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Preoperative Imaging for Cochlear Implantation: A Global Consensus

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Abstract

Objective. Preoperative imaging is vital for cochlear implant surgeries, aiding diagnosis, and surgical planning. This study evaluated global practices and the value of preoperative imaging through an international survey.

Methods. A cross-sectional survey was conducted among international cochlear implantation experts using a 112-item questionnaire. The study explored imaging modalities, anatomical targets, evaluated parameters, and different imaging approaches' perceived value and risks. Participants were recruited from a global consortium of otolaryngology, otology, neurotology, and cochlear implant surgery professionals.

Results. Thirty-nine practitioners from 36 centers in 16 countries completed the survey (95.1% response rate). All used computed tomography (CT) and magnetic resonance imaging (MRI) for preoperative evaluation; MRI was deemed more valuable for diagnosis and candidacy assessment, while CT was preferred for surgical planning. Nearly half utilized

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additional imaging modalities, with functional MRI being the most common (20.5%). Additionally, 79.5% of respondents reported using image-based surgical planning software.

Discussion. Results show a universal reliance on CT and MRI for cochlear implant evaluations, with MRI aiding diagnosis and CT focusing on surgical planning. Advanced imaging techniques may emerge in specific clinical cases.

Implications for Practice. Modern imaging practices and their potential changes can enhance protocol development and improve preoperative evaluations, ultimately boosting patient safety and outcomes in cochlear implantation.

Keywords

cochlear implantation, computed X ray tomography, consensus, diagnostic imaging, preoperative care, magnetic resonance imaging, surveys and questionnaires

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Prior to cochlear implantation (CI), the functional and structural integrity of the auditory system should be evaluated. Functionality refers to the ability of the auditory system to convey auditory percepts, and is necessary, for example, to evaluate whether the individual meets the audiological criteria for implantation candidacy. Structural integrity refers to the physical state of the inner ear, external and middle ear, and the ascending auditory pathway. This is essential for evaluating cochlear implantability, checking for the auditory nerve, planning surgery, and identifying any factors hindering effective CI use.

Functional assessment of the auditory system is well established through psychoacoustic tests like speech perception and sound localization, as well as objective electrophysiological tests of the auditory nerve and pathways. Evaluating the structural integrity of the hearing system is more complex since most structures are encased within the temporal bone and brain, making them inaccessible to direct evaluation. Currently, imaging is the primary method for assessing these structures.

Radiological imaging in otolaryngology, especially plain-film X-rays, has been used since cochlear implants (CIs) were developed. Early on, the importance of preoperative imaging for assessing candidates for implantation was acknowledged.[1,2] Over the years, imaging technologies have evolved alongside the refinement of CIs.

Today, various imaging modalities are available for preoperative evaluation, including computed tomography (CT) of the temporal bones and magnetic resonance imaging (MRI) of the brain and internal auditory canals.[3] Both provide 3-dimensional representations that effectively visualize key components of the auditory system. Additionally, functional MRI (fMRI) and diffusion tensor imaging (DTI) are gaining attention for their ability to offer clinically useful information beyond traditional CT or MRI.[4]

At present, to the best of our knowledge, there is no consensus on which imaging modalities, if any, should be used in preoperative evaluation, nor in which clinical populations or under what circumstances imaging is warranted. Reviewing the published literature on this topic suggests that major differences of opinion exist on the above questions. One way to begin to resolve these questions is to broadly examine imaging practices as they currently exist.

This study conducted a comprehensive survey of preoperative imaging practices in cochlear implantation. We engaged otolaryngology professionals with expertise in otology, neurotology, and cochlear surgery to evaluate various imaging modalities, their value and risks, anatomical targets, and parameters assessed from the images. The findings offer insight into the current state of pre-op imaging.

Methods

Participant Recruitment

Survey respondents were recruited from associates of an international consortium of otolaryngology practitioners with a focus on hearing implants that have worked together on previous consensus statements.[5,6] Respondents were invited to take part in the survey via email invitation. Invitations were sent to 41 individuals in total. Respondents were not pre-selected based on their use of pre-op imaging.

Survey Development

Imaging Modalities

To develop the survey, a literature review was conducted to identify imaging modalities which have been used during preoperative evaluation for cochlear implantation in patients. Modalities which have been reported only in human cadaveric or animal model studies were not included.

Nine imaging modalities were identified, as summarized in **Table 1**. Imaging modalities were classified into 2 groups. The first contained CT imaging and MRI, which are the most

Table 1. Imaging Modalities Selected for Inclusion in the Survey. The Abbreviations Used Are Given to the Right

Imaging modality	Abbreviation
Computed tomography (all types)	CT
Magnetic resonance imaging	MRI
Plain (nontomographic) X-ray	X-ray
Functional MRI	fMRI
Positron emission tomography/Single-photon emission CT	PET/SPECT
Functional near-infrared spectroscopy	fNIRS
Diffusion tensor imaging/auditory tractography	DTI/AT
Visible light imaging (photography, digital video, etc.)	VLI
Ultrasound	US

common modalities used currently. Because of this, more detailed questions were developed to assess the clinical application of these modalities. The second group was defined as *additional imaging modalities*. These modalities are less commonly reported than CT imaging or MRI in the context of cochlear implantation and were treated separately in the survey.

Evaluated Parameters

To identify the clinically evaluated parameters for inclusion in the survey, the studies from the literature review were examined for all reported parameters evaluated. Parameters included those which are evaluated qualitatively or quantitatively. Duplicate or redundant parameters were removed.

The remaining 42 parameters were then grouped into 10 categories based on the anatomic target: *cochlear morphology*, *inner ear*, *middle ear*, *mastoid*, *external auditory canal*, *internal auditory canal (IAC)*, *brain*, *nerves and vessels*, *lesions and malformations*, and *other* (Supplemental Table S1, available online). Inner ear malformations, otosclerosis/labyrinthitis ossification, and cholesteatoma were placed in the *lesions and malformations* anatomic target group, but may equally have been placed in the *inner ear* and *middle ear* targets, respectively. This choice of categorization had a relatively minor impact on the results and interpretation of this set of findings.

Survey Details

The survey was conducted on the SurveyMonkey platform from July to August 2024. Respondents completed it individually without seeing others' answers. It included a total of one hundred and twelve items, organized into several sections.

Basic Demographic and General Imaging Practices

Respondents were asked to state the country where their main clinical practice is situated. Respondents were asked if they use any kind of pre-op imaging. Possible answers were (*always/in most cases/in unusual or complex cases/never*). Respondents were also asked if they used multiple types of imaging in their practice. Possible answers were (*yes, routinely/yes, in special cases/no*).

Purpose of Imaging

Respondents were asked *In your practice, what is pre-op imaging used for? Please select all that apply*. The response options are shown in **Table 2**. Respondents could also select *other* to provide additional purposes which were not listed. In the sections below, the *other* option also allowed free text comments.

Table 2. Distributions of the Reported Purposes of Pre-op Imaging

Purposes of pre-op imaging	N	%
Diagnosis/confirmation of cochlear structural malformations	39	100.0
Diagnosis/confirmation of cochlear nerve abnormalities	39	100.0
Diagnosis/confirmation of noninner ear pathologies	36	92.3
Selection of the appropriate electrode array type	33	84.6
Measurement of cochlear morphological parameters	31	79.5
Decision-making between different types of hearing implants	29	74.4
Planning of the surgical approach	27	69.2
Assessing the functional status of non-inner ear structures	19	48.7
Planning the positioning of the implant body	10	25.6
Other	6	15.4

Abbreviation: N, number of respondents.

Evaluated Parameters

Respondents were asked *If you use pre-op imaging to evaluate anatomic parameters, which of the following do you evaluate? Please select all that apply*. The response options are given in Supplemental Table S1, available online. Respondents could also select *other*.

Use of CT Imaging and MRI

Respondents were separately asked if they used either CT imaging or MRI. Possible answers were (*yes, routinely/yes, in special cases/no*). Those who used CT were further asked which type was used, with the options of (*multi-slice CT/cone beam CT/other*). They were also asked if a (lower) age limit for CT imaging was used, and if so, what that age limit was. Those who used MRI were further asked what magnetic field strength was used in their practice, with the options of (*1.5 T/3 T/ > 3 T/other*).

Value of CT Imaging and MRI

Respondents were asked to rate the value of both modalities across four categories of value. These categories were *value for diagnosis* (what is the cause of the patient's hearing loss?), *value for candidacy* (is this patient suitable for implantation?), *value for surgical decision-making* (for planning and carrying out surgery), and *value for resources* (value relative to the financial costs and other resources required to perform the test).

Respondents rated the value of each modality according to a 5-point Likert scale ranging from 1 to 5. Visible scale response anchors were provided for the ratings of 1 ("no value") and 5 ("the greatest value").

Relative risks of CT Imaging and MRI

Respondents were asked to rate the comparative risks of the ionizing radiation associated with CT imaging and the sedation/anesthesia (if applicable, eg, in young children) associated with MRI. The risks were rated according to a 5-point Likert scale ranging from 1 to 5. Visible scale response anchors were provided for the

Table 3. Reported Functions of Pre-Op Image-Based Planning Software

Function	N	% (of software users)
Selecting the appropriate electrode array	29	93.5
To facilitate later post-op measurement of intracochlear electrode position	27	87.1
Diagnosis/confirmation of inner ear pathologies	11	35.5
Identifying risk structures such as the facial nerve	10	32.3
Planning the drilling trajectory and/or cochlear access	9	29.0
Other	4	12.9

ratings of ("the lowest risk") and a rating of 5 ("the highest risk").

Additional Imaging Modalities

For each modality, respondents were asked if they used it in their clinical practice. Possible answers were (*yes, routinely/yes, in special cases/no*).

Respondents were also asked to rate the potential value of each modality according to 3 value categories: *value for diagnosis*, *value for candidacy*, and *value for surgical decision-making*. The *value for resources* category was omitted as some of these modalities are more experimental and less well established, and their resource inputs may be difficult to estimate.

Image-Based Planning Software

Respondents were asked if they use any kind of image-based surgical planning software in their practice. Possible answers were (*yes, routinely/yes, in special cases/no*). Those who reported using such software were further asked which aspects of the surgery were planned with the software. These questions were intended to cover the basic functionality offered by various planning software products currently available. The full list of functions is detailed in **Table 3**.

Statistical Methods

Software

All statistical analyses were preplanned before the beginning of data collection. Statistical analyses were conducted in R (version 4.3.2, 2023; R Foundation) and Excel (version 2402, 2024; Microsoft Corporation).

Descriptive and Inferential Statistics

Counts, sums, and percentages were reported for survey responses, with medians used as point estimates. Distributions were described by means and standard deviations. The null hypothesis was rejected at a significance level of 0.05, using 0.025 for 2-tailed tests.

Calculation of Preference Asymmetry between CT and MRI

To evaluate respondents' preferences for CT or MRI, we computed the number of Likert ratings for each of the four value categories and created value rating matrices (**Figure 1**). If respondents showed no preference, their

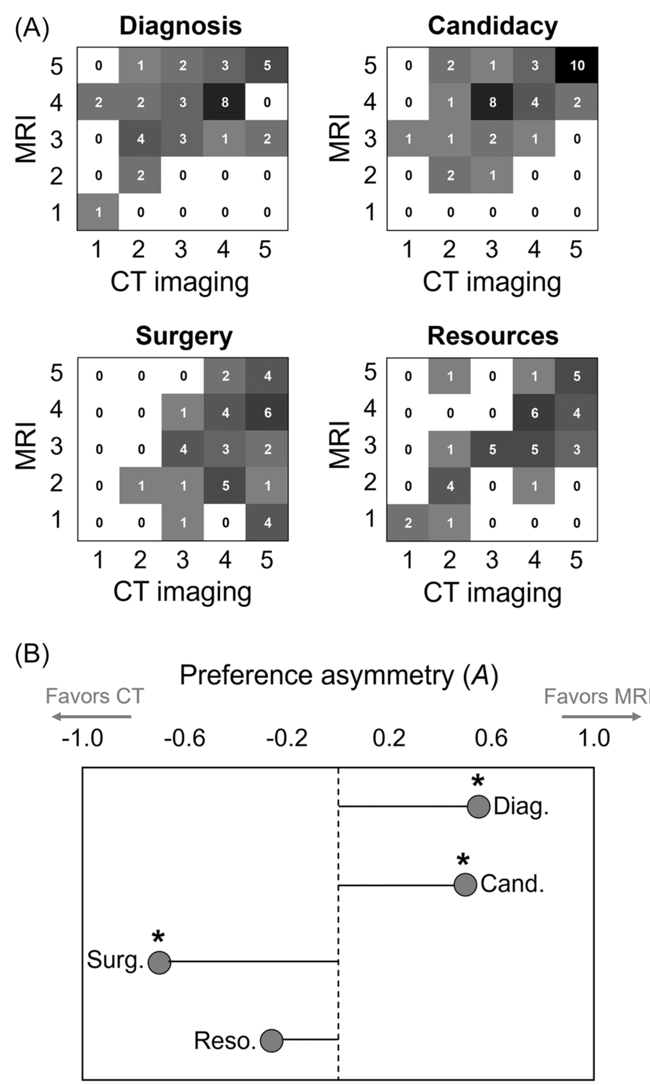


Figure 1. Relative value rating for CT and MRI. (A) Combined ratings of CT and MRI for four value categories. Darker colors indicate higher agreement. (B) Preference asymmetry values (−1.0: CT preference, +1.0: MRI preference). $P < .05$.

ratings would align diagonally, indicating symmetry (eg, those rating CT as "1" would also rate MRI as "1"). Conversely, a preference for one modality would result in a significant concentration of ratings either above or below the diagonal. We quantified this preference asymmetry (A) as follows:

$$A = \frac{1}{n}\sum\left(\frac{u-l}{u+l}\right)$$

Where u and l are the number of ratings in the corresponding pairs of the *upper* and *lower* and n is the number of non-diagonal pairs in the matrix. This metric provides a value between −1.0 and 1.0, where −1.0 indicates a total preference for CT imaging and 1.0 indicates a total preference for MRI. Note that when both the values in u and l were 0, an A of 0 was assigned (no asymmetry).

Permutation testing was used to estimate P-values for the preference asymmetries. For each of the four value rating categories, a synthetic null distribution was created by scrambling the non-diagonal ratings, and the preference asymmetry value was calculated. This was repeated 10,000 times to produce a distribution of null asymmetry values (each of which was centered at $A = 0$, and normally distributed by visual inspection of QQ plots).

The observed preference asymmetry value was then compared to this synthetic null distribution. If the observed A was found to be less than the 2.5th percentile or greater than the 97.5th percentile of the synthetic values (corresponding to a 2-tailed test), this is equivalent to a $P < .05$, and the null hypothesis of preference symmetry was rejected.

Results

Respondent Characteristics and General Imaging Practices

Overall, 39 invitees responded to the survey (response rate 95.1%). Respondents came from 36 centers across 16 countries. These were drawn from the World Health Organization regions of the Americas (n = 10), the Eastern Mediterranean (n = 4), Europe (n = 20), South-East Asia (n = 1), and the Western Pacific (n = 4).

All respondents reported that they use pre-op imaging in their clinical practice. Thirty-eight of 39 (97.4%) stated to use imaging in every case and 1 respondent in most cases.

All respondents stated that they perform multiple types of pre-op imaging in the context of an individual patient. Multiple imaging types were routinely used by 24 respondents (61.5%), while 15 (38.5%) stated to use multiple imaging types in special cases only.

Purpose of Imaging

Table 2 lists the reported imaging purposes. Additionally, 6 respondents mentioned other purposes, including diagnosing intrascalar pathologies, ruling out tumors in the internal auditory canal, determining facial nerve position, selecting between scala tympani and scala vestibuli for cochleostomy, and planning array insertion in ossification cases.

Targets of Imaging

The anatomic targets of imaging are shown in **Table 4**. Twenty-six respondents (66.7%) evaluated at least one parameter at all 8 anatomic targets.

The individual parameters assessed for each anatomic target are listed in Supplemental Table S1, available online. Respondents evaluated a varying number of parameters, with a median of 27 out of 42 options. However, not all 27 parameters will be evaluated in every case.

The most reported parameters evaluated were the detection of the presence of inner ear malformations (n = 37, 94.9%), of cholesteatomas (n = 36, 92.3%), and of otosclerosis/ossification (n = 36, 92.3%), all belonging to the *lesions and malformations* set of anatomic targets.

Beyond those listed as options in the survey, other reported parameters included the facial recess assessment, cochlear rotation, cochlear aperture size, posterior wall status of the external auditory canal, the mastoid segment of the facial nerve relative to the lateral semicircular canal, and any otic capsule dehiscence.

CT and MRI Imaging

All 39 respondents reported using CT imaging. The types of CT imaging used were multi-slice CT (n = 24, 61.5%), cone-beam CT (n = 11, 28.2%), photon-counting CT (n = 2, 5.1%), high-resolution CT (n = 1, 2.6%), and flat-panel volume CT (n = 1, 2.6%).

The age groups on which CT imaging was performed were all age groups (n = 27, 69.2%), adults only (n = 5, 12.8%), and adults and pediatric patients above an age limit (n = 7, 17.9%). For the latter, the age limits ranged from 1–12 years, with a median age limit of 5 years.

MRI was used by all 39 respondents, 2 of whom reported using it only in special cases. The field strengths reported were 3 T (n = 27, 69.2%), 1.5 T (n = 10, 25.6%), and >3 T (n = 2, 5.1%).

Table 4. Distributions of the Reported Anatomic Targets of Pre-op Imaging

Anatomic target	N	%
Inner ear	38	97.4
Lesions and malformations	37	94.9
Cochlear morphology (ie, parameters such as width, height, etc.)	36	92.3
Brain	36	92.3
Nerves and vessels	36	92.3
Mastoid	35	89.7
External and internal auditory canal	33	84.6
Middle ear	32	82.1
Other	7	17.9

Abbreviation: N, number of respondents.

Value of CT and MRI

The ratings for diagnosis, candidacy, surgical decision-making, and resources are shown in **Figure 1A**. Higher values above or below the diagonal indicate a preference for MRI or CT imaging. Median ratings for both modalities were similar across all categories, ranging from 3 to 4.

Figure 1B shows the value preference asymmetry between CT and MRI. Respondents rated MRI as being significantly more valuable for diagnosis ($A = 0.55$, $P = .005$) and candidacy ($A = 0.50$, $P = .015$). Respondents rated CT as being significantly more valuable for surgical decision-making ($A = -0.70$, $P = .0005$). CT was also rated as more valuable for resources, but this was not significant ($A = -0.26$, $P = .126$).

Comparative Risks of CT and MRI

Ratings of the risks associated with radiation exposure in CT imaging and with sedation/anesthesia (if applicable, eg, in young children) in MRI are given in **Figure 2**. Greater numbers above or below the diagonal indicate an asymmetric perception of risk toward radiation or sedation/anesthesia in young children, respectively. There was a small asymmetry in the distribution of risk ratings, with a tendency for higher risk ratings associated with CT imaging, but this was not statistically significant ($A = 0.25$, $P = .172$).

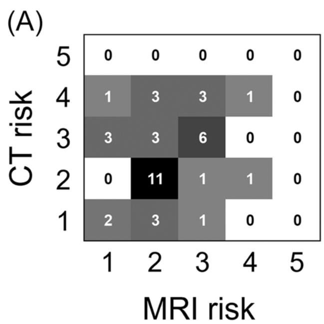
No participant rated either imaging modality as having a risk of 5/5. The median rating of the risk with CT imaging (3/5) was somewhat higher than that of the risk of MRI (2/5).

Additional Imaging Modalities

Overall, 19 respondents (48.7%) reported using at least one of these modalities in their clinical practice. Nine stated to use one of these modalities in their regular practice and not only in special cases (23.1% of the group as a whole and 47.4% of those who use any of these modalities).

The distributions of modalities and individual ratings for diagnosis, candidacy, and surgical decision-making are shown in **Figure 3**. Functional MRI (fMRI) was the

(A)



(B)

	CT	MRI
Median	3.0	2.0
Mean	2.6	2.2
SD	1.0	0.8
Min	1.0	1.0
Max	4.0	4.0

Figure 2. Relative risk ratings for CT and MRI. (A) Combined risk ratings for CT (ionizing radiation) and MRI (sedation/anesthesia, if applicable). Darker colors indicate higher agreement. (B) Summary statistics of risk ratings for each modality.

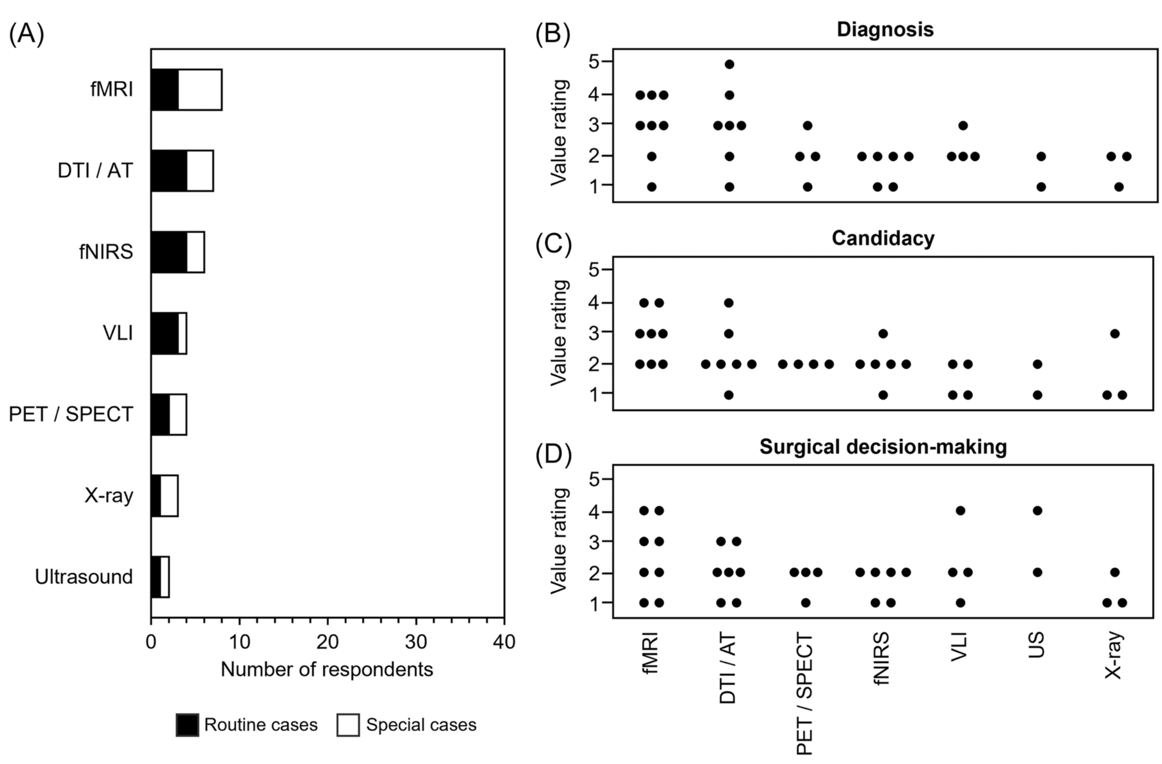


Figure 3. Use and value ratings for additional imaging modalities. (A) Number of respondents using each modality routinely or in exceptional cases. Individual value ratings for each modality are also shown for the categories of diagnosis (B), candidacy (C), and surgical decision-making (D). See **Table 1** for abbreviations.

most used modality (8 responders, 20.5%). Diffusion tensor imaging/auditory tractography (DTI/AT) and functional near-infrared spectroscopy (fNIRS) were frequently used in routine practice (each 4 of 39, 10.3%). Only DTI/AT for diagnosis received a value rating 5 from 1 respondent. Due to the small number of participants using pairs of modalities, preference asymmetries were not calculated.

Image-Based Planning Software

Thirty-one respondents (79.5%) reported using image-based planning software. The functions that planning software was used for are provided in **Table 3**. In addition, 3 respondents noted that they also used planning software for robotic surgery, and one noted that they used it to perform anatomy-based fitting.

Discussion

Imaging in General and Purposes of Imaging

All respondents reported using pre-op imaging in their practice, and most also reported using multiple imaging modalities. It is likely that the wide range of parameters evaluated is the cause of the need for multiple imaging modalities. CT imaging and MRI are optimal for different assessment, and the use of both is needed to acquire a holistic picture in pre-op evaluation.[7,8]

The most reported purposes of imaging were for the diagnosis or confirmation of a diagnosis of cochlear structural malformations and cochlear nerve abnormalities, which were reported by all respondents.

The least reported purpose of imaging was for planning implant positioning, likely because manufacturers provide templates that aid in this decision, making imaging less necessary.

Use of CT Imaging and MRI

CT and MRI were used by all respondents, although 2 reported that they use MRI only in special cases. These findings underscore the apparent predominance of CT and MRI as the main imaging modalities used for pre-op evaluation in the CI field.[3,9]

Various CT types were used, with multi-slice CT being the most common (61.5%). Cone-beam CT offers better image quality, particularly for soft tissues,[10] and has lower radiation exposure than multi-slice CT.[11,12] This concern over radiation may explain why 30.8% of respondents either avoid using CT for preoperative evaluations in children or set age limits for scans.

Nearly all respondents routinely use MRI, with 2 reserving it for special cases. The most common field strength was 3 T (69.2%), although some reported using devices above this level. Devices with field strengths of 7 T are entering clinical practice,[13] and 11.7 T devices have been shown to define cochlear structures clearly.[14] Currently, 14 T devices are in development.[15]

It should be noted that although all participants reported using both CT imaging and MRI in this survey, this practice is not universal. Several studies have questioned the use of routine preoperative imaging in adult populations without additional reasons for imaging such as a history of meningitis or otosclerosis, a childhood onset of deafness, or additional reasons to conduct an imaging (such as to investigate otoscopic findings).[16,17] Tamplen et al reported that imaging is unlikely to alter surgical decision-making in cases of postlingually-deafened adults without conductive or asymmetrical hearing loss.[18] Keidar also reported similar findings with elderly adults.[19] In both studies, the cost of imaging and the relatively low diagnostic yield were cited as reasons against deploying routine pre-op imaging.

Value and Risks of CT and MRI

Asymmetric preference analysis demonstrated clear and significant differences in the value ratings for CT and MRI for different purposes. Respondents rated MRI as significantly more useful for diagnosis and evaluation of CI candidacy. MRI has a higher detection rate for radiological abnormalities that affect subsequent management[20] and can better reveal features such as retrocochlear or intracochlear pathology, cochlear patency, and fluid signals, such as in an enlarged vestibular aqueduct.[18] The use of specific MRI sequences was not considered in this survey. Gadolinium enhancement on MRI is useful for the differential diagnosis of intracochlear pathologies, such as inflammation and tumours,[21,22] while specific sequences are useful for the evaluation of endolymphatic hydrops.[23] Although not specifically assessed in this survey, MRI is also important for CI candidates with suspected cochlear nerve hypoplasia or aplasia, particularly in CI candidates with congenital single-sided deafness,[24] with an inner ear malformation, or a narrow internal auditory canal.[25] Despite this, it has been argued that for diagnosis and assessment of CI candidacy, dual-modal imaging with CT and MRI is superior to either modality alone, since data from one modality can clarify ambiguous signals obtained from the other.[7]

Respondents rated CT imaging as significantly more valuable for surgical decision-making than MRI. CT is superior for (1) measuring anatomical parameters of the cochlea, such as the width, height, and diameter and (2) facilitating direct and indirect measurement of cochlear duct length.[26] This information is highly relevant, for example, for selection of electrode array length and flexibility. The distance between the cochlea and the facial nerve and the density of the bone separating them can also be estimated with CT imaging, which can influence the planning of the surgical drilling path.[27] Likewise, CT achieves high detection rates of cochlear ossification,[28] which can also strongly affect surgical decision-making.[29]

MRI was rated as having somewhat lower value than CT imaging in terms of resource-effectiveness, although this difference was not statistically significant. This difference may be attributable to the higher financial cost associated with MRI scans[30,31] or with the possible necessity of using sedation or anesthesia in some patients (eg, young children) which causes additional resources and costs.[32,33]

The ionizing radiation in CT imaging poses a slightly higher risk than the sedation or anesthesia used in MRI, although the difference isn't statistically significant. MRI's lower perceived risk partly stems from the possibility of omitting sedation in some cases, especially for adolescents and adults, while very young children may undergo MRI during natural sleep.[34] Unlike MRI, CT inherently involves ionizing radiation, but newer technologies like cone-beam CT and photon-counting CT can help reduce this exposure.[35]

It should be noted that there are 2 facts which complicate the interpretation of the relative risks of CT and MRI. Sedation and/or anesthesia are mainly used in young children, whereas the radiation dose is a risk for all age groups, but is greater in young children. We also did not assess risks associated with contrast agents used in MRI.

Additional Imaging Modalities

Other modalities were less frequently used than CT imaging or MRI. It was found that almost half of the respondents used at least one other imaging technique in their clinical practice, and one quarter used at least one in their routine cases.

The most common modality was fMRI, which has various reported uses in pre-op evaluations. It has been shown to correlate with post-implantation language skills in pediatric patients,[36] and with improvements in hearing thresholds.[37] Therefore, fMRI may be a valuable tool for patient selection, particularly in pediatric populations.

The most common additional modalities used for routine cases were DTI/AT and fNIRS, reported by four respondents each (10.3%). DTI processes diffusion-weighted MRI sequences to estimate structural connectivity within brain regions.[38] AT, an application of DTI, delineates auditory fiber tracts to the primary and secondary auditory cortices.[39] AT can detect structural deficits in individuals with hearing loss and improvements in those with auditory recovery.[4] It also assesses cochlear implant candidacy, particularly excluding patients with severe central auditory pathway disorders.[40]

Like fMRI, fNIRS relies on the indirect detection of cortical neural activity through the measurement of cortical hemodynamic responses.[41] Although fNIRS has a highly restricted penetration depth (approximately 3 cm), this is sufficient to image activity within the auditory cortices as well as other cortices associated with hearing and language.[42] It has been shown that fNIRS responses to auditory and speech stimuli have some degree of predictive value for postoperative speech perception in CI users.[43] As such, it may have a value for the evaluation of CI candidacy, although the candidacy value ratings provided by the respondents in the present study were not high (median 2, **Figure 3C**).

Image-Based Surgical Planning Software

It was found that almost 80% of respondents used planning software in their clinical practice. The functions that these tools were used for varied widely among respondents. Most users reported using this software for selection of the appropriate electrode array and to facilitate later post-op measurement of intracochlear electrode position (ie, through registration of pre-op and post-op images). This reflects the previously reported uses of planning software described in a systematic review.[44]

Less than half of those using planning software reported its application for the diagnosis or confirmation of inner ear pathologies, for identifying risk structures such as the facial nerve, or for planning the drilling trajectory and/or cochlear access. Several users who employed robotic surgery reported using planning software as part of this workflow. In these cases, planning software is necessary to determine the optimal drilling trajectory and angle of cochlear approach toward the middle ear and inner ear, among other parameters.[8,45,46]

Limitations of the Study, Unasked and Unanswered Questions

It would have been desirable to gather additional data from the survey group. For example, we would have liked to know which imaging method was used for the individual parameter evaluations, or which reconstruction and analysis methods were used for CT imaging and MRI.

These additional questions were omitted in order not to overload the questionnaire. With the final survey design the respondents were asked to respond to over one hundred items, and the median time taken to complete the survey was more than 20 minutes. Additional questions may have risked inducing fatigue in respondents, an increase in nonresponders, or a deterioration in the quality of the data obtained.

An additional limitation is that we did not address the possibility of an "upper" age limit for MRI; that is, that MRI may not be warranted for routine use in cases of adults without childhood onset of deafness, asymmetric hearing loss, or other reasons to suspect retrocochlear pathologies or other abnormalities.[47,48] It may be the case that, although routine MRI was reportedly used by all respondents in this study, there may have been differences in which clinical populations or other circumstances it was used.

For the additional imaging modalities, only those respondents who actually used each modality also rated its potential value. Consequently, the value ratings for these modalities were sparse compared to those for CT imaging and MRI, and conclusions drawn from these specific data should be tentative.

In addition, the practitioners were drawn from a limited range of countries and were particularly concentrated in high-income countries. This also provides a more limited viewpoint into global CI practice. In lower resource environments, practitioners may have different perspectives on the value gained from different imaging modalities. The participants here are also involved in data collection and scientific research, which may have skewed opinions regarding additional imaging modalities and their value for practice.

Conclusions

In this survey on current practices of pre-operative imaging for cochlear implantation, it was found that the use of CT and MRI is frequent and has complementary purposes. Additional imaging modalities are used by almost half of the participating practitioners and may play an increasing role in research and specific clinical cases. As mentioned above, these conclusions come with the caveat that the practitioners surveyed here were drawn largely from high-income countries, and these perspectives may not necessarily be applicable to practitioners in low-income countries.

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Description

Frequency of anatomical parameters assessed via preoperative CT/MRI for surgical planning, categorized by anatomic target (cochlea, inner ear, middle ear, mastoid, nerves, vessels, lesions).

Ethics Statement

This study was a voluntary survey of professional attitudes and practices. As such, no approval from an ethics body was required.

Disclosures

Competing interests: Yassin Abdelsamad, Patrick F. Connolly, Dovile Jankunaite, and Ilona Anderson are all employees of MED-EL GmbH with scientific roles only. The remaining authors do not declare any conflicts of interest relating to this work.

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Supplemental Material

Additional supporting information is available in the online version of the article.

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