CLINICAL EXPERIENCE OPEN ACCESS

Intraoperative Detection of Extracochlear Electrodes Using Stimulation Current Induced Non-Stimulating Electrode Voltage (SCINSEV) Measures (Transimpedance Measures)—A Case Series

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1 | Introduction

Cochlear implants (CIs) are prosthetic devices used to restore hearing sensation in people with severe to profound sensorineural hearing loss [1]. The success of the CI surgery relies on the surgical placement of the electrodes within the scala tympani. Electrode migration post placement is well documented and could significantly affect the overall CI performance [2]. Migration may result in extracochlear electrodes (EE). Notably, this is under-reported in the existing literature [3, 4]. Routine intraoperative measures, such as contact impedances, may not indicate misplacement or extrusion of electrodes, particularly if there is an electrically conductive blood, fluid, or soft tissue around the EEs, which may result in the normal contact impedances. If the EE are in air, the contact impedances will show an open circuit and so are easier to detect [5, 6]. Advanced measures such as the stimulation current induced non-stimulating electrode voltage (SCINSEV- termed differently in various clinical software as transimpedance matrix (TIM) by Cochlear Corp, electric field imaging (EFI) by Advanced Bionics(AB) and impedance field telemetry (IFT) by MEDEL), could potentially be used to detect the extrusion EE. The application of SCINSEV measurements in cadaveric studies demonstrates a comparable and well-defined role in the identification of electrode EE, as detailed in the existing literature [5, 6]. Here, we report three cases of intraoperative electrode extrusion detected using SCINSEV measures, subsequently performing corrective repositioning during the same surgical session which prevented the need for delayed revision surgery. This report further highlights the potential of SCINSEV as an important tool in intraoperative measures and enhancing CI surgical outcomes and reports for the first time their use in live patient surgery as determinants of EE and for intraoperative decision-making and correction.

2 | Method

Three paediatric patients are reported, implanted either bilaterally or unilaterally on the basis of multidisciplinary team decisions. All the 3 patients were females, with a mean age of 11 ± 3 years

Abbreviations: AB, advanced bionics; AIM, active insertion monitoring; CI, cochlear implant; ECAP, electrical compound action potential; EE, extracochlear electrodes; EFI, electrical field imaging; IFT, impedance field telemetry; SCINSEV, stimulation current induced non-stimulating electrode voltages; TIM, transimpedance matrix.

Summary

- SCINSEV plays a crucial role in intraoperative detection of EE.
- SCINSEV, combined with ECAPs, helps in the confirmation of electrode extrusion intraoperatively.
- Drop in intracochlear voltage profile at the basal electrode array is a key indication of EE.
- SCINSEV may potentially reduce the reliance on x-ray resources intraoperatively.
- Intraoperative testing may improve operational efficiency of theatre utilization by reducing the need for revision surgery.

(Table 1). Preoperative magnetic resonance imaging (MRI) was performed to evaluate cochlear anatomical structures and assess the integrity of the auditory nerve. All the patients were implanted with AB HiRes Ultra 3D implants using the round window approach. After periosteal closure, intraoperative electrical impedance and other measurements were performed.

In our centre, the intraoperative test protocol follows a battery of tests including initial contact impedance measures, subsequent SCINSEV (termed EFI by AB) and Electrical Compound Action Potentials (ECAP). Following CI placement in the subperiosteal pocket and electrode insertion, the external coil is attached underneath the sterile surgical drapes and connected to a AB-AIM (active insertion monitoring) tablet system, and SCINSEV recordings are analysed by EFI analysis tool version 1.2 software (this software, currently experimental on the AIM tablet, is not commercially available at the moment). In instances where SCINSEV measures yielded inconclusive results regarding the presence of EE, ECAP assessments were also used to make determinations, particularly those from the basal end of the electrode array. It is important to note again that the contact impedances by themselves are not sensitive for detection of EE if the electrodes are surrounded by blood, saline or soft-tissue [5, 6].

If ECAP responses were absent in basal electrodes, such as for electrodes 16 or 15 for AB electrode arrays, adjacent electrode ECAP measurement were examined to determine the first electrode where robust responses were obtained. The ECAP profiles were subsequently compared with SCINSEV data to make a definitive determination of EE, indicated by a decreased intracochlear electrode voltage profile at the basal end of the array in the absence of ECAP response for the most basal electrodes. Where EE were expected, the wound was reopened, and the electrode repositioned. The entire battery of tests was then repeated. Post-operative x-rays were performed for all the patients approximately two to three weeks later to check for extrusion of the electrode array. The study followed the CARE reporting guidelines [7].

2.1 | Ethical Considerations

Written informed consent was collected from all the patients for anonymised data presentation.

TABLE 1 | Characteristics of each case.

Case	Age/gender	Aetiology	Implant	Implant type	Ear with EE		Cochlear anatomy	Surgical mode	1st EFI	1st ECAP +/−			2nd EFI	2nd ECAP +/−			x-ray	
					Left	Right				E1	E15	E16		E1	E15	E16	I-op	P-op
1	10/F	Genetic	1st Implant	AB Hifocus Slim J	Y	N	Normal	RW	02 EE	+	−	−	0 EE	+	+	+	N	Y
2	9/F	CMV	Re-implant	AB Hifocus Slim J	N	Y	Normal	RW	02 EE	+	High	−	0 EE	+	+	+	N	Y
3	14/F	Unknown	Re-implant	AB Hifocus Slim J	N	Y	Normal	RW	02 EE	+	−	−	0 EE	+	+	+	N	Y

Abbreviations: −, absent, +, present; AB, advanced bionics; E, electrodes, E1, most apical electrode; E16, most basal electrode; ECAP, electrical compound action potentials; EE, extracochlear electrodes; EFI, electrical field imaging; I-op, intraoperatively; N, no; P-op, postoperatively; RW, round window; Y, yes.

3 | Results

3.1 | Case 1

A 10-year-old female patient underwent a bilateral CI implantation surgery with full electrode insertion to the end-marker. Post-closure SCINSEV(EFI) was revealed by a heat map and line graph indicative of two potential EE in one ear, using the SCINSEV criteria from previous cadaveric studies [5, 6], with the unremarkable contact impedance measures (Figure 1A,B). Upon reopening of the periosteal closure, two EE were found, and the electrode was re-advanced into the cochlea. Immediately, repeated EFI confirmed the absence of EE post-repositioning. Post-closure ECAP measures presented with robust responses at electrodes 15 and 16, confirming the efficacy of the corrective intervention (see Figure 1C,D).

3.2 | Case 2

A 9-year-old female patient underwent an unilateral reimplantation due to a soft device failure with full electrode insertion. Post-closure SCINSEV (EFI) indicated two EE (Figure 2A,B), a finding further supported by the absence of responses in electrode 16 and elevated ECAP thresholds in electrode 15. Surgical reopening confirmed 2 EE electrode displacement, prompting reinsertion. Post-closure SCINSEV (EFI) verified proper electrode positioning, and subsequent ECAP assessments at electrodes 15 and 16 demonstrated robust responses, validating the success of the corrective measures (Figure 2C,D).

3.3 | Case 3

A 14-year-old female patient underwent a reimplantation with full insertion, following soft device failure. The post-closure SCINSEV (EFI) results were inconclusive but were suggestive of two potential EE (Figure 3A,B). ECAP measures at electrodes 15 and 16 were unresponsive, prompting surgical re-evaluation and reinsertion. Validation through repeat SCINSEV (EFI) confirmed normal transimpedance and the electrode positioning with subsequent ECAP responses across all electrode arrays (see Figure 3C,D).

4 | Discussion

In this report we presented three cases of intraoperative electrode extrusion that occurred after the operating surgeon felt that full insertion of the electrode had been achieved. Intraoperative SCINSEV measurements subsequently identified EE and allowed for surgical correction, thereby averting the need for basal electrode inactivation during programming or delayed revision surgery for electrode repositioning.

Electrode extrusion is an important factor that can significantly affect the overall outcome in the patients with CI [8]. A recently

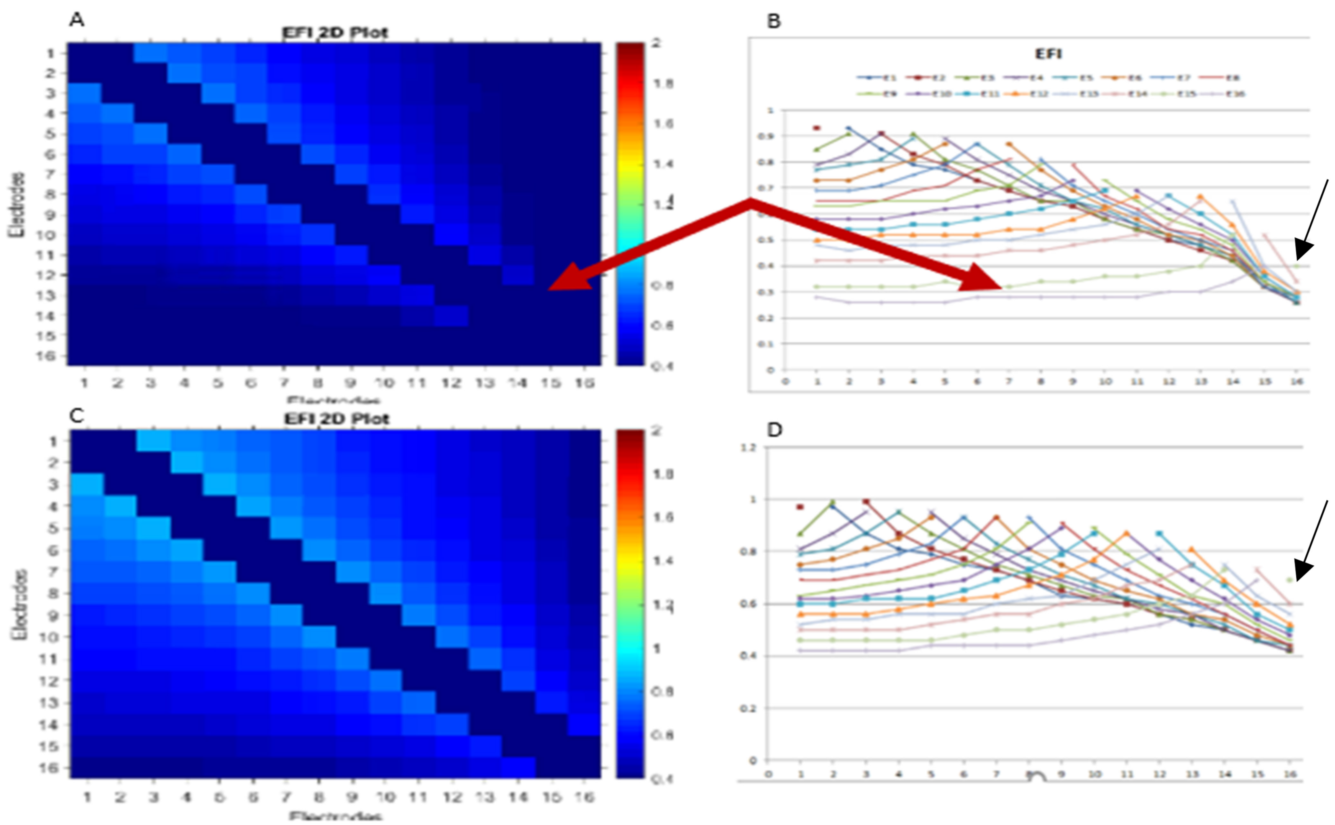

FIGURE 1 | (Case-1)-EFI measurements: (A) heat map and (B) line graph show 2 EE e-15 and e-16. (C, D) indicate normal voltage distribution profile of all electrodes including e-15 and e-16. The black arrows indicate the collapse of the EFI at the basal end (B), seen with EE, and its recovery after replacement (D).

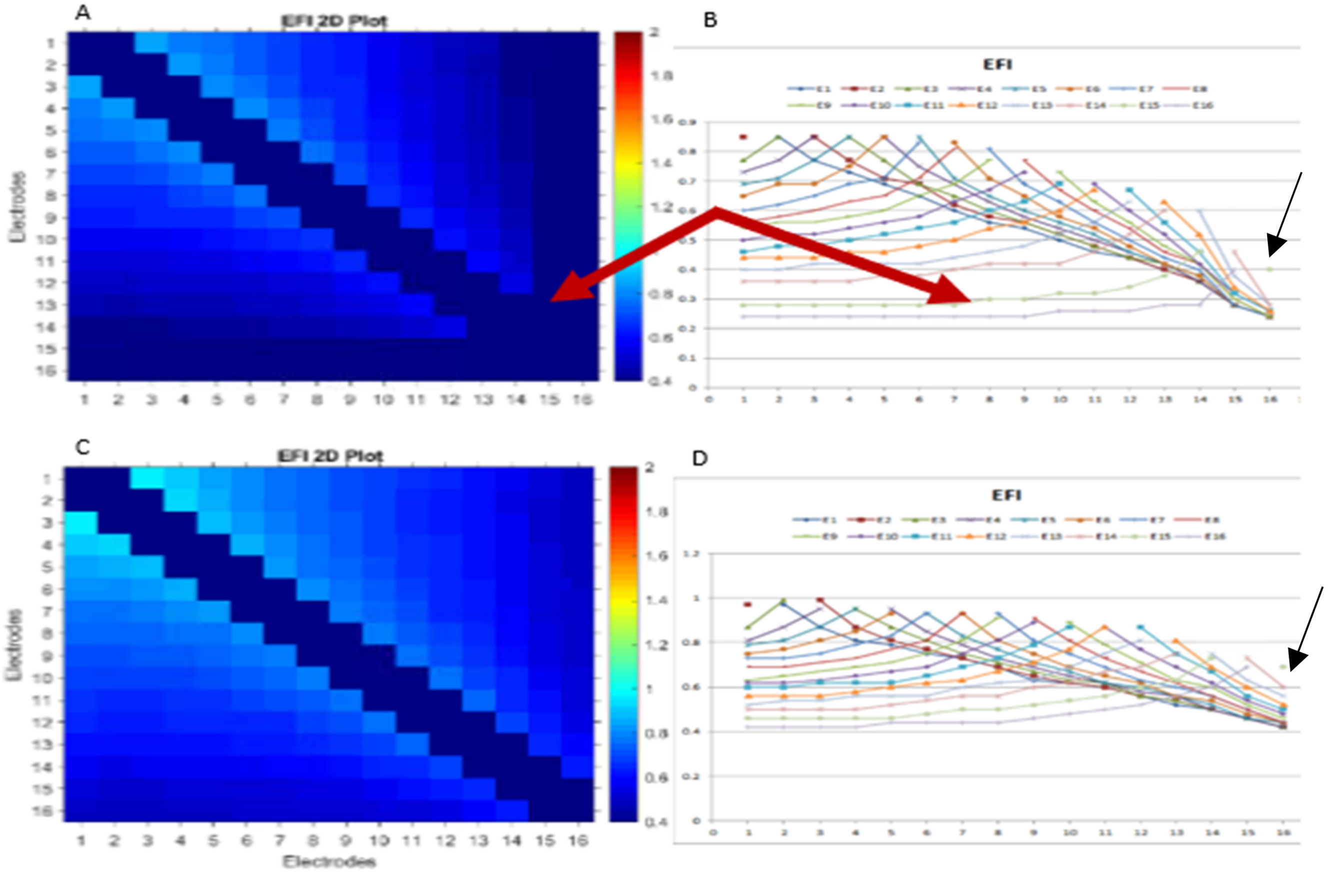

FIGURE 2 | (Case-2) EFI measurements: (A) heat map and (B) line graph show 2 EE e-15 and e-16. (C, D) indicate normal voltage distribution profile of all electrodes including e-15 and e-16. The black arrows indicate the collapse of the EFI at the basal end (B), seen with EE, and its recovery after replacement (D).

published report indicates that approximately 11.5% of CI recipients experience electrode extrusion of various numbers of electrodes within the first few weeks of post-surgery [3]. This is alarming, as it necessitates the deactivation of approximately one to two electrodes during the CI programming stage, thereby potentially limiting the overall benefits [9]. The effective application of SCINSEVs and timely intervention by the surgical team have proven to be a critical factor in immediate repositioning of the electrodes completely inside the cochlea in our three cases. In three cases, lack of ECAPs at the base might have led to suspicion and need for intraoperative x-ray, but the confirmatory SCINSEV avoided this.

The salient marker for EE in the three cases presented here are that they show a notable decline in the intracochlear voltage profile especially at the basal electrode array. This is in keeping with what has been previously described as the marker for EE in cadaveric models [5, 6] but not, to date, reported in living human subjects. The SCINSEV measurements depicted in the heat map and in the line graph are essentially generated after the transimpedance measures by removing the contact impedances and plotting the 'tails' of the transimpedance measure [6, 10]. They basically document the electric field generated by each individual stimulated electrode by measuring the voltage generated on every other electrode in the array. These are generally available in all the CI manufacturers' clinical software in different versions. This enables clinicians to identify both the presence, and often the number of electrodes that are outside the cochlea.

This study not only underscores the clinical significance of SCINSEV but also affirms its role as an important tool in intraoperative settings. Detecting and addressing the electrode extrusion during the same surgical session not only avoids radiation but also mitigates potential delays in waiting for radiographers. This could significantly enhance consistency and cost-effectiveness of CI surgical placement. Stimulation current induced non-stimulating electrode voltage measures from most companies take less than 5 min to perform and can be easily repeated for several times such as after insertion and after full closure of the wound. This might be useful, for instance if an electrode is felt to be unstable and shows tendencies for extrusion during the surgery.

5 | Conclusion

This case series reports the use of SCINSEVs for the intraoperative detection and correction of EE in live human patients. It validates the important role of SCINSEV measurements in ensuring

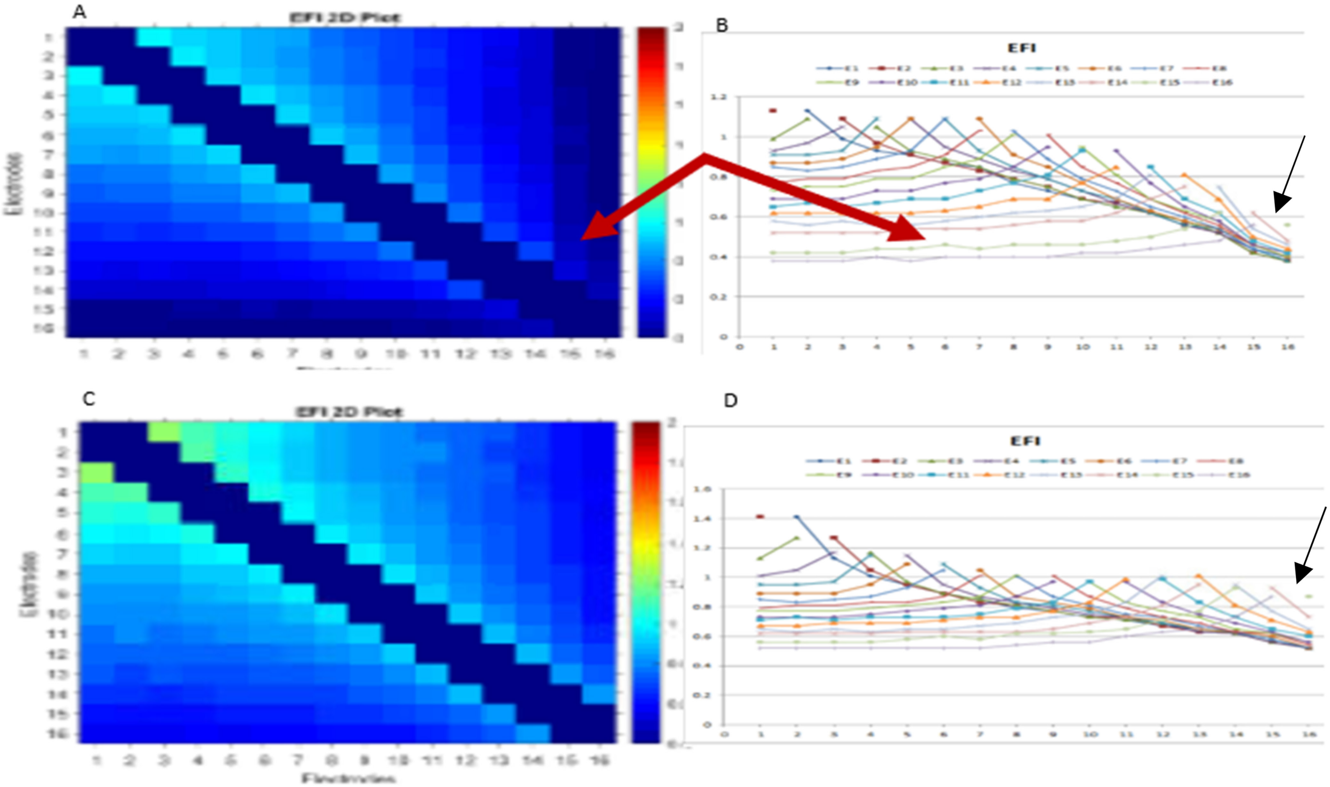

FIGURE 3 | (Case-3) EFI measurements: (A) heat map and (B) line graph show 2 EE e-15 and e-16. (C, D), indicate normal voltage distribution profile of all electrodes including e-15 and e-16. The black arrows indicate the collapse of the EFI at the basal end (B), seen with EE, and its recovery after replacement (D).

optimal electrode array placement intraoperatively. Importantly, employing SCINSEV measures intraoperatively not only facilitates the corrective repositioning of electrode arrays within the same session but may also enhance operational efficiency for theatre utilization as these measures are rapid and do not use x-ray resources. Our clinical experience leads us to recommend the routine use of these measures in all CI surgeries.

Author Contributions

Muhammed Ayas, Manohar L Bance, Yu Cheun Tam designed the work. Muhammed Ayas acquired, analysed and drafted the manuscript. Yu Chuen Tam, Dakota Bysouth-Young, Susan T. Eitutis, Marina Salorio-Corbetto acquired the data, reviewed and provided critical revision of the manuscript. Patrick R. Axon, Manohar L. Bance, James R. Tysome, Neil P. Donnelly, Mathew E. Smith, Daniele Borsetto performed cochlear implant surgeries, reviewed and provided critical revision of the manuscript. The authors discussed the results and implications and commented on the work at all stages.

Conflicts of Interest

Dr. James Tysome is Editor-in-Chief and Dr. Smith, Matthew is AE of the journal and co-author of this article. They were excluded from the peer-review process and all the editorial decisions related to the acceptance and publication of this article.

Peer Review

The peer review history for this article is available at https://www.webofscience.com/api/gateway/wos/peer-review/10.1111/coa.14212.

Data Availability Statement

The authors confirm that the data supporting the findings of this study are available within the article.

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