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Cochlear Implant Translocation: Diagnosis, Prevention, and Clinical Implications

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Abstract

Purpose of Review To summarize the literature on scalar translocation of cochlear implant (CI) electrode arrays (EAs), including diagnosis, prevention, and clinical implications of such.

Recent Findings Rates of translocation vary by EA design, with lateral wall (straight) EAs having rates ranging from 5 to 22% and pre-curved (perimodiolar) having rates of approximately 7% (external stylet) and 30–50% (internal stylet). All three FDA-cleared CI manufacturers are working on preoperative planning software with the intent of optimizing final EA location and preventing translocation.

Summary Translocations typically lead to poorer audiologic outcomes. The gold standard for diagnosis involves computed tomography (CT) imaging with portable CT scanners providing immediate postoperative information to detect and potentially correct translocations intraoperatively. Insertion monitoring methods, such as impedance measurements and electrocochleography (ECochG), may alert surgeons of a potential translocation. Robotic insertions with preoperative trajectory plan and insertion monitoring (e.g., ECochG and/or force feedback) may dramatically reduce the incidence of translocations in the not-too-distant future.

Keywords Cochlear implant · Scalar translocation · Electrode insertion · Surgical trauma

Introduction

Scalar translocation is a potential complication of cochlear implant (CI) surgery in which the CI electrode array (EA) crosses into scala vestibuli (SV) instead of remaining in its intended location within scala tympani (ST) [1]. It most commonly occurs within the basal turn approximately 180° from the round window (RW) where the EA is hypothesized to deflect off the lateral wall and cross the basilar membrane (BM) as opposed to following the natural curvature of the cochlea [2]. Once translocated, the EA will typically remain in SV but may re-translocate back into ST. Some posit an alternative mechanism for translocation in which the EA may dissect between the internal cochlear wall and spiral ligament and enter SV by disrupting but not violating scala media (SM). Ultimately, EA translocation, by whichever mechanism, has important clinical implications as studies have shown that translocation is associated with poorer audiologic outcomes [3–7].

These poorer outcomes are thought to occur either secondary to trauma resulting in the disruption of residual hearing and/or suboptimal final positioning of the EA in SV. While the trauma associated with translocation is relatively straightforward to appreciate, suboptimal positioning requires more explanation. Translocation pushes the EA towards the lateral wall by the osseous spiral lamina resulting in pre-curved arrays ending up against the lateral wall for at least some of their intracochlear course. Furthermore, translocation into SV can result in the EA ending up closer

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to the modiolus of the next cochlear turn increasing the risk of cross-turn stimulation. Such stimulation goes against the expected ordinate relationship between electrode number and stimulation frequency (i.e., basally placed electrodes stimulating higher frequencies) making CI mapping challenging. While poorer outcomes do not occur in all patients with translocation [8], given the overall poorer audiologic outcomes, it is clinically important to identify, prevent, and potentially rectify translocations. Towards this goal, various technologies have been employed including pre-op planning based on pre-op imaging, intraoperative electrophysiological measurements, intraoperative imaging, and postoperative CI programming to account for translocation when it occurs.

Incidence of Translocation

A 2019 systematic review and meta-analysis on both tip fold-over and scalar translocation (also referred to as scalar deviation in that paper) found an overall rate of 22.4% in over 2000 implanted ears without separating out by CI brand or EA design [9•]. The differences among CI EAs include length, shape, mechanism of stylet advancement (for pre-curved EA), and, of particular importance for scalar translocation, the intended final positioning of the EA. Electrode arrays can be broadly classified by the resting state, i.e., the shape of the EA without stylet as they come of the box. Straight EAs are designed to rest against the lateral wall of the cochlea to minimize risk of trauma to the cochlea and help preserve remaining hearing [10, 11]. Pre-curved EAs are intended to lay in close proximity to the modiolus to maximize neural stimulation for improved audiologic outcomes. Given the nature of translocations causing displacement from the intended EA positioning, the nomenclature "perimodiolar" or "lateral wall" may misrepresent the final location. Therefore, as others have previously utilized, the terms "straight"—in place of lateral wall—and "pre-curved"—instead of perimodiolar—will be used in this paper [12].

Overall, pre-curved EAs have higher rates of translocation than straight EAs [13••, 14]. Pre-curved EAs may be internally or externally styleted with each differing in their rates of translocation [13••]. For internally styleted pre-curved EAs (e.g., Cochlear CI512 and CI612 and Advanced Bionics mid-scalar EA), the incidence of translocation ranged from 30 to 50% across multiple CI centers [3, 4, 9•]. Although there are fewer studies on the newer, externally styleted pre-curved EAs (i.e., Cochlear CI532 and CI632), rates of scalar translocation appear to be much lower with no reports higher than 7% [6, 15–18], although tip fold-over appears to occur approximately twice as frequently [15, 19]. Straight electrode arrays (e.g., Cochlear CI522, CI622, and CI624; Medel standard, Flex 24, and Flex 28; and Advanced Bionics Slim J) have low translocation rates as well. The 2019 review mentioned previously found an overall scalar translocation rate of 32% for pre-curved EAs and 7% for straight EAs [9•].

In addition to varying EA designs, the surgical approach appears to play a role in translocation. There are three primary approaches to enter the cochlear—via the RW, via a separate cochleostomy, or via a hybrid of these in which the RW is surgically enlarged with the hybrid approach commonly referred to as an extended RW (ERW) approach. While there are various reasons a surgeon may choose one of these approaches versus another, this discussion focuses on the varying rates of scalar translocation associated with each. Most large clinical studies have shown that RW or ERW approaches have higher rates of ST insertion (and consequently less instances of scalar translocation) compared with cochleostomy [5]. Wanna et al. found that 91% of RW and 84% of ERW resulted in ST insertion of the electrode array compared with only 37% of cochleostomy approaches for both pre-curved and straight EAs [20]. O'Connell et al. reported similar findings, with an overall reduction in translocation of approximately 70% with RW or ERW instead of cochleostomy [21].

The data presented above suggests that the scalar translocation can be minimized using straight EAs with an RW or ERW approach. But does this result in better residual hearing preservation and/or audiologic outcomes? Regarding hearing preservation, while straight arrays are commonly referred to as "hearing preservation EAs," recent analysis suggests that there may be little difference in hearing preservation based on EA design as long as atraumatic approaches are utilized [22]. And recent reports indicate that the best audiological outcomes are associated with pre-curved EAs [23••], especially when translocation is avoided [13••]. Chakravorti et al. present compelling data that translocation, which is more common in pre-curved versus straight EAs, masks better audiologic outcomes of pre-curved EAs if translocation can be avoided. Regardless of which brand or style of EA is utilized, the vast majority of studies support the hypothesis that better outcomes are obtained by decreasing the rate of translocations.

Diagnosis and Prevention of Translocation

Post-Implant Diagnosis

If there is a current standard of care in the confirmatory diagnosis of translocation (with the ultimate gold standard being post-mortem histopathology), it is post-implant computerized tomography (CT) scanning. This can be done in a radiology suite using conventional CT (e.g., stationary multi-slice CT) or intraoperatively with portable models

including cone-beam CT scanners. The availability of such portable CT scanning has allowed for intraoperative diagnosis and successful repositioning and correction of tip fold-over and translocations [24, 25]. Institutions without access to intraoperative or immediate postoperative CT scanning typically rely on audiologic testing combined with flat-plate x-rays/fluoroscopy for perioperative quality assurance [25] noting that they most commonly are used to diagnose electrode tip fold-over as opposed to scalar translocation [26].

Preoperative Planning

Various programs have been developed to help assess cochlear anatomy preoperatively and guide surgical planning in the hopes of preventing translocation and other intracochlear trauma. While the different preoperative planning tools all rely on preoperative imaging, they focus on different aspects of cochlear anatomy to guide insertion of EAs. MED-EL has developed a 3D reconstructive software, OTOPLAN®, intended to help improve EA insertion with depth estimates based on a single measurement of the cochlear diameter to estimate the two-turn length of the cochlea [27]. Output from this formula results in recommendation for EA length to optimize cochlear coverage while minimizing intracochlear trauma. This method is predicated on the hypothesis that over-insertion of the electrode array causes increased intracochlear trauma [28]. Preoperative planning software developed by faculty at Vanderbilt University, Oto-Pilot®, focuses on insertion trajectory and depth of insertion (Fig. 1; Table 1). Using this software, the incidence of translocation was reduced, and better perimodiolar positioning of pre-curved EAs was achieved in temporal bones [29]. Other image guidance software incorporated into manufacturers' platforms is in various stages of development including Cochlear Corporation's SmartNAV® and Advanced Bionics' CImago®.

Intraoperative Feedback

Active surgical feedback has been another area of proposed benefit with real-time impedance measurements and electrocochleography (ECochG) showing the most promise. Impedance measurements are a form of audiologic testing that have been utilized to help determine implant functionality and, more recently, intracochlear positioning. Impedance is defined as the resistance of current flow. As applied to CI EA positioning, real-time measurement of impedance between various pairs of electrodes within the EA has been shown to correlate with the intracochlear environment [30, 31] and be predictive of depth of insertion, translocation, and perimodiolar positioning. Regarding depth of insertion, in a study evaluating 20 EAs using impedance measurements, the average absolute error for estimating insertion depth was under 1 mm with a maximum error of 2.38 mm [32]. Regarding translocation, in a study involving 100 patients, two different impedance measurements were found to be useful in detecting translocation as compared with postoperative CT analysis being considered the gold standard with these impedance measurements having accuracies of 83% and 91% [33]. And most recently, in a bench-top model, paired impedance measurements have been shown to correlate to distance from the medial cochlear wall (a.k.a. modiolus) of the EA (between the electrode pairs) [34] with the clinical application being pull back of pre-curved EAs to achieve more optimal perimodiolar positioning.

While only applicable to CI recipients who have a threshold of hearing prior to surgery, intraoperative recording of compound actions potentials of auditory neurons, more commonly referred to as ECochG [35], has been integrated into commercially available CI systems. The ECochG response is elicited by presenting an audible tone to the EAC with the ECochG signal having been shown to provide reliable information about hearing preservation and audiometric thresholds [36] and postoperative hearing preservation [37]. Its use

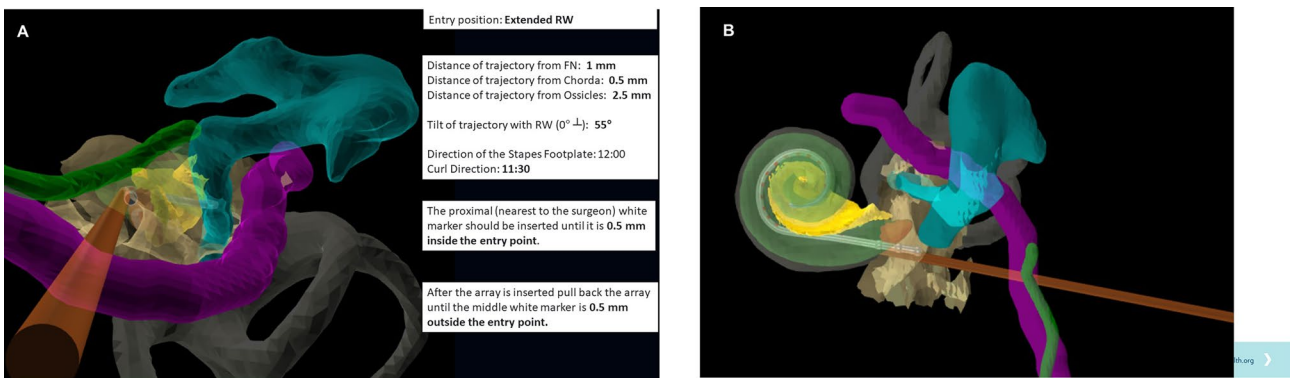
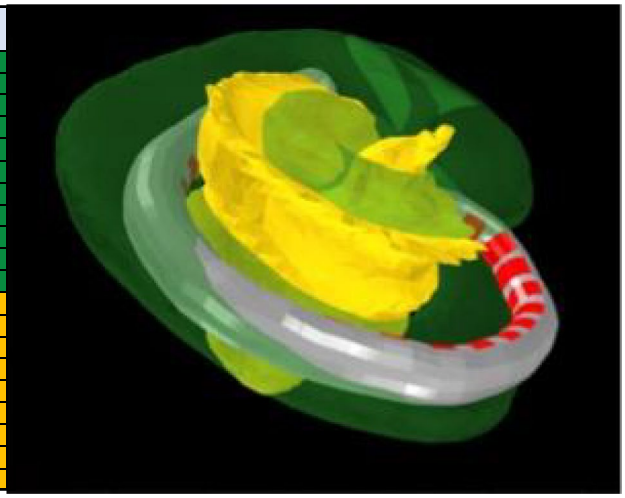


Fig. 1 Insertion plan showing surgical view with text instructions based on preoperative CT (**A**). Resultant EA position following insertion plan displayed after image processing of intraoperative CT (**B**)

Table 1 Intracochlear location of each electrode in reference to angle of insertion, scala tympani versus scala vestibuli, distance to closest point on modiolus, place frequency based on function derived by Stakhovskaya et al. [42], and default manufacturer frequency allocation. 3D image of translocated electrode array (shown right panel)—green (scala tympani) and yellow (modiolus)

Electrode	Distance (mm)	Angle (Degree)	Place Frequency (Hz)	Channel Frequency (Hz)	Scalar Location
1	0.47	27.11	12958.25	7,438	Scala Tympani
2	0.28	38.69	11132.85	6,501	Scala Tympani
3	0.18	53.71	9384.77	5,688	Scala Tympani
4	0.12	72.45	7332.82	5,001	Scala Tympani
5	0.21	93.40	5951.18	4,376	Scala Tympani
6	0.35	112.69	5112.85	3,813	Scala Tympani
7	0.52	129.47	4476.77	3,313	Scala Tympani
8	0.65	144.65	3994.94	2,876	Scala Tympani
9	0.80	158.14	3702.88	2,501	Scala Tympani
10	0.89	170.58	3121.46	2,188	Scala Tympani
11	0.96	183.21	2948.70	1,938	Scala Tympani
12	1.02	195.70	2438.96	1,688	Scala Vestibuli
13	0.99	207.74	2303.97	1,438	Scala Vestibuli
14	0.94	220.06	2135.54	1,251	Scala Vestibuli
15	0.95	232.47	1979.42	1,126	Scala Vestibuli
16	1.03	244.97	1766.37	1,001	Scala Vestibuli
17	1.13	257.63	1637.24	876	Scala Vestibuli
18	1.10	270.08	1406.60	751	Scala Vestibuli
19	1.04	282.40	1231.61	626	Scala Vestibuli
20	0.92	293.65	1058.12	501	Scala Vestibuli



in identifying translocation is not as straightforward necessitating algorithms incorporating changes in ECochG phase and amplitude during EA insertion able to correctly predict final scalar location 81% of the time in a study involving 32 patients with CT confirmation of location the gold standard [38]. Findings such as the above have led to an NIH-funded (U01DC018920), randomized controlled trial entitled *Clinical Utility of Residual Hearing in the Cochlear Implant Ear* (ClinicalTrials.gov Identifier: NCT04707885) to investigate the clinical utility of ECochG in preserving residual hearing and led to better audiologic outcomes presumably by minimizing intracochlear trauma including translocation.

One additional translocation mitigation technique to mention is force measurement and limitation during insertion with the concept being that EAs and/or insertion tools be designed to have an upper force limit which would prevent intracochlear trauma including translocation. Preliminary work towards this end examined the force required to translocate from ST to SV on fresh cadaveric cochleae and reported that force to vary from 42 to 122 mN [39]. The clinically relevant next experiment was to determine force perception thresholds among O-HNS resident and attending MDs from a large, experienced CI center and found a range of 10.8 to 36.5 mN implying that surgeons may have the ability to sense some translocations but that human tactile feedback is probably not sensitive enough to make this a reliable strategy [40]. What is more likely to be effective is robotic insertion which could be programmed to stop advancement and redirect trajectory before a damaging force is reached [41•]. Ideally, robotic insertion could be coupled with preoperative planning to achieve the optimal insertion trajectory and have a safety constraint of stopping insertion should intracochlear trauma risk be detected by force measurement.

Conclusion

Despite increasing standardization of surgical techniques, there are still significant differences in audiologic outcomes for CI recipients. The various factors which lead to such variability have been largely categorized as bottom-up and top-down factors with top-down factors consisting of central processing abilities and bottom-up factors being largely EA-neural match. Much of what has been covered above is bottom-up using technology to take into account variations in the sizes and physical orientation of cochleae and intracochlear structures to more optimally place EAs and limit intracochlear trauma. Such technology will likely lower translocation rates for all EAs especially pre-curved ones which have been shown to be associated with better audiological outcomes especially when translocation can be avoided. Post insertion CT scanning, the current gold standard for diagnosis of translocation, can allow for re-insertion and correction of a poorly positioned EA. While portable CT scanners have allowed some institutions to rapidly identify and correct such complications before leaving the operating room, they cannot prevent the initial traumatic intracochlear event. Given the anatomical variation among cochleae, there is a strong case to be made for the benefit of preoperative assessment of cochlear anatomy with imaging and individually tailored surgical planning. Given the variety of planning softwares used to generate preoperative surgical recommendations, more research is needed to determine the optimal guidance for EA insertion based on individual cochlear anatomy. In combination with preoperative planning, real-time information to assess intracochlear trauma using audiologic technologies or force perception thresholds intraoperatively may offer guidance during insertion. Ultimately, coupling robotic insertions, which can achieve supra-human

force threshold, with pre-op planning and/or intraoperative monitoring may make translocation a rare event optimizing the EA-neural interface for each patient.

Declarations

Conflict of Interest Jack H. Noble, Benoit Dawant, and Robert F. Labadie report patents related to a preoperative planning software for EA insertion managed by Vanderbilt University. They have not received any royalties or payments in relation to these patents. Robert F. Labadie reports personal fees from Spiral Therapeutics. C. Cooper Munhall has no disclosures to report.

Human and Animal Rights and Informed Consent Information presented within this article has been subject to and is compliant with local Institutional Review Board(s) policies and procedures.

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- • Of importance
- •• Of major importance

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