Premiere Publications from The Triological Society

Read all three of our prestigious publications, each offering high-quality content to keep you informed with the latest developments in the field.

**Laryngoscope**

*Founded in 1896*

Editor-in-Chief: Samuel H. Selesnick, MD, FACS

The leading source for information in head and neck disorders.

[Laryngoscope.com](http://Laryngoscope.com)

**Investigative Otolaryngology**

Editor-in-Chief: D. Bradley Welling, MD, PhD, FACS

Rapid dissemination of the science and practice of otolaryngology-head and neck surgery.

[InvestigativeOto.com](http://InvestigativeOto.com)

**ENTtoday**

A publication of the Triological Society

Editor-in-Chief: Alexander Chiu, MD

Must-have timely information that Otolaryngologist-head and neck surgeons can use in daily practice.

[Enttoday.org](http://Enttoday.org)
Efficacy of a Selective Imaging Paradigm Prior to Pediatric Cochlear Implantation

Jennifer M. Siu, MD; Susan I. Blaser, MD, FRCPC; Karen A. Gordon, PhD, CCC-A, Reg. CASLPO; Blake C. Papsin, MD, MSc, FRCSC, FACS, FAAP; Sharon L. Cushing, MD, MSc, FRCSC

Objectives/Hypothesis: There is no consensus on the necessary preoperative imaging in children being evaluated for cochlear implantation (CI). Dual-imaging protocols that implement both magnetic resonance imaging (MRI) and high resolution computed tomography (HRCT) create diagnostic redundancy in the face of potentially unnecessary radiation and anaesthetic exposure. The objectives of the current study were to examine the efficacy of an MRI-predominant with selective HRCT imaging protocol.

Study Design: Retrospective review.

Methods: The protocol was implemented over a 4-year period, during which HRCT was obtained in addition to MRI only if specific risk factors on clinical assessment were identified or if imaging findings in need of further evaluation were detected on initial MRI evaluation. Retrospective review of operative reports and prospective review of imaging were performed; anaesthetic exposure and costing information were also obtained.

Results: Of the 240 patients who underwent assessment, seven (2.9%) had combined HRCT and MRI performed concurrently based on initial clinical assessment, 15 (6.3%) underwent HRCT based on imaging anomalies found on MRI, and MRI alone was ordered for the remaining 218 (90.1%). All patients were implanted without complication. Overall, radiation exposure, general anaesthesia (GA), and healthcare costs were reduced.

Conclusions: MRI alone can be used in the vast majority of cases for preoperative evaluation of pediatric CI candidates resulting in a significant reduction in healthcare costs, radiation, and GA exposure in children. The additional need for HRCT occurs in a small proportion and can be predicted up front on clinical assessment or on initial MRI.

Key Words: Sensorineural hearing loss, imaging, children, high-resolution computed tomography, magnetic resonance imaging, cochleovestibular anomaly.

Level of Evidence: 4

Laryngoscope, 129:2627–2633, 2019

INTRODUCTION

Diagnostic imaging prior to pediatric cochlear implantation (CI) is essential in determining implant candidacy, assessing abnormal anatomy, diagnosing the etiology of deafness, and providing realistic perioperative expectations for patients and their families.1 Imaging in children with hearing loss is of particular importance, as the incidence of inner ear anatomic abnormalities ranges as high as 20% to 35%.2,3

Currently, there is no widespread consensus on the requisite modality of cross-sectional imaging in this population. Historically, high-resolution computed tomography (HRCT) had been the standard imaging approach. However, more recently, numerous studies have demonstrated magnetic resonance imaging (MRI) to be superior compared to HRCT in the assessment of several important clinically and surgically relevant findings. These include direct assessment of the cochlear nerve, diagnosis of congenital cytomegalovirus (CMV), white matter soft tissue findings, and early identification of cochlear ossification.4–6 Despite its advantage and diagnostic superiority for these conditions, MRI in children requires a longer image acquisition time, often necessitating general anesthesia (GA) to prevent motion artifact, and is more costly than HRCT. Therefore, there is a reluctance to completely give up the familiar bony detail in HRCT that otolaryngologists are traditionally trained with.

Acknowledging the benefits of both modalities, this led many institutions, including ours, to adopt a standard approach of routine dual imaging with HRCT and MRI. We previously implemented the dual-imaging protocol and prospectively compared the utility of these two imaging modalities.4 Overall, although HRCT and MRI

From the Department of Otolaryngology–Head and Neck Surgery (J.M.S., K.A.G., R.C.P., S.L.C.) and Department of Diagnostic Imaging–Head and Neck Surgery (S.I.B.), Archie's Cochlear Implant Laboratory (K.A.G., B.C.P., S.L.C.) and Department of Communication Disorders (K.A.G., B.C.P., S.L.C.), The Hospital for Sick Children, Toronto, Ontario, Canada; and the Department of Otolaryngology–Head and Neck Surgery (J.M.S., S.I.B., K.A.G., B.C.P., S.L.C.) and Institute of Medical Sciences (K.A.G.), University of Toronto, Toronto, Ontario, Canada.

Editor's Note: This Manuscript was accepted for publication on October 12, 2018.

Presented as a podium presentation at the Triological Society 121st Annual Meeting at COSM, National Harbor, Maryland, U.S.A., April 18–22, 2018.

K.A.G., B.C.P., and S.L.C. are on the speakers' bureau for Cochlear Corporation. S.L.C. is also on the speaker's bureau for Oticon and Interacoustics.

The authors have no other funding, financial relationships, or conflicts of interest to disclose.

Send correspondence to Sharon L. Cushing, MD, Department of Otolaryngology–Head and Neck Surgery, The Hospital for Sick Children (SickKids), 555 University Avenue, Room 6103C, Burton Wing, Toronto, ON M5G 1X8, Canada. E-mail: sharon.cushing@sickkids.ca

DOI: 10.1002/lary.27666

Laryngoscope 129: November 2019

Siu et al.: Imaging Algorithm in Children With Deafness
together provided maximal soft tissue and bony detail about surgical landmarks and inner ear dysplasia, there was a significant redundancy in the information afforded by the two modalities. Given this redundancy and inefficient use of resources of a universal dual-imaging approach, we proposed the implementation of a new algorithm involving the predominant use of MRI, and selective ordering of HRCT to aid in certain clinical circumstances that may influence surgery. The focus of this study was to retrospectively analyze the results of this new MRI-predominant protocol.

MATERIALS AND METHODS

Inclusion/Exclusion Criteria

The study population included all pediatric implant candidates who had imaging performed preoperatively at our institution and were implanted between January 2013 and September 2017. All patients were aged 18 years or under. Patients were excluded if imaging was performed in an outside hospital. Patients who were assessed by the CI team but deemed not candidates for CI for any reason were not analyzed. Procedures followed for this study were in accordance with the ethical standards of the hospital research ethics board (1000007199).

Diagnostic Imaging Systems

All images were stored on a picture archiving and communication system for accessible viewing and measuring on workstations. MRI scans were acquired from a 3T Philips magnet (Philips, Amsterdam, the Netherlands) using our CI protocol with surface and head coils. Qualitative MRI brain evaluation was performed to exclude malformations, kermicterus, and findings suggesting intrauterine TORCH (toxoplasmosis, Other (syphilis, varicella-zoster, parvovirus B19), rubella CMV, and herpes simplex) infections. Inner ear imaging included axial and coronal fast spin echo (FSE) T2 (repetition time [TR] 3,300/echo time [TE] 109) with 2-mm slices, 13-cm field of view (FOV) and 0.254 × 0.254 pixel spacing and direct sagittal oblique FSE T2 of the internal auditory canals (IACs). Additionally, balanced fast field echo axial images (TR 9.2/TE 4.6) sequences of the petrous bones, with 0.4-mm slice thickness and 14-cm FOV. HRCT petrous examinations were performed without contrast administration using a GE HD 750 64-slice HRCT scanner (GE Healthcare, Waukesha, WI) and low-dose protocol providing 0.625-mm-thick slices.

MRI-Selective HRCT Imaging Protocol

All patients were assessed for candidacy by members of the CI team using a graded profile analysis. The MRI-selective HRCT imaging protocol was then implemented as outlined in detail in Figure 1. In this protocol, all patients received an MRI after the initial clinical assessment. An additional HRCT was ordered under two circumstances. First, if risk factors for challenging anatomy including conditions where there is a known association with anomalous facial nerve anatomy were identified at the initial history and physical examination (for example CHARGE [coloboma of the eye, heart defects, atresia of the choanae, retardation of growth and development, and ear abnormalities and deafness] syndrome), upfront MRI and HRCT were ordered together. For

Fig. 1. Clinical examination flowchart for an MRI-predominant imaging protocol. The necessity for HRCT imaging is evaluated at two time points: A and B. Otherwise, all patients underwent MRI only. CHARGE = coloboma of the eye, heart defects, atresia of the choanae, retardation of growth and development, and ear abnormalities and deafness; CT = computed tomography; HRCT = high-resolution computed tomography; MRI = magnetic resonance imaging.
all other patients who underwent MRI alone, if specific imaging anomalies were detected on the initial MRI, a subsequent HRCT was ordered. An institutional set of radiologic criteria (described in detail in our previous report), was used by our neuroradiologists to diagnose petrous bone and brain abnormalities on HRCT and MRI.4 Afterward, each of the temporal bone images was rereviewed systematically for surgically and diagnostically relevant anatomy in a weekly multidisciplinary cochlear implantation meeting including the neuroradiologist (S.I.B.) and otologists. Detailed notes were taken during this review containing clinically and surgically relevant features. Where required, imaging studies were again reviewed for any necessary clarification. For this current study, all of the imaging reports, multidisciplinary notes, clinical notes, and operative reports were retrospectively collected and reviewed.

RESULTS

During the 4-year, 9-month period between January 2013 and September 2017, 291 children underwent CI. Fifty-one patients (18%) were excluded, as they presented to our institution with prior imaging. Therefore, a total of 240 children were evaluated by the MRI with selective HRCT imaging protocol. Of the 240 children, seven (2.9%) underwent concurrent HRCT and MRI after risk factors were identified on history or physical examination. HRCT was ordered after abnormal findings were found on initial MRI in 15 (6.3%) cases, leaving 218 (90%) who underwent MRI only. A flowchart of the study can be found in Figure 2.

Concurrent MRI With HRCT

The seven patients (2.9%) who had dual HRCT and MR imaging requested at the outset had known diagnoses of Beckwith-Wiedemann, Phelp's syndrome (incomplete partition type III), CHARGE syndrome, suspicion of cholesteatoma on physical exam, and a history of temporal bone trauma (Table I). All of these patients showed abnormalities with respect to the temporal bone, aside from the suspected cholesteatoma, where no soft tissue findings on imaging were consistent with cholesteatoma. In the case of CHARGE syndrome, the facial nerve was found to follow an abnormal course over the promontory given the congenital absence of the posterior crus of the stapes. The abnormal imaging findings were predictive of challenging approaches to the cochlea, with five of the seven cases reported to have deviations from the standard operative protocol. Although these events made the surgery more challenging, all critical surgical landmarks were located and resulted in successful CI without complication.

MRI With Subsequent HRCT

Fifteen patients (6.3%) underwent subsequent HRCT after the initial MRI demonstrated imaging abnormalities. Nine of these patients had deviations from the

---

Fig. 2. Study flowchart. Patients were excluded if they presented with imaging performed at another institution. The necessity for HRCT imaging was evaluated at two time points. Intraoperative events were recorded as documentation of a challenging approach to the cochlea or deviation from standard surgical technique. HRCT = high-resolution computed tomography; MRI = magnetic resonance imaging.
normal surgical protocol or abnormal anatomy noted intraoperatively (Fig. 2). Four patients had incomplete partition type I detected on imaging, and all were found to have small, restricted facial recess, challenging entry to the cochlea, and cerebrospinal fluid gushers. Four cases of labyrinthitis ossificans were detected on imaging. One had a small amount of fibrous tissue at the cochleostomy site, and another was noted to have challenging access to the cochlea; both of these had full electrode insertions. In one patient with Branchio-oto-renal (BOR) syndrome, access to the cochlea was deemed particularly challenging given the restricted mastoid and facial recess, along with loss of typical landmarks that is common in this syndrome. In the six patients who had no intraoperative challenges, HRCT was ordered following review of the MRI for an indication of incomplete partition type II (IP2) (n = 2), abnormal cochlear nerve (n = 2), an abnormal small bony horizontal semicircular canal island, and a cystic pituitary lesion to assess for possible Rathke’s cleft cyst. Of note, the cases of IP2 and the small bone island that were imaged with HRCT early on in the protocol and this follow-up imaging were requested by the neuroradiologist to allow for complete and thorough evaluation. Following this, it was felt that further HRCT of these types of dysplasias was not necessary on an ongoing basis. In the two cases of cochlear nerve hypoplasia, HRCT was ordered to specifically measure the bony cochlear nerve canal diameter, which in our program is used in the candidacy assessment for implantation given

<table>
<thead>
<tr>
<th>Timing of Scan</th>
<th>No. of HRCT Scans</th>
<th>Indication</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concurrent HRCT + MRI on the same day</td>
<td>7 (2.9%)</td>
<td>CHARGE syndrome (n = 2)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pfeifer’s syndrome (incomplete partition type III) (n = 2)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Beckwith-Wiedemann syndrome (n = 1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Suspected cholesteatoma on physical exam (n = 1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Temporal bone trauma (n = 1)</td>
</tr>
<tr>
<td>HRCT after MRI</td>
<td>15 (6.9%)</td>
<td>Incomplete partition type I (n = 4)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Incomplete partition type II (n = 2)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Labyrinthitis ossificans (trauma or meningitis) (n = 4)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Narrowing of cochlear nerve (n = 1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Clumping of cochleovestibular nerves (n = 1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Small bony HSCC island (n = 1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cystic pituitary lesion (n = 1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Branchio-oto-renal syndrome (n = 1)</td>
</tr>
<tr>
<td>Total</td>
<td>22 (9.2%)</td>
<td></td>
</tr>
</tbody>
</table>

CHARGE = coloboma of the eye, heart defects, atresia of the choanae, retardation of growth and development, and ear abnormalities and deafness. HRCT = high-resolution computed tomography; HSCC = horizontal semicircular canal; MRI = magnetic resonance imaging.

Fig. 3. Comparison of HRCT and MRI findings in a patient with unilateral, right atresia, right progressive, single-sided deafness due to congenital cytomegalovirus. (A) Three-dimensional surface reconstruction of the pinna and external acoustic canal. (B) Coronal CT images of the abnormal pinna, absent external auditory canal, conglomerate ossicles (white arrowhead). (C) Coronal CT images of a thin bony plate across the oval window (white arrowhead). (D) MRI showing normal cochlear nerve (white arrowhead) and mild cochlear/modiolar hypoplasia (white arrow). (E) Typical temporal pole cysts (white arrowheads). (F) Confluent white matter signal increase (black asterisks). CT = computed tomography; HRCT = high-resolution computed tomography; MRI = magnetic resonance imaging. [Color figure can be viewed in the online issue, which is available at www.laryngoscope.com.]
a previously published predictive model of electrophysiological outcomes in cochlear nerve hypoplasia.8

**MRI Only**

Of the patients who underwent MRI only, 79.8% (174/218) had normal and 20.1% (44/218) had abnormal imaging findings (Fig. 1). Of the 44 patients who had abnormal imaging findings, 29 (65.9%) had IP2, unilateral or bilateral enlarged vestibular aqueduct (EVA), and the remaining 15 (34.1%) had incidental abnormalities such as vascular loops within the internal auditory canal (IAC), bilateral funnel-shaped IAC, or small central bone island of the horizontal semicircular canal. Out of all 218 cases that were imaged with MRI only, there were four (1.8%) incidences of intraoperative challenges. On further review of these four patients, two patients had imaging reported as normal, whereas the other two had abnormal imaging relating to an underlying syndromic diagnosis, specifically BOR and Hunter syndrome. This emphasized the importance of having both specific temporal bone imaging with HRCT and MRI for these two conditions. The patient with Hunter syndrome had a small facial recess, and aberrant petrosal sinus and may have benefitted from HRCT. Following this case, diagnosis of Hunter syndrome has now become an indication for upfront dual imaging. Similarly, the patient with BOR would have benefitted from having both an MRI and HRCT to assist in further delineation of the bony anatomy. Intraoperatively, this patient had a difficult cortical mastoidectomy due to complete sclerosis of the bone, and access to the facial recess was challenging due to an abnormally positioned facial nerve.

**General Anesthesia Requirements and Cost Comparison**

Of the 240 patients who were imaged, 191 (79.6%) required GA. For patients receiving GA for MRI only, the average time was 69.4 minutes, whereas patients receiving GA for MRI and subsequent HRCT on a different day, the average total time was 64.67 minutes (standard deviation [SD] = 60.6 minutes). For those imaged concurrently with MR and HRCT, the average time was 131.23 minutes (SD = 42.9 minutes), which includes the transfer under GA between the MRI and computed tomography suites, which are situated in different locations within our institution.

Costs of imaging are part of a global budget at our Institution, and therefore cost savings cannot be easily or directly calculated. Therefore, we have used the charges for research scans combined with the reimbursement rates for 2017 according to the schedule of benefits published by the Ontario Health Insurance Program to provide a rough estimate of potential cost savings. Specifically, at our Institution, temporal bone HRCT would cost approximately $680.12, and MRI of the brain and IAC would cost approximately $1200.20 CAD, including estimated additional costs for administration of GA. Using these parameters for the current study, the protocol amounts to approximately $302,960; meanwhile, a universal dual imaging approach for the number of patient in this study (240) is estimated to cost $451,228. Therefore, the current protocol accrues potential cost savings of $148,268 CAD, or $617 CAD per person when spread across the study group.

**DISCUSSION**

Imaging prior to CI is essential for diagnosis, candidacy assessment, and surgical planning. Imaging modalities each come with their advantages and disadvantages; however, there is variability in use across institutions and CI programs. Dual imaging with MRI and HRCT offers maximal information; however, it may not be the most effective use of resources while also subjecting children to unnecessary exposure to radiation and anesthesia.

There are several retrospective analyses of dual-imaging protocols with mixed findings. Some studies concluded that both MRI and HRCT are important modalities required to analyze the inner ear in children with unexplained sensorineural hearing loss (SNHL).9 Others suggest that the use of MRI alone is sufficient, offering important information with direct visualization of the vestibulocochlear nerve bundle, and more likely to identify clinically and surgically relevant inner ear and central nervous system (CNS) findings.4,5,10 One study suggests that MRI does not offer a substantial benefit over computed tomography for routine evaluation of the pediatric inner ear, although this conclusion was drawn in the context of a larger study involving primarily adults with only a handful of children.11

The current review demonstrates that MRI alone can be used in the vast majority of cases for preoperative evaluation of children with deafness requiring CI, and most patients will have normal anatomy and undergo uneventful implantation. Importantly, implementation of this MRI-predominant protocol resulted in successful CI without complications for all patients. The additional need for HRCT occurs in a small proportion and can be predicted a priori based on characteristics detected on clinical history and exam, or imaging anomalies detected on initial MRI, such that in almost all cases that were noted to have a challenging approach to the cochlea, both MR and HRCT imaging were available.

The addition of HRCT to MRI is helpful in defining the course of the facial nerve and distinguishing abnormal bony anatomy. From this series, we have subsequently reported on the typical abnormal temporal bone features of BOR including mastoid underdevelopment, dysplasia of Koerner’s septum, antrum, lateral canal, and short process. These abnormal findings often result in loss of typical surgical landmarks and a restricted facial recess, creating a challenging approach to the cochlea in these patients.12 In the current study, syndromes with known association with anomalous courses of the facial nerve (i.e., CHARGE syndrome, aural atresia) received up-front HRCT, as an abnormal course of the facial nerve can create a tight and difficult access to the round window and, correspondingly, a challenging electrode implantation with increased risk of injury.13,14 At least four
large reports have demonstrated an association between inner ear malformation and facial nerve anomaly, with a range of 0.3% to 23% facial nerve abnormality coexisting with an inner ear abnormality.\textsuperscript{3,15–17} Importantly, in each of these studies, no facial nerve anomalies were detected in children with normal inner ear structures. This is consistent with our findings. Early on in the protocol, all cochleovestibular anomalies detected on MRI would receive HRCT including IP2. Although HRCT would be indicated to complete diagnostic evaluation by our neuroradiologist, in the absence of a concurrent craniofacial indication to complete diagnostic evaluation by our neuro-otologist, it was determined that such imaging was not required to facilitate a safe and efficient surgical approach. Therefore, following the HRCT evaluation of the first two children with IP2 on MRI, IP2 was no longer considered as a criterion for further imaging evaluation with HRCT. Overall, all patients in the current study with IP2 were not found to have an abnormal course of the facial nerve intraoperatively nor were any changes in the site of the cochleostomy or electrode selection required. Besides IP2, we do not feel that HRCT is warranted in addition to MRI for certain other anomalies, including bilateral or unilateral enlarged endolympathic sacs, which suggest the presence of EVA. One of the limitations in this MRI-predominant protocol is the inability to predict cases that are challenging intraoperatively due to sclerotic mastoids and poor middle ear aeration but demonstrate otherwise normal anatomy on MRI due to inferior sensitivity in demonstrating bony landmarks as compared to HRCT.\textsuperscript{19} This occurred in only two of the 218 (0.09%) cases. Although poor pneumatization can create a more challenging mastoidectomy, it rarely results in a fundamentally different surgical approach, impossible mastoidectomy, or aborted CI.\textsuperscript{19} Certainly, prior knowledge of the degree of poorly pneumatized bone may have been an asset in these challenging intraoperative encounters; however, both surgeries proceeded with the fundamentally identical approach and resulted in successful CI. We did not consider this to be a failure of the current imaging approach; however, further investigation of potential risk factors in this subset of patients may be helpful to better predict these cases in the future.

The reduction in unnecessary radiation exposure was an important driving factor for the implementation of our imaging algorithm, which in the current study amounted to 218 HRCT scans avoided. At our institution, the petrous HRCT radiation dose is low (191.65 mGy/cm in a typical 24-month-old patient); however, the established correlation between radiation exposure from HRCT scans in childhood and subsequent risk of malignancy,\textsuperscript{20,22} as well as cataracts, is well reported, thus providing enough evidence to justify limiting adverse radiation exposure in this population.\textsuperscript{20–23}

In addition to reduction in radiation, the current protocol resulted in avoidance of transport of patients and prolonged anesthesia in 218 patients who were imaged with MRI alone. In comparison, a dual-imaging protocol often requires MRI and HRCT to be conducted under the same GA in children. In addition, regarding the well-known potential developmental age and dose-dependent neurotoxicity with GA exposure,\textsuperscript{24,25} this presents several logistical challenges depending on the institution and breadth of resources. At our institution, the MRI and HRCT suites are located in different floors of the hospital, requiring a prolonged total time under a GA, and created potential risks associated with transporting anesthetized children. Interestingly, the total anesthesia time for sequential imaging was less than for concurrent imaging. This is, in part, due to the absence of anesthetized transit time between scanners, but likely also due to the fact that the children undergoing concurrent imaging were more likely to have a secondary syndromic diagnosis, which may have added medical and airway complexity to their anesthetics. The difference in time under anesthesia between children imaged solely with MRI compared to MRI and HRCT was almost an hour on average. At our center, these imaging suites are located on different floors of the hospital, and the extended time under anesthesia is due to extra personnel and precautions taken to transport an intubated child across the hospital. Cost estimates for the combined HRCT and MRI protocol in this study may be overestimated due to this additional time, as compared to other institutions that have a more efficient system. Some centers have developed “feed and sleep” MRI protocols for infants undergoing MRI prior to cochlear implantation to decrease imaging scan time, sedation requirement, need for GA, and cost, as well as avoid altogether any radiation dose associated with HRCT. To decrease imaging time, this often involves adjusting the imaging protocol to a limited view of only the inner ear and IAC. However, the authors recommend adherence to a comprehensive MRI that extends beyond views of the inner ear and IAC to include the brain and CNS structures. The rational for this is to avoid missing clinically important, although less surgically relevant, CNS causes of SNHL such as signs of congenital CMV, or kernicterus, which are either difficult or impossible to detect with HRCT (Fig. 3).\textsuperscript{26}

In our current fiscal environment, efficient use of resources is critical. Avoidance of 218 unnecessary HRCT scans in this study population of 240 resulted in a substantial cost savings of $113,377.44 CAD. Though these findings reflect the experience at a single Canadian center, we would expect these cost savings to be corroborated and even amplified in different institutions and healthcare settings. Previous publications on imaging for CI report MRI scans costing $2,440 and HRCT $1,735, including GA.\textsuperscript{5} Applied to our study population, which avoided 218 HRCT scans, this translates into a cost savings of approximately $378,230 USD. Given that examining cost is a secondary outcome for this study, variables such as use of sedation as opposed to GA or the fact that subsequent HRCT can, given its shorter acquisition time, be done without anesthesia, were not considered but would have a potentially significant impact on cost.

\textbf{Limitations}

There are several limitations to this study. First, interpretation of temporal bone imaging findings is limited in...
that the retrospective review of the images relied on the original reports written by the pediatric neuroradiologist rather than a complete rereview independently by the research team. Although neuroradiology staff at our institution follow a set of fixed criteria for reporting on pediatric temporal bones, and subsequently, all imaging is rereviewed prospectively during combined weekly cochlear implant rounds with the neuroradiology and surgical teams, underreporting or inconsistencies of reporting imaging findings may limit the interpretation of our review. Second, our cost analysis was based on very crude estimations based on costing at a single institution. A formal cost-minimization analysis study is required for a more comprehensive understanding of the value of the different imaging protocols.

CONCLUSION

MRI alone can be used in the vast majority of cases for preoperative evaluation of pediatric CI candidates. The option to additionally request a preoperative HRCT to better delineate complex anatomy based on both preimaging clinical characteristics as well as post-MRI findings provides the flexibility required to achieve optimal outcomes in cases that present diagnostic and surgical challenges. Widespread implementation of this MRI protocol with HRCT optionally added to the assessment of CI candidacy has the potential to significantly reduce radiation and anesthesia exposure in a cost-effective manner while maintaining a high degree of diagnostic accuracy.

BIBLIOGRAPHY