A Comparison of ECochG With the Subjective Sound Perception During Cochlear Implantation Under Local Anesthesia—A Case Series Study

*Pia Linder, †Matti Iso-Mustajarvi, and †Aarno Dietz

*Department of Otorhinolaryngology; and †Microsurgery Center of Eastern Finland, Kuopio University Hospital, Finland

Objective: Intraoperative electrocochleography (ECochG) has been proposed for cochlear monitoring to minimize trauma during the insertion of the electrode of a cochlear implant (CI). CI surgery is normally performed under general anesthesia, which is why intraoperative ECochG measurements have never been validated against the patient’s subjective sound perception. The main objectives of this study were to investigate the feasibility of cochlear monitoring based on the patients hearing and to validate it against intraoperative ECochG measurements during CI surgery under local anesthesia.

Study Design: Prospective case series study.

Setting: Tertiary referral center.

Patients: Patients eligible for cochlear implantation with residual hearing (pure-tone threshold averages [PTA] 250–1000 Hz ≤ 75 dB HL). Additionally, patients should be able to hear ECochG stimuli at 250, 500, or 1000 Hz at less than or equal to 100 dB (HL).

Interventions: Cochlear implantation under local anesthesia without conscious sedation. Intraoperative ECochG monitoring.

Main Outcome Measures: The development of ECochG amplitudes and the patients’ subjective perception to the sound stimuli.

Results: In all patients, monitoring based on their subjective sound perception was feasible, whereas, reliable ECochG responses could be measured in seven patients. Sixty percent of the registered declines in ECochG amplitude were associated with a concomitant attenuation of the subjectively perceived sound.

Conclusions: The developments in the ECochG responses matched well with the changes of the sound stimulus perceived by the patients, which supports the applicability of ECochG for preventing insertion trauma. Monitoring of the patients subjective hearing appears to be more reliable than ECochG but requires surgery under local anesthesia without conscious sedation.

Key Words: Cochlear implantation—Electrocochleography—Hearing preservation—Intraoperative monitoring—Local anesthesia.

Electrocochleography (ECochG) is presently a topic of interest to researchers and is increasingly being applied also in the clinics to monitor cochlear function during cochlear implantation. It has been proposed that ECochG responses measured during the cochlear implant (CI) electrode insertion could predict postoperative hearing preservation and could act as a guide for the surgeon when inserting the electrode array to its optimal insertion depth. Furthermore, a real-time intraoperative ECochG measurement could give the surgeon feedback about the insertion process, which could help to prevent insertion trauma (1–4).

ECochG is an objective measurement, which assesses the electrophysiological response from the inner ear and the auditory nerve to an acoustic stimulus. During an intraoperative ECochG measurement, an acoustic stimulus of a certain frequency is provided through an inserted earphone. The most apical contact of the CI electrode array is generally used for monitoring during the electrode insertion. The response consists of compound action potential, a summation potential, cochlear microphonics, and auditory nerve neurophonics (3). In intraoperative monitoring, the focus is on the amplitude of the cochlear microphonic, although it is sometimes difficult
to separate from the auditory nerve neurophonics, when stimulating with low frequencies. Cochlear microphonics are thought to originate from the outer hair cells (5), thus the amplitude of cochlear microphonics, from now on referred to as the ECochG amplitude, depends on the presence and functional integrity of the outer hair cells. Therefore, it reflects the level of hearing if other neural structures are functional. Secondly, the size of the ECochG amplitude depends also on the distance of the recording site to the response site, i.e., the amplitude is smaller when the recording contact is at the level of the round window. The amplitude increases as the electrode contact proceeds into the cochlea and becomes closer to the cochlear depth, which is most sensitive to the frequency of the stimulation sound (4). If the recording contact passes beyond this point, the ECochG amplitude is expected to decrease. Other reasons thought to be responsible for a weaker or a total loss of response may be that the electrode array elevates the basilar membrane hindering its ability to vibrate, or that there has been a gross insertion trauma (e.g., rupture or breakage of the basilar membrane) leading to a loss of residual hearing (6,7). Thus, a decrease in ECochG amplitude may serve as a warning sign, to which the surgeon should react by trying to adjust the insertion process in the hope of avoiding imminent trauma. However, researchers and clinicians alike are still discussing how best to react appropriately to the amplitude changes and how ECochG responses can be reliably exploited during implantation procedures. Importantly, intraoperative ECochG measurements have never been validated against the patient’s subjective hearing perception of the loudness of stimuli during electrode insertion.

The aim of the present study was to investigate the feasibility of monitoring cochlear function by the patients’ subjective hearing perception to the presentation of a sound stimulus during cochlear implantation under local anesthesia. The second objective was to compare the changes in the sound quality and loudness against possible ECochG events. The study strives to gain further insights of the value of intraoperative ECochG monitoring in hearing preservation surgeries.

METHODS

Subjects

The study was conducted at the Kuopio University Hospital according to the guidelines of the Declaration of Helsinki, and it has been approved by the Institutional Review Board (5551877) as well as the Research Ethics Committee of the Northern Savo Hospital District (1600/2019). All the adult patients with low-frequency residual hearing and undergoing hearing preservation cochlear implantation between December 2019 and December 2020 were recruited to the study. Residual hearing was considered adequate with preoperative pure-tone threshold averages (PTA) at 250 to 1000 Hz were less than or equal to 75 dB (HL) and the patient could clearly hear the ECochG stimuli in frequencies 250, 500, or 1000 Hz at less than or equal to 100 dB (HL). Exclusion criteria were the inability to cooperate and to communicate during the surgery or if the patient had to be sedated intraoperatively. Ten patients were included and gave informed consent to participate in the study.

Pure-tone Audiometry and Hearing Preservation

The patients’ residual hearing was measured as pure-tone air-conduction thresholds before implantation, on the first postoperative day, and 2-to-7 months postimplantation. The measurements were conducted in a standard sound booth, with a calibrated audiometer (Aurical Aud, Otometrics/Natus Medical Inc., Taastrup, Denmark), and using the modified Hughson-Westlake procedure. Low-frequency pure-tone average (PTA125-500 Hz) was calculated as an average hearing threshold of frequencies 125, 250, and 500 Hz. The postoperative hearing preservation was classified based on PTA125-500 Hz shift from the preoperative value to the 2-to-7 months’ postoperative value: PTA125-500 Hz shift less than or equal to 15 dB was classified as complete hearing preservation, 15 dB < PTA125-500 Hz shift ≤ 30 dB as partial hearing preservation, and PTA125-500 Hz shift > 30 dB as a hearing loss (8).

Surgical Procedure and Strategy of Electrode Insertion

Cochlear implantations were performed under local anesthesia without conscious sedation by the author (A.D.). The surgical procedure being conducted under local anesthesia has been recently described in detail elsewhere (9). The electrode insertion was performed through the round window membrane under ECochG monitoring. A sound stimulus of 250 to 1000 Hz was presented via an inserted earphone and patients were instructed to report promptly about any changes in the perceived tone during the electrode insertion. We started the monitoring after the opening of the round window membrane up until the electrode was fixated or the wound was closed.

In this study, we pursued two different insertion strategies. In all patients, we continued the insertion up to a preoperatively planned insertion depth angle, whenever the subjective loudness perception did not change, irrespective of the ECochG amplitudes. In subjects eligible for electric-acoustic stimulation, we preoperatively planned, based on preoperative imaging, for an insertion depth angle of at least 300 degrees accepting also partial insertions. Depending on the cochlea size, we either chose a 12-channel lateral wall electrode of an appropriate length (24 or 26 mm) (Flex array series; MED-EL Medical Electronics GmbH, Innsbruck, Austria) or a 23 mm long 16-channel array (Slim J; Advanced Bionics, Stafa, Switzerland). The rationale behind this approach was to maximize atraumaticity for more reliable hearing preservation associated with shallower insertion depth angles. The advantage of partial insertion is that it provides the opportunity of advancing the electrode deeper into the cochlea for better neural coverage at a later stage, should the patient’s residual hearing deteriorate. Whenever the patient reported a decline in the one presenting sound, the insertion was immediately stopped and the electrode was retracted to regain the original loudness of sound. For patients in whom electric-acoustic stimulation was not feasible, we planned for an insertion depth angle of at least 360 degrees for a full electrode insertion. Again, when the patient reported a change in the stimulus loudness, the insertion was stopped and the electrode was retracted. We tried to adjust the insertion trajectory by lightly rotating the array counterclockwise (right ear) or clockwise (left ear) in the expectation that the tip of the electrode would turn away from the basilar membrane so that it could move more freely. In these patients, however, we did accept changes in the sound quality and loudness and...
continued the insertion until one of the above mentioned criteria were fulfilled. Patients received dexamethasone 7.5 mg (intravenously) before the start of the procedure but we administered no postoperative steroid therapy.

**ECochG Measurements**

Two different systems were used for ECochG measurements. In the MED-EL CIs, ECochG recordings were conducted with MED-EL Maestro software (Maestro 9.0; MED-EL Medical Electronics GmbH), MAX stimulation Box (MED-EL Medical Electronics GmbH), MAX coil S (MED-EL Medical Electronics GmbH), and a separate stimulator (Eclipse; Interacoustics A/S, Middelfart, Denmark) with an insert earphone (E-A-RTONE Insert Earphone 3A ABR; 3 M, St. Paul, MN). When applying Advanced Bionics CIs, the AIM system (Active Insertion Monitoring system; Advanced Bionics) with its own stimulation probe was used for both recording and stimulation. The most apical contact of the electrode array was always used as the recording electrode and impedances were checked before measurements.

The stimuli were calibrated tone bursts, of which both frequency and amplitude were chosen for each patient based on their preoperative hearing thresholds (Table 1); briefly, the highest stimulus frequency that was assumed to evoke reliable ECochG response was chosen, and the patient verified the audibility and comfort of the stimulus level before starting the measurement. The AIM system uses a stimulus of alternating polarity and exploits a subtraction method to extract the cochlear microphonics component of the recorded response. It determines the response amplitude automatically and continuously as a function of time and uses approximately 40 iterations (depending on the amount of noise) for each data point. We monitored the ECochG amplitude continuously throughout the whole insertion. The MED-EL system measures the average response of a set number of iterations; we used 200 iterations for each measurement. Due to current software limitations, continuous measurement was not available and therefore repeated measurements were taken each time when two additional electrode contacts were inserted. During the measurement, the electrode was held in place and the patient reported about the quality and loudness of the stimuli. The stimulus in the MED-EL system was condensation polarity, as our system was not able to exploit the subtraction method in real time. To ensure the discrimination of cochlear microphonics from noise, in a pilot measurement we confirmed that response was inverted with an inverted stimulus, and no response was detected if the insert earphone was off the ear during the measurement. The ECochG amplitude was determined as the highest peak-to-peak amplitude of the raw ECochG response with approximately the stimulus frequency.

**Electrode Position**

Surgical notes and video recordings from the operating microscope were used to estimate the insertion duration and the insertion depth at any point in time. The insertion depth angle (IDA) (10) and the cochlea size (A and B measures) (11) were determined from postoperative cone-beam computed tomography image (ProMax, Planmeca Oy, Helsinki, Finland; tube voltage 96 kV, tube current 7 mA, exposure time 15 s).

**RESULTS**

Patient characteristics, devices used, cochlear size, hearing thresholds, and hearing preservation are listed in Tables 1 and 2. Five patients were preoperatively candidates for electric-acoustic stimulation, i.e., their hearing thresholds at 125 to 500 Hz were less than or equal to 55 dB (HL) made it possible to have adequate acoustic amplification which then took into account the average postoperative deterioration (Table 1). Five patients did not qualify for electric-acoustic stimulation. All patients were able to assess on a scale the loudness of the sound stimuli. Intraoperative ECochG was successfully measured in seven patients.

**Continuous ECochG With the AIM System (SlimJ Electrodes)**

Five patients were implanted with a SlimJ electrode. Two patients deemed feasible for electric-acoustic stimulation (Nos. 2 and 3). Reliable ECochG responses could be detected in four patients (see Figs. 1–5). For one patient (No. 4) ECochG recording was unreliable for analyses due to low amplitudes (<3 μV). We recorded a total of 14 distinct ECochG events and in eight of them, patients also described a simultaneous attenuation of the perceived sound. In one case (No. 5), an accidental head movement caused a scala translocation with a complete loss of the sound and tinnitus. One patient (No. 1) reported that the sound attenuated several times during insertion and at the end of the insertion. We detected concomitant drops in the ECochG response, which did not recover at the end of the insertion. In two patients with good hearing preservation (Nos. 2 and 3), the ECochG amplitudes increased as a function of insertion depth up to the end of the insertion. Both patients did not report any changes in the loudness of sound.

**ECochG Measurements With the Maestro Software (Flex Series Electrodes)**

In the five patients implanted with Flex electrodes, continuous monitoring was not possible, but the ECochG responses were measured at different insertion depths (Fig. 5). Good hearing preservation was achieved in all patients. Reliable ECochG responses could not be detected in two patients (Nos. 7 and 10). However, both patients were able to clearly hear the sound stimuli. In patient 7, the sound stimuli did not change during the whole insertion procedure up to the preoperatively planned insertion depth. In patient 10, however, the sound became quieter at the end of the insertion, but recovered after a slight retraction of the electrode. In two patients (Nos. 8 and 9), we recorded a steady increase in the ECochG responses up to the end of the insertion with no notable change in their sound perception. In one patient (No. 6), however, we detected a decrease in the ECochG responses, which correlated with the attenuation of the perceived sound reported by the patient. Both ECochG and sound perception recovered after a retraction of the electrode.

**Summary**

In summary, 15 distinct ECochG events (distinct decline in amplitude) were recorded of which in nine
### TABLE 1. Patients’ pre- and postoperative hearing thresholds at low frequencies

| Patient | Pre-op Hearing Thresholds (dB [HL]) | 1st Postoperative Day Hearing Thresholds (dB [HL]) | 2-to-7-months Postoperative Hearing Thresholds (dB [HL]) | Hearing Preservation (Suhling et al. (8)) |
|---------|--------------------------------------|-----------------------------------------------|-----------------------------------------------|-----------------------------------------|
|         | 125 Hz 250 Hz 500 Hz 750 Hz 1000 Hz | 125 Hz 250 Hz 500 Hz 750 Hz 1000 Hz | 125 Hz 250 Hz 500 Hz 750 Hz 1000 Hz | |
| 1       | 50 55 60 55 80 80 90 70 70 | 70 95 115 115 115 115 115 115 115 | Partial |
| 2       | 40 45 55 65 80 80 90 73 73 | 45 65 70 80 75 60 60 60 60 | Complete |
| 3       | 35 40 50 70 80 80 90 65 65 | 35 50 65 90 90 50 50 50 50 | Complete |
| 4       | 50 60 70 80 90 90 100 75 75 | 75 95 105 105 105 105 105 105 105 | Complete |
| 5       | 65 75 85 90 90 115 115 115 115 | 115 115 115 115 115 115 115 115 115 | Complete |
| 6       | 10 10 10 10 12 12 12 12 12 | 12 12 12 12 12 12 12 12 12 | Complete |
| 7       | 20 30 65 95 115 115 115 115 115 | 115 115 115 115 115 115 115 115 115 | Complete |
| 8       | 15 15 30 70 105 105 105 105 105 | 105 105 105 105 105 105 105 105 105 | Complete |
| 9       | 20 20 50 90 90 90 90 90 90 | 90 90 90 90 90 90 90 90 90 | Complete |
| 10      | 35 40 60 75 80 80 80 80 80 | 80 80 80 80 80 80 80 80 80 | Complete |
|         | mean 42 59 56 56 56 56 56 56 56 | SD 19 26 26 26 26 26 26 26 26 | |

*Could not be heard. 115 dB was used for PTA125-500Hz calculation.

\(^a\)Candidate for electric-acoustic stimulation.

SD indicates standard deviation.
events (60%) patients reported a simultaneous decrease in the perceived loudness of the stimulus. We detected multiple declines in ECochG amplitude in two patients of which one developed a total loss of residual hearing and the other had only partial hearing preservation. However, in one patient with complete hearing preservation, a decline was detected at the end of the insertion, but it recovered after slight retraction of the electrode. A closer description including the ECochG-plots are illustrated in Figures 1–5.

**DISCUSSION**

In this study, we investigated the feasibility of monitoring the actual hearing of patients undergoing cochlear implantation under local anesthesia without conscious sedation by the presentation of sound stimuli during electrode insertion. We also investigated how intraoperatively measured ECochG amplitude events compare with the patient’s subjectively perceived sound sensation. To the best of our knowledge, this is the very first study of its kind.

These results demonstrate that the changes in the patient’s subjectively evaluated sound perception to the stimulus at a constant sound level matched well with the events evident in ECochG responses (i.e., amplitude

| Patient | Age | Etiology          | Electrode     | Side | A Measure (mm) | B Measure (mm) | IDA (degrees) | Insertion Time (min) |
|---------|-----|-------------------|---------------|------|----------------|----------------|---------------|----------------------|
| 1       | 71  | Unknown           | AB HiFocus SlimJ | Right| 9.5            | 6.3            | 423           | 12                   |
| 2       | 83  | Meniere disease  | AB HiFocus SlimJ | Right| 9.3            | 6.9            | 334           | 6                    |
| 3       | 79  | Unknown           | AB HiFocus SlimJ | Left | 9.7            | 6.5            | 310           | 7                    |
| 4       | 69  | Unknown           | AB HiFocus SlimJ | Left | 9.4            | 7.0            | 377           | 6                    |
| 5       | 82  | Unknown           | AB HiFocus SlimJ | Left | 9.6            | 7.1            | 428           | 8                    |
| 6       | 45  | Noise-induced SNHL | MED-EL Flex24 | Left | 9.7            | 6.6            | 310           | 12                   |
| 7       | 68  | Unknown           | MED-EL Flex26  | Right| 9.0            | 7.2            | 360           | 10                   |
| 8       | 64  | Noise-induced SNHL | MED-EL Flex26 | Left | 9.9            | 6.9            | 329           | 9                    |
| 9       | 64  | Post-meningitis SNHL | MED-EL Flex26 | Left | 9.4            | 6.9            | 302           | 8                    |
| 10      | 59  | Congenital SNHL   | MED-EL Flex26  | Left | 9.2            | 6.4            | 377           | 20                   |

**TABLE 2.** A patient demographics and insertion data

| Patient | A Measure (mm) | B Measure (mm) | IDA (degrees) | Insertion Time (min) |
|---------|----------------|----------------|---------------|----------------------|
| 1       | 9.5            | 6.3            | 423           | 12                   |
| 2       | 9.3            | 6.9            | 334           | 6                    |
| 3       | 9.7            | 6.5            | 310           | 7                    |
| 4       | 9.4            | 7.0            | 377           | 6                    |
| 5       | 9.6            | 7.1            | 428           | 8                    |
| 6       | 9.7            | 6.6            | 310           | 12                   |
| 7       | 9.0            | 7.2            | 360           | 10                   |
| 8       | 9.9            | 6.9            | 329           | 9                    |
| 9       | 9.4            | 6.9            | 302           | 8                    |
| 10      | 9.2            | 6.4            | 377           | 20                   |

Mean: 68.4
SD: 10.9

*Measures of cochlear size according to Adunka et al. (14). IDA indicates insertion depth angle; SD, standard deviation.
development) during the electrode insertion. This strongly endorses the use of ECochG for intraoperative monitoring of residual hearing under general anesthesia. Unfortunately, ECochG is not always measurable or the response remains too small for reliable interpretation, as was the case in three out of 10 patients in our study.

In addition to pure recording failure (e.g., high impedance), poor residual hearing and an inadequate stimuli level may prevent obtaining robust responses. The patients in whom we failed to record ECochG responses had hearing threshold levels of 60 to 70 dB (HL) at 500 Hz. We used presentation levels of 90 to 100 dB (HL), thus well above their threshold levels so that successful ECochG recordings were expected. If they had been operated under general anesthesia, then higher sound pressure levels could have been applied. All patients were able to hear the sound stimuli clearly and to evaluate its loudness and quality during the electrode insertion. Especially in continuous monitoring, in which a constant sound was presented, the patients were able to continuously inform the surgeon about their hearing perception, whereupon the surgeon could stop or adjust the insertion to prevent trauma. However, monitoring was feasible also with the MED-EL system applying repetitive measurements. For example, patient 7 reported about an attenuation of the stimulus upon which the insertion was stopped and the electrode retracted. The insertion trajectory was adjusted (i.e., different trajectory and slightly rotating the array) and insertion was proceeded during a next measurement sequence in which the patient did not report of any change in sound. Thus, performing cochlear implantation under local anesthesia may provide additional value for hearing preservation surgeries.

A distinct decrease in intraoperative ECochG amplitudes may indicate a change in cochlear mechanics due to pressure on the basilar membrane, or an imminent or completed cochlear trauma. Some investigators have claimed to detect a correlation between intraoperative ECochG and postoperative audiometric thresholds (6,7,12), but these results have not been confirmed by others (13,14). It is likely that inflammatory processes...
induced by insertion trauma or by an intracochlear foreign body reaction do not occur immediately, and their effect on hearing are not necessarily appreciable during the operation, neither in the ECochG measurements nor through the patient’s subjective feedback. It is however, proposed that patients, who maintain a high ECochG amplitude throughout the insertion process are more likely to have hearing preserved postoperative (6, 7). Accordingly, a high number of ECochG events and larger amplitude declines have been found to trend towards worse hearing preservation (15). The present results point also in this direction, although the number of patients in this study is too small to allow any meaningful statistical analysis. All patients with no notable decrease in ECochG amplitude or a reversible decline in amplitude obtained complete hearing preservation, whereas the patients with an irreversible decrease in ECochG amplitude had only moderate hearing preservation or lost their residual hearing. Similarly, the patients’ subjective hearing perception to the loudness of the stimuli during the electrode insertion matched well with the 2-to-7-months’ hearing preservation.

In the present study, the surgeon was constantly aware of the patient’s feedback and the ECochG events. From the surgeon’s viewpoint, cochlear monitoring proved to be very beneficial, as the insertion process could be adapted based on both patient feedback and ECochG amplitude. During insertion, we prioritized the patient’s feedback over ECochG, since the changes in hearing were expected to be the most sensitive measure of cochlear integrity and because reliable amplitudes could not be measured in every patient. Thus, we think that cochlear implantation under local anesthesia without conscious sedation represents a very promising novel approach for hearing preservation cases.

The following limitations need to be considered. The number of patients is too small to permit a meaningful statistical analysis, thus making this study observational and the results preliminary. The participating patients were not preselected with the result that half of our sample were not candidates for electric-acoustic stimulation. This sample, however, is representative of the types of patients in whom we aim for hearing and structure preservation to optimize their postoperative hearing performance. The sound level presented to the patient is limited in awake patients so it cannot be too loud and uncomfortable. This was most probably the main reason why we did not obtain robust ECochG responses in all of our patients. In awake patients, there is an inherent difficulty of balancing between a sufficiently strong but tolerable stimulus due to the individual thresholds, however, 100 dB (HL) was most often well tolerated. Surgery under general anesthesia would allow for considerable higher sound levels, which may facilitate the detection of reliable ECochG responses. Furthermore, the patients can evaluate the perceived sound level only in coarse scales and evaluate changes in sound level more reliably rather than the sound level itself. In addition, the noisy environment in the operating theatre means that a finer scaling of the presented sound is difficult. During surgery under local anesthesia, it is of paramount importance that the patient should be able hold his/her head for several minutes during electrode insertion. In our study, one electrode translocation occurred due to an accidental head movement of the patient. Any patient undergoing cochlear implantation under local anesthesia must be made aware of this potential risk.

We used two different systems and procedures for the ECochG measurements: continuous response recordings and repeated measurements at distinct insertion depths. The first enabled quicker detection of response amplitude drops and continuous patient feedback. The latter made the recordings less noisy; however, the insertion had to be paused for each measurement.

CONCLUSIONS

This is the first report of comparing cochlear monitoring by means of ECochG with the patient’s actual hearing during cochlear implantation. We observed a good match between the patient’s sound perception to the stimuli loudness and ECochG results during insertion of the cochlear implant electrode. Cochlear monitoring by ECochG or the patient’s feedback could be used for guiding the insertion process and both may facilitate the prevention of insertion trauma. Multiple or large negative events, or the lack of them, may predict the postoperative hearing preservation. Hence, this study supports the application of ECochG monitoring in cochlear implantation to prevent insertion trauma, whenever direct feedback from patient is not possible (i.e., surgery under general anesthesia).

REFERENCES

1. Calloway NH, Fitzpatrick DC, Campbell AP, et al. Intracochlear electrocochleography during cochlear implantation. Otol Neurotol 2014;35:1451–7.
2. Trecca EMC, Riggs WJ, Mattingly JK, et al. Electrocochleography and cochlear implantation: a systematic review. Otol Neurotol 2020;41:864–78.
3. Mandala M, Colletti L, Tonoli G, Colletti V. Electrocochleography during cochlear implantation for hearing preservation. Otolaryngol Head Neck Surg 2012;146:774–81.
4. Kim J-S. Electrocochleography in cochlear implant users with residual acoustic hearing: a systematic review. Int J Environ Res Public Health 2020;17:7043.
5. Choudhury B, Fitzpatrick DC, Buchman CA, et al. Intraoperative round window recordings to acoustic stimuli from cochlear implant patients. Otol Neurotol 2012;33:1507–15.
6. O’Leary S, Briggs R, Gerard J-M, et al. Intraoperative observational real-time electrocochleography as a predictor of hearing loss after cochlear implantation: 3 and 12 month outcomes. Otol Neurotol 2020;41:1222–9.
7. Campbell L, Kaicer A, Sly D, et al. Intraoperative real-time cochlear response telemetry predicts hearing preservation in cochlear implantation. Otol Neurotol 2016;37:332–8.
8. Stuhling M-C, Majdani O, Salcher R, et al. The impact of electrode array length on hearing preservation in cochlear implantation. Otol Neurotol 2016;37:1006–15.
9. Dietz A, Lenartz T. Cochlear implantation under local anaesthesia in 117 cases: patients’ subjective experience and outcomes. Eur Arch Otorhinolaryngol 2021;6:1–7.
10. Iso-Mustajarvi M, Matikka H, Risi F, et al. A new slim modiolar electrode array for cochlear implantation: a radiological and histological study. Otol Neurotol 2017;38:e327–34.
11. Escudé B, James C, Degueine O, et al. The size of the cochlea and predictions of insertion depth angles for cochlear implant electrodes. Audiol Neurootol 2006;11:27–33.
12. Dalbert A, Pfiffner F, Hoesli M, et al. Assessment of cochlear function during cochlear implantation by extra- and intracochlear electrocochleography. Front Neurosci 2018;12:18.
13. O’Connell BP, Holder JT, Dwyer RT, et al. Intra- and postoperative electrocochleography may be predictive of final electrode position and postoperative hearing preservation. Front Neurosci 2017;11:129.
14. Adunka OF, Giardina CK, Formeister EJ, et al. Round window electrocochleography before and after cochlear implant electrode insertion. Laryngoscope 2016;126:1193–200.
15. Weder S, Bester C, Collins A, et al. Toward a better understanding of electrocochleography: analysis of real-time recordings. Ear Hear 2020;41:1560–7.