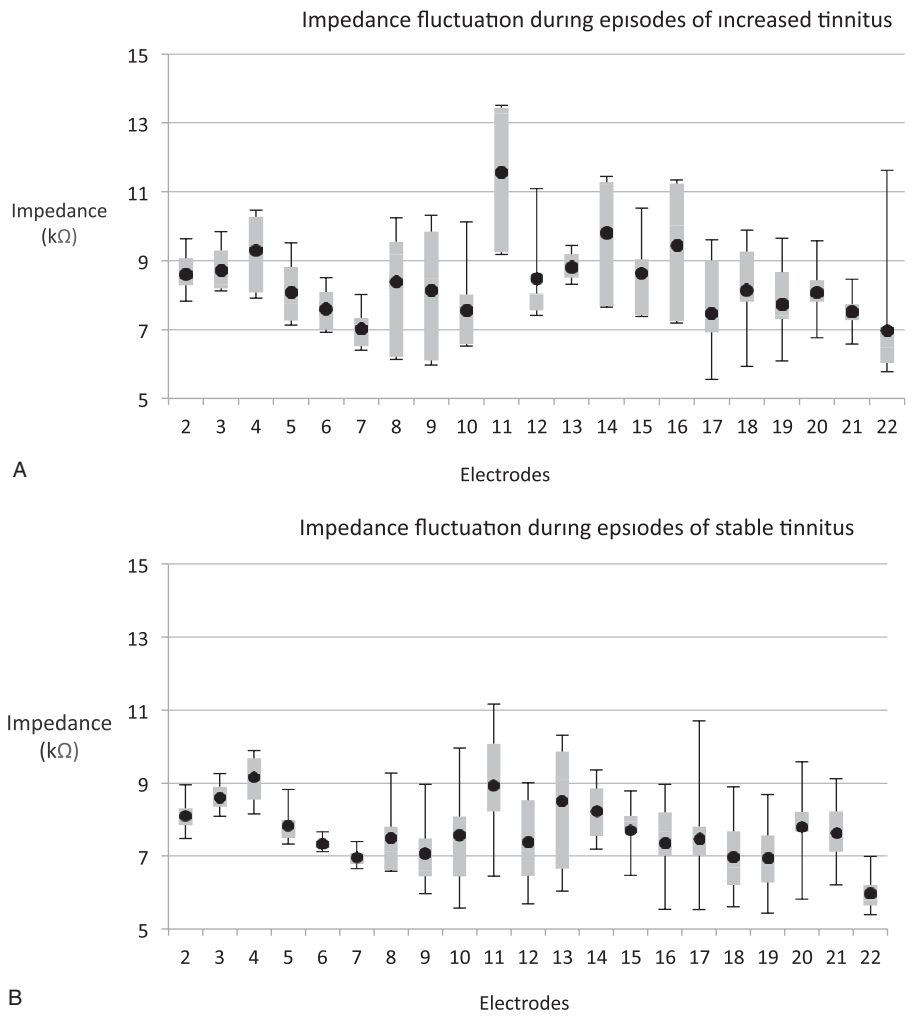

FIG. 3. *A*, Impedance measurements in kΩ of the 21 active intracochlear electrodes in the MD ear averaged from 9 occasions when the patient reported increase in tinnitus. Box plots represent the second and third quartiles and mean is marked by circle. *B*, Impedance measurements in kΩ of the 21 active intracochlear electrodes in the MD ear averaged from 9 occasions when the patient reported stable tinnitus. Box plots represent the second and third quartiles and mean is marked by circle.

Figure 2A and B provides a detailed comparison of the variability in impedances across electrodes. Standard deviation and variance showed the greatest fluctuation occurred in electrodes 9 to 16 in the MD ear, which according to proprietor software and the patient's map represents the mid frequency range in the cochlea (electrode 16 is allocated to around 900 Hz, electrode 9 is allocated to around 3000 Hz).

Despite constant impedance fluctuation there was only one episode of vertigo reported over this 9-year period and did not coincide with any noticeable differences in impedance fluctuation.

Tinnitus, on the other hand, showed some association with impedance fluctuation. As seen in Figure 3, electrodes 11, 12, 14, 15, and16 showed a spike compared with subsequent measurement when tinnitus had resolved. Figure 3A was obtained when the patient attended the clinic for review complaining of a sudden reoccurrence of roaring tinnitus in the MD ear. Figure 3B was obtained at subsequent review when tinnitus had gone back into remission.

It should be noted that simple remapping of the implant was sufficient to resolve the patient's reported hearing and tinnitus disturbance. Speech perception tests performed after remapping also returned to baseline scores.

DISCUSSION

The primary finding of this study was that there was a significant difference in the stability of electrode impedances in a MD compared with a non-MD ear within the same subject. Such variations are unlikely to be attributed to electrode differences as both were the contour design from the same manufacturer and insertions were performed by the same surgeon using the same technique

with no post-op complications. Such variations are also unlikely to be attributed to duration of deafness (another point of difference between ears), as binaural sequential CI has been well documented in the research and no article to date has reported a similar pattern of asymmetrical impedance fluctuation (4,7,10).

Hearing fluctuation was not expected in an ear after implantation, as CI by-passes sensory structures and directly stimulates the eighth nerve via electric current pulses. However, this case study clearly shows that this phenomenon can occur. Consistent with other studies, we also found that simple remapping of the implant addressing impedance fluctuation was sufficient to restore hearing and speech perception (5,6). These findings seem to suggest that fluctuation of CI performance is unlikely to be caused by changes in the sensitivity of the auditory nerve.

In our case study there was a relationship between electrodes impedance changes and tinnitus perception. Roaring tinnitus was reported during impedance spikes suggesting that alterations of electrical activity in the cochlea are perceived by the auditory cortex.

Importantly, there was no association between electrode impedance fluctuation and vestibular symptoms. This is consistent with previous findings that hearing fluctuation does not always correlate with vertigo attacks in patients with MD (11).

Different theories try to explain fluctuation of CI performance in MD. The most common postulates that endolymphatic hydrops cause the scala media to bulge, altering the electrode position relative to target neurons, leading to changes in implant impedances. Scarring, fibrosis, and ossification after implantation, however, make this possibility less likely (6). Furthermore, recent unpublished animal studies (Brown) (12) have shown no CI impedance changes after endolymph injection in the cochlea of guinea pigs. A more recent theory suggests that CI fluctuation may not be because of electrode displacement, but rather that endolymphatic hydrops directly affect the connection between the electrode and the afferent and spiral ganglion neurons (6).

Although the mechanisms causing CI fluctuation remain speculative, we think it is fundamentally related to the pathology underlying MD. In our case study, the patient's contralateral non-MD ear with a similar device had stable impedances in stark contrast to the ongoing fluctuation observed in the ipsilateral MD ear.

MD is most likely because of multifactorial causes. Our hypothesis in this case is that cyclic immune activity in the inner ear may be one such cause contributing to CI impedance fluctuations. We think that changes in the permeability of the blood–labyrinth barrier alter the electrical resistance between the scala tympani and blood, in particular the blood–labyrinth barrier. This resistance creates fluctuations in endolymph potential and cochlear implant sensitivity in MD ears. Further animal studies by Brown et al. (13) are planned to test this hypothesis.

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