Utility of Preoperative Computed Tomography and Magnetic Resonance Imaging in Adult and Pediatric Cochlear Implant Candidates

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Objectives/Hypothesis: Determine the utility of preoperative imaging in adult and pediatric cochlear implant candidates.

Study Design: Retrospective chart review.

Methods: Medical records of 101 consecutive adult and 20 consecutive pediatric patients who underwent 137 cochlear implantation (CI) procedures at a single institution were reviewed.

Results: Computed tomography (CT) was obtained preoperatively in 110 (90.9%) patients, preoperative magnetic resonance imaging (MRI) was obtained in 102 (84.3%) patients, and both were obtained in 94 (77.7%) patients. MRI revealed one acoustic neuroma and two meningiomas, which affected surgical planning for three (2.2%) procedures. MRI identified enlarged vestibular aqueduct (EVA) in 2.0% of adult patients. CT demonstrated middle ear disease in four (3.3%) patients. CT was useful in indicating round window and cochlear patency in three (2.2%) patients with cochlear otosclerosis. Twenty pediatric patients underwent 27 CI procedures. Preoperative CT in the pediatric cohort demonstrated five (25%) dysplastic cochleae, three (15%) dysplastic vestibules and/or semicircular canals, and three (15%) EVAs. In one patient, CT demonstrated a duplicated right internal auditory canal (IAC) and hypoplastic left IAC; MRI confirmed hypoplastic cochlear nerves.

Conclusions: Preoperative MRI can demonstrate retrocochlear pathology, cochlear patency, and EVA in adults being evaluated for cochlear implantation. CT may provide additional information in patients with chronic otitis media or otosclerosis. However, in postlingually deafened adults without conductive or asymmetrical hearing loss, imaging is unlikely to affect surgical decision making. Both CT and MRI can identify anomalies in pediatric patients. MRI does not offer substantial benefit over CT for routine evaluation of pediatric inner ear and temporal bone anatomy.

Key Words: Cochlear implant, radiology, otology, pediatric otology.

Level of Evidence: 4

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INTRODUCTION

Preoperative imaging, including computed tomography (CT) and/or magnetic resonance imaging (MRI), has historically been used in the evaluation of candidates for cochlear implant (CI). However, the utility of each imaging strategy has not been clearly defined. Patients often receive CT or MRI or both, with no clear indication for each independent imaging study. A blanket approach of routine CT and MRI imaging in all CI candidates may not be cost-effective. Roberts et al. suggested that in adult patients with symmetric sensorineural hearing loss (SNHL) without a history of congenital hearing loss, meningitis, or head trauma, preoperative imaging was unlikely to change the surgical plan for cochlear implantation.1 Schwartz and Chen also suggested that in postlingually deafened adults, there was limited utility in routine imaging without a concerning clinical history.2

The theoretical utility of preoperative imaging includes evaluation of round window patency, course of the facial nerve and location of the jugular bulb and other important landmarks, identification of cochlear anomalies including hypoplasia, detection of infection, and evaluation of the vestibular aqueduct system for increased likelihood of a cerebrospinal fluid (CSP) gusher.3,4 However, the rate of such findings in adult patients is low, and the rate of any finding on imaging affecting the surgical approach is even lower.1 There is no consensus on the preferred preoperative imaging strategy for CI candidates. Viad and Vaid outlined the utility of both CT and MRI for possible anatomic abnormalities that would affect CI operations and recommended both imaging strategies for the complimentary information they provide.4 Sweeney et al.
recommended MRI for CI candidates for the diagnosis of acoustic neuromas, although this was a very rare finding without concerning clinical history.\textsuperscript{5}

The incidence of anatomic anomalies is different in different patient populations. Pediatric patients with congenital hearing loss have a 20% rate of anatomic abnormalities, which may make preoperative cross-sectional imaging much more useful.\textsuperscript{3} However, the best imaging strategy for pediatric CI candidates is still debated. The majority of anatomic abnormalities that would affect the operation can be diagnosed with either CT or MRI.\textsuperscript{4} Parry et al. suggested that MRI is more sensitive for soft tissue findings that would affect pediatric CI operations than CT and should be the first choice for imaging in pediatric patients.\textsuperscript{6} Historically, the role for MRI has been to visualize a hypoplastic acoustic nerve, but it is unclear how common this finding is without any finding on CT such as a narrowed internal auditory canal (IAC) or cochlear or vestibular dysplasia. The risk-benefit ratio of each imaging study always has to be considered in pediatric patients. MRI often requires sedation in pediatric patients, and there are potential long-term effects of radiation exposure from temporal bone CT (Fig. 1).

In adult patients, it appears the cause of deafness may significantly affect the likelihood of imaging findings that affect the operation. Postlingually deafened adults without history of meningitis, trauma, or asymmetrical loss may not require any imaging at all.\textsuperscript{1} Those with asymmetry or additional clinical history may benefit from an MRI without the need for CT unless there is a significant conductive component to their hearing loss.\textsuperscript{7} The goal of this study was to evaluate the diagnostic yield of both CT and MRI in both children and adults receiving a CI to help clarify these issues.

MATERIALS AND METHODS

The University of California, San Francisco Committee of Human Research reviewed and approved this study. We preformed a retrospective chart review of the medical records for 121 consecutive patients (101 adult and 20 pediatric) who underwent 137 cochlear implantation procedures between May 14, 2011 and July 30, 2014 at a single institution. Seven pediatric and nine adult patients underwent bilateral cochlear implantation. During the study period it was institutional practice to obtain routine preoperative CT and MRI in all CI candidates. Clinical notes, radiology reports, and operative reports were reviewed for any complications or planned or unplanned operative changes.

Cost analysis was done using California Medicaid (Medi-Cal) reimbursement rates for 2014. Cost per significant finding was calculated using the equation: (number of individual scans × Medi-Cal reimbursement rate for that type of scan) / number of significant findings reported by that type of scan. The potential cost savings in the adult cohort if only adult patients with preoperative indications were scanned was also evaluated. This was done by subtracting the number of scans from patients with preoperative indications for that individual scan from the total number of each scan preformed and multiplying this by the cost of each scan.

The potential cost savings was also evaluated in the pediatric cohort if all patients had undergone routine CT, and MRI was only done if there was any abnormal finding on routine CT. The risks of radiation exposure were estimated by using previously published lifetime attributable risk of solid cancer and lifetime attributable risk of leukemia per head CT scan and multiplying this by the number of pediatric head CTs preformed.

RESULTS

CT was obtained preoperatively in 110 (90.9%) patients, preoperative MRI was obtained in 102 (84.3%) patients, and both were obtained in 94 (77.7%) patients (Table I). Significant findings are listed in Table II. MRI revealed one acoustic neuroma and two meningiomas, which affected surgical planning for three (2.2%) of the 137 procedures. The patient with the acoustic neuroma presented with a significant asymmetrical SNHL. Fourteen (13.8%) of the adult patients in this cohort had a significant asymmetrical SNHL. The majority of patients received both imaging studies, however, and 37 (22.3%) patients received only MRI or CT. The retrospective nature of the current study did not allow for evaluation of reasoning behind individual imaging decisions.

Twenty pediatric patients underwent 27 CI procedures. Significant findings on preoperative imaging are listed in Table II. In one patient, CT demonstrated a duplicated right IAC and hypoplastic left IAC; MRI confirmed hypoplastic cochlear nerves in this patient (Fig. 2). There were no pediatric patients who underwent both CT and MRI who had a significant MRI finding with a normal CT scan (Table III).

There was a documented change in surgical plan based on imaging findings for eight (7.9%) of the adult patients and 13 (65%) of the pediatric patients (Table III). The eight adult patients with documented change in surgical plan consisted of three intracranial neoplasms that changed side and/or type of implant, three cases of restricted cochlear patency that changed the side of implantation, and two enlarged vestibular aqueducts that...
changed the side of implantation. The 13 pediatric patients with documented change in surgical plan consisted of eight dysplastic cochlea, three enlarged vestibular aqueducts, and two hypoplastic cochlear nerves, all changing the side of implantation.

The surgical plan was changed based on findings considered exclusive to CT (or documented only on the CT report) for three (3%) adult patients and 12 (60%) pediatric patients. The surgical plan was changed by findings considered exclusive to MRI (or documented only on the MRI report) for three (3%) adult patients and zero (0%) pediatric patients (Table III). No patients in this study had a history of meningitis.

Based on Medi-Cal reimbursement rates for MRI and CT, it cost $36,062 to find a single significant finding on routine preoperative MRI for our adult cohort. In our pediatric cohort, it cost $310 to find one significant finding on routine preoperative CT. All CTs performed lead to an estimated 0.0053 lifetime risk for solid tumor or leukemia based on previously published data on radiation risks of head CTs in children.

DISCUSSION

The utility of routine preoperative imaging for CI candidates is still debated and is highly dependent on clinical history. In patients who have a congenital hearing loss, imaging is used to screen for the approximately 20% who have malformations of the inner ear, some of which may impact surgical planning; however, there is still debate regarding the optimal imaging study. In adult patients with postlingual hearing loss, preoperative imaging has historically been standard, although there is no consensus on the type of scan or the utility of imaging without consideration of pertinent clinical history. Recent studies have shown limited utility of preoperative imaging in postlingually deafened adults. In a retrospective chart review of 118 adults with progressive sensorineural hearing loss, Roberts et al. found that preoperative imaging led to no mandatory changes in surgical management, even when an abnormality was found. Notably, six of these patients had intraoperative findings, including round window ossification, multiple insertion attempts, or CSF leak, which were not predicted by preoperative scans. This led the authors to recommend imaging only for cases where there was another clinical indication for imaging such as a history of head trauma, history of meningitis, significant asymmetry on audiogram, or significant conductive hearing loss.

Schwartz and Chen also found limited utility of routine preoperative imaging in postlingually deafened adults. In 109 postlingually deafened adult CI candidates without concerning features on history or physical exam, they found imaging results were unlikely to affect surgical management. In two of these patients (1.8%), an incidental cerebellopontine angle (CPA) tumor was found; however, both patients presented with asymmetrical hearing loss. These findings are similar to the findings in the current study, in which only eight (7.9%) adult patients had their operation affected by preoperative imaging, three (3.0%) intracranial neoplasms

<table>
<thead>
<tr>
<th>TABLE I.</th>
<th>Patient Characteristics.</th>
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<tbody>
<tr>
<td></td>
<td>Adult (101)</td>
</tr>
<tr>
<td>Age, yr, mean, range (SD)</td>
<td>58, 18–90 (16.9)</td>
</tr>
<tr>
<td>Preoperative CT, n (%)</td>
<td>91 (90.1%)</td>
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<tr>
<td>Preoperative MRI, n (%)</td>
<td>85 (84.1%)</td>
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<td>Preoperative MRI and CT, n (%)</td>
<td>78 (77.2%)</td>
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<th>TABLE II.</th>
<th>Imaging Findings.</th>
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<tr>
<td></td>
<td>Adult</td>
</tr>
<tr>
<td>CT</td>
<td>91 (4.4%)</td>
</tr>
<tr>
<td>Restricted cochlear patency, n (%)</td>
<td>3 (3.3%)</td>
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<tr>
<td>Dysplastic cochlea/ vestibule, n (%)</td>
<td>0 (0%)</td>
</tr>
<tr>
<td>EVA, n (%)</td>
<td>0 (0%)</td>
</tr>
<tr>
<td>Hypoplastic IAC, n (%)</td>
<td>0 (0%)</td>
</tr>
<tr>
<td>MRI</td>
<td>85 (3.3%)</td>
</tr>
<tr>
<td>Acoustic neuroma/ meningioma, n (%)</td>
<td>2 (2.4%)</td>
</tr>
<tr>
<td>Hypoplastic cochlear nerve, n (%)</td>
<td>0 (0%)</td>
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<th>TABLE III.</th>
<th>Surgical Plan Changed by Imaging.</th>
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<tr>
<td></td>
<td>Adult (101)</td>
</tr>
<tr>
<td>Abnormal CT, n (%)</td>
<td>7 (6.9%)</td>
</tr>
<tr>
<td>Abnormal MRI, n (%)</td>
<td>5 (5.0%)</td>
</tr>
<tr>
<td>Surgical plan changed by imaging, n (%)</td>
<td>8 (7.9%)</td>
</tr>
<tr>
<td>Surgical plan changed by finding exclusive to or read best on CT, n (%)</td>
<td>3 (3.0%)</td>
</tr>
<tr>
<td>Surgical plan changed by finding exclusive to or read best on MRI, n (%)</td>
<td>3 (3.0%)</td>
</tr>
</tbody>
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CT = computed tomography; MRI = magnetic resonance imaging.
affecting the side and type of implant (due to anticipated MRI artifact or implant-specific MRI compatibility), three (3.0%) cases of restricted cochlear patency in patients with otosclerosis affecting the side of implantation, and two (2.0%) cases of enlarged vestibular aqueduct affecting the side of implantation.

In the current study, the single patient with a CPA neoplasm met institutional criteria of MRI imaging for asymmetrical hearing loss with either $>10$ dB asymmetry across three consecutive frequencies, 15 dB in two consecutive frequencies, or 20 dB in one frequency and/or marked differences in speech discrimination between the two ears. Thirteen other adult patients also met these criteria for asymmetric hearing loss; each of which had an MRI scan that was read as normal. The findings of an intracranial neoplasm led to operative changes in both side and device choice. In total, three intracranial neoplasms were found in this study. A single 9-mm vestibular schwannoma was managed with serial MRIs for observation. The patient had the side and type of implant changed by this preoperative finding. There were two meningiomas. One has been undergoing observation with serial MRIs and one underwent radiotherapy. Both had the type of implant changed by the preoperative finding to ensure MRI compatibility. Although some studies have shown that MRI with CI in situ is safe for all CI manufacturers, Despite MED-EL being the only device that is Food and Drug Administration-approved with head wrap at 1.5 T (and more recently 3 T), and the others currently recommend magnet removal. Also, due to artifact from the CI, the side contralateral to the tumor is often preferred.

Cochlear otosclerosis was a rare finding in this cohort, which was found in only three (2.2%) adult patients. All patients with otosclerosis, and thus possible round window obliteration, had a significant conductive hearing loss with a $>20$ dB air-bone gap preoperatively. Four (3.3%) patients had a CT scan that confirmed middle ear disease. All of these patients with CT evidence of middle ear disease were noted to have concern for middle ear disease on preoperative clinical examination. There was no documented change in surgical plan based on the imaging findings for the patients with noted middle ear disease; however, CT may have assisted in confirming the diagnosis or evaluating the extent of middle ear disease. Thus, the current study is in agreement with others in that CT is most useful when there is a clinical or audimetric concern for otosclerosis or middle ear/mastoid disease.

Pediatric patients have been found to have a much higher rate of abnormal findings on preoperative imaging that may affect surgical planning. The current study corroborates this finding, as 13 (65%) pediatric patients had their operation affected by imaging findings (Table III). There is often a debate regarding the preferred imaging study, as MRI has been shown to be superior for soft tissue abnormalities and the absence of a cochlear nerve. However, it is very rare for an MRI to show a significant abnormality if the CT was read as normal. On review of the literature, there is not a single case of a cochlear implant candidate with a completely normal CT scan and a hypoplastic or aplastic cochlear nerve on MRI. Often a narrow IAC is found if there is significant dysplasia of the cochlear nerve. Kutz et al. demonstrated 86% of patients with a hypoplastic or aplastic cochlear nerve had an IAC $<1.4$ mm in diameter. McClay et al. demonstrated that out of 170 pediatric patients with SNHL, 18% had a hypoplastic or aplastic cochlear nerve on MRI, and of these 82% had narrow IAC and 76% had additional cochlear abnormalities. Bamiou et al. reported 93% of patients with cochlear nerve hypoplasia had a narrow IAC. There is consistently reported to be a high rate of associated inner ear abnormalities and narrow IAC in pediatric patients with clinically significant hypoplasia of the cochlear nerve. In our cohort of 32 pediatric temporal bones that underwent both imaging modalities, there was no significant MRI finding with a normal CT scan. This may provide clinical utility, as pediatric patients often require sedation for MRI imaging, and CT may be more available and cost-effective for routine screening.

When deciding the preferred imaging strategy for pediatric CI screening, one must consider the cost of each imaging modality and the potential risks associated with each imaging modality. Medi-Cal reimbursement rates for 2014 are $212$ for a CT temporal bone, $853$ for an MRI of the IAC, and an estimated additional $250$ for sedation during the exam. The lifetime risk of solid tumor and leukemia attributable to a single CT scan was estimated by Migliorietti et al., who found the number of solid tumors or leukemia associated to one head CT in children $<5$ years of age to be 0.00144 and 0.000288 in children $<5$ years of age. Pediatric MRIs often require sedation due to the length of the exam. Although the risks of pediatric sedation outside the operating room are often debated, Cravero et al., from a voluntary database of 35,000 pediatric sedation encounters, reported that there were no deaths reported and only one cardiac emergency. There was a single aspiration...
episode reported, but one in 400 procedures was associated with stridor, laryngospasm, wheezing, or apnea. One in every 200 sedation encounters required airway interventions ranging from bag-mask ventilation to oral airway placement to emergency intubation. Long-term affects of early anesthesia are still debated; however, several studies have suggested early pediatric anesthesia is a significant risk factor for learning disabilities, and this must be considered when ordering procedural sedation for any pediatric patient.

In our adult patient cohort, it cost $36,062 to find a single significant finding on routine preoperative MRI. In our pediatric cohort it cost $310 to find one significant finding on routine preoperative CT scan, with a total attributable lifetime risk for solid cancer or leukemia of 0.0053 (0.00028 x 19) for all scans performed. The findings of the current study suggest that routine imaging may not be cost-effective for postlingually deafened adults without a clinical history of asymmetrical hearing loss or a conductive hearing loss. These findings also suggest the routine CT scan is cost-effective in the pediatric cohort and may be a preferred imaging strategy in pediatric CI candidates where an MRI can be performed if CT scan reveals any abnormal finding. Following this algorithm (Fig. 3) in the current adult cohort would have led to only 14 MRIs and seven CT scans. This would have saved 71 MRI scans and 84 CT scans, for a total savings of $85,471 or $846 per adult patient. Following this algorithm in the pediatric cohort would have lead to 13 MRI scans and two CT scans. This would have saved four MRI scans and added one CT scan, for a total savings of $3,600 or $180 per pediatric patient.

This study has several limitations. It is retrospective and includes a limited number of subjects. In particular, 40 pediatric temporal bones may be too few to derive a reliable conclusion regarding the preferred imaging strategy for pediatric patients in general. Several studies have demonstrated that routine MRI screening of children during the CI evaluation may detect cytomegalovirus-related changes or subtle brain developmental malformations important for developing appropriate expectations for parents. However, the current study does suggest that CT is useful in this cohort, and may be an acceptable routine imaging strategy for the surgical planning of pediatric cochlear implant candidates.

CONCLUSION
Preoperative MRI can demonstrate retrocochlear pathology, cochlear patency, and an enlarged vestibular aqueduct in adults being evaluated for cochlear implantation, and CT may provide additional information in patients with chronic otitis media or otosclerosis. However, routine preoperative imaging in adults may not be cost-effective unless patients have an asymmetric or conductive hearing loss. Both CT and MRI can identify inner ear anomalies in pediatric patients. Routine MRI scanning in children does not offer substantial diagnostic benefit over CT for routine evaluation of pediatric inner ear and temporal bone anatomy for surgical planning and may not be cost-effective for routine CI screening.

BIBLIOGRAPHY


