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EDITORIAL COMMENT

# Measuring the cochlea and cochlear implant electrode depth

Jeffrey P. Guenette[1]

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The functional benefit of cochlear implants can vary considerably in both children and adults [1, 2]. Outcomes appear to be dependent upon demographic, audiologic, and surgical factors [3]. Given that surgical factors can be optimized and managed, there has been a substantial amount of literature published in recent years with the aim of identifying surgical factors that can be adjusted to improve outcomes. Much of this research has focused on the insertion depth of the cochlear implant electrode arrays. Electrodes that are placed deeply may improve hearing of low-pitched sounds, but also can damage structures and cause loss of residual hearing, cause pitch confusion, and reduce stimulation within the basilar turn [4]. The human cochlea outer wall and first turn lengths can vary by nearly 20% and first turn internal diameters can vary by nearly 80% [5]. Preoperative measurement of the cochlear duct length (CDL) has thus been posited as helpful in projecting electrode insertion depth, which then informs electrode size selection. However, there are multiple proposed methods to measure electrode insertion depth and CDL.

The obvious method to measure insertion depth is the linear insertion depth—the length of electrode inserted into the cochlea. However, linear insertion depth does not always accurately reflect the location of the tip of the electrode within the cochlea. For example, an electrode located along the modiolus will have a deeper tip than an electrode located along the lateral cochlea wall with the same measured linear insertion depth. Similarly, an electrode located in a small cochlea will have a deeper tip than an electrode located in a large cochlea with the same measured linear insertion depth. Moreover, a kink or unintended redundancy in positioning of the electrode will result in a long insertion depth that does not accurately reflect the position of the electrode tip. Angular insertion depth—the radiographic measurement in degrees of the location of the tip of the electrode relative to the round window membrane [6]—is thus generally the preferred measurement as it more accurately indicates the position of the electrode tip within the cochlear spiral.

Multiple studies over the last 15 years have investigated a variety of CDL measurements with a nice overview recently published [7]. In 2005, hand-drawn measurements of the basilar turn of the cochlea on high-resolution CT in cadavers were demonstrated to be feasible and angular depths of electrodes inserted into these temporal bones correlated with depth on histology [8]. In 2006, a simpler cochlear distance measurement was proposed, called the cochlear basal turn diameter, measuring from the round window to the lateral wall and then extrapolating that measurement with a 2D spiral approximation mathematical function to a basilar turn estimated CDL [9]. This method was updated in 2015 to approximate two-turn and complete CDL estimations [10]. In 2009, the cochlear basal turn diameter was shown to correlate with insertion depth angle and was shown to be similar when measured on both CT and MRI [11]. In 2014, a 3D-curved MPR was used to accurately and directly measure dummy electrode markers placed within cadaver ears [12]. Also in 2014, it was shown that outer cochlea wall measurements could be measured on cone beam CT and these measurements fall in a normal distribution [13]. Then in 2018, it was shown that the inner wall could also be measured on cone beam CT [14]. And in 2017, a method for automated two-turn CDL measurements was presented to decrease clinical time spent measuring CDL and to address user-dependent measurement variability [15].

The study by Oh et al [16], published in this month's edition of *European Radiology*, investigated whether CT measurements of lateral wall CDL and/or the cochlear basal turn diameter correlate with final insertion depth angle. The

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✉ Jeffrey P. Guenette
jpguenette@bwh.harvard.edu

[1] Division of Neuroradiology, Brigham and Women's Hospital, Dana-Farber Cancer Institute, Harvard Medical School, 75 Francis Street, MA 02115 Boston, USA

cochlear basilar turn diameter negatively correlated with insertion depth angle, suggesting that a larger basilar turn results in shallower electrode placement. Interestingly, CDL did not correlate with final insertion depth angle, yet CDL did strongly correlate with the cochlear basal turn diameter. These findings suggest that the size of the basilar turn is a more important predictor of electrode insertion depth than overall CDL, which can be rationalized in that the primary linear length of insertion depth is within the basilar turn. It is unclear whether these results are generalizable across devices or device lengths because a single cochlear implant electrode device was utilized in all of the patients in this study. Further exploration of basilar turn measurements compared with CDL measurements appears warranted to potentially improve accuracy and precision of electrode insertion depth planning.

A potential barrier of implementing the approach as outlined in this study is the requirement that the temporal bone CT images be reformatted in a specific plane through the basal turn and round window. In routine temporal bone CT, the acquisition plane can be highly variable. While reconstruction and reformat planes are not standardized, an axial plane parallel to the lateral semicircular canal has been described as the optimal clinical imaging plane in a primary head and neck imaging text book [17], used in research studies [18, 19], and implemented in large clinical settings [20]. This plane is easily reproduceable, decreases variance within a practice to facilitate comparison imaging, and allows adoption of study findings such as measuring otic capsule thickness to evaluate for otosclerosis. Requiring manual radiologist reformats in an additional imaging plane can be cumbersome within a busy clinical practice, but is achievable and feasible with the readily available MPR tools available in many current PACS systems.

In summary, the cochlear basal turn diameter may more accurately predict cochlear implant electrode placement depth than CDL. Ideally, robust preoperative CT measurements, postoperative insertion depth angle measurements, and clinical outcomes would next be investigated in a multi-center prospective study utilizing multiple devices and electrode lengths.

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## Compliance with ethical standards

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**Methodology**
• Invited editorial

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