The deleterious effects of radiation exposure in children from CT are now well defined. The risk of developing a radiation-induced malignancy is relative to a patient's cumulative radiation exposure and increases with exposure at younger ages. Radiation exposure in children with shunted hydrocephalus is particularly concerning given their lifetime exposure to numerous head CT scans for shunt evaluation. Reported high failure rates after primary shunt insertion is one factor contributing to an increased likelihood of CT exposure in younger populations.

Gaskill and Marlin found that children with myelomeningocele receive on average 3.6 head CT scans during their lifetime, and an average of 6.38 rad/year (range 0.79–37.81 rad/year) from radiography and CT. Another report found that children with complex hydrocephalus received an average of 13.4 head CT scans (range 1–94 scans) during a 5-year period. This exposure to radiation is more than the annual limit of 5 rad for occupational doses and 0.1 rad for the general public as specified by the US Nuclear Regulatory Commission.

To reduce the amount of lifetime radiation exposure in children with shunts, some institutions use rapid-sequence (or quick-brain) MRI to evaluate ventricle size. There are obstacles, however, to widespread implementation of this imaging modality. The purpose of this study was to define and quantify these obstacles to positively affect institutional and governmental policy.

Methods. A 9-question survey was emailed to pediatric neurosurgeons who were either members or candidate members of the American Society of Pediatric Neurosurgeons at every one of 101 institutions in the US and Canada having such a neurosurgeon on staff. Responses were compiled and descriptive statistics were performed.

Results. Fifty-six institutions completed the survey. Forty-four (79%) of the 56 institutions currently have a rapid-sequence MRI protocol to evaluate ventricle size, while 36 (64%) use it routinely. Of the 44 institutions with a rapid-sequence MRI protocol, 29 (66%) have had a rapid-sequence MRI protocol for less than 5 years while 39 (89%) have had a rapid-sequence MRI protocol for no more than 10 years. Thirty-six (88%) of 41 rapid-sequence MRI users responding to this question obtain a T2-weighted rapid-sequence MRI while 13 (32%) obtain a T1-weighted rapid-sequence MRI. Twenty-eight (64%) of 44 institutions never use sedation while an additional 12 (27%) rarely use sedation to obtain a rapid-sequence MRI (less than 5% of studies). Of the institutions with an established rapid-sequence MRI protocol, obstacles to routine use include lack of emergency access to MRI facilities in 18 (41%), lack of staffing of MRI facilities in 12 (27%), and the inability to reimburse a rapid-sequence MRI protocol in 6 (14%). In the 12 institutions without rapid-sequence MRI, obstacles to implementation include lack of emergency access to MRI facilities in 8 (67%), lack of staffing of MRI facilities in 7 (58%), the inability to reimburse in 3 (25%), and lack of administrative support in 3 (25%). To evaluate pediatric head trauma, 53 (96%) of 55 institutions responding to this question use noncontrast CT, no institution uses rapid-sequence MRI, and only 2 (4%) use standard MRI.

Conclusions. Many North American institutions have a rapid-sequence MRI protocol to evaluate ventricle size, with most developing this technique within the past 5 years. Most institutions never use sedation, and most obtain T2-weighted sequences. The greatest obstacles to the routine use of rapid-sequence MRI in institutions with and in those without a rapid-sequence MRI protocol are the lack of emergency access and staffing of the MRI facility during nights and weekends.

**Key Words** • rapid sequence MRI • radiation • hydrocephalus • ventricles • technique

Abbreviation used in this paper: TBI = traumatic brain injury.
Rapid-sequence MRI use in North America

America, to determine the primary obstacles for expanding use of this safer imaging technique, and to provide data for institutions without this resource to subsequently positively affect institutional and governmental policy.

Methods

A 9-question survey (Table 1) was emailed to pediatric neurosurgeons who were either members or candidate members of the American Society of Pediatric Neurosurgeons at every one of 101 institutions in the US and Canada having such a neurosurgeon on staff. Only 1 individual per institution was surveyed to eliminate duplicate institutional responses. Response data were collected using Survey Monkey (https://www.surveymonkey.com). Stata (version 10.1, StataCorp LP) and Microsoft Excel were used to tabulate the results.

Results

Fifty-six of 101 institutions completed the survey (55% response rate). Forty-four (79%) of 56 institutions have a rapid-sequence MRI protocol to evaluate ventricle size, and 36 (82%) of those 44 institutions use it routinely. The majority of institutions have used rapid-sequence MRI for less than 5 years (29/44, 66%), obtain at least T2-weighted sequences (36/41, 88%), and never use sedation (28/44, 64%; Fig. 1). Of the 44 institutions with a rapid-sequence MRI protocol, obstacles to routine use include lack of emergency access to MRI facilities in 18 (41%), lack of staffing for MRI facilities in 12 (27%), and inability to reimburse a rapid-sequence MRI protocol from third-party payers in 6 (14%). Of those who noted the inability to reimburse a rapid-sequence MRI protocol, 3 (50%) indicated that they had made an effort to appropriately reimburse rapid-sequence MRI, while 3 (50%) were unsure if an effort had been made.

In the 12 institutions without rapid-sequence MRI, obstacles to implementation included lack of emergency access to MRI facilities in 8 (67%), lack of staffing for MRI facilities in 7 (58%), inability to reimburse a rapid-sequence MRI protocol from third-party payers in 3 (25%), and lack of administrative support in 3 (25%). Of those with reimbursement difficulties, 1 had made an effort to reimburse rapid-sequence MRI, 1 had made an effort, and 1 was unsure if any effort had been made.

To evaluate nonpenetrating traumatic brain injury (TBI), 53 (96%) of 55 institutions responding to this question use noncontrast head CT while 2 (4%) use standard MRI. Forty-nine (89%) of the 55 institutions have a radiation reduction protocol for CT head imaging in children while 3 (5%) do not and 3 (5%) were unsure.

Discussion

Based on the results of this survey, a large number of institutions in the US and Canada have a rapid-sequence MRI protocol to evaluate ventricle size in pediatric patients. Only 81% of these institutions, however, routinely use this technology. The most commonly cited obstacles for the routine use of rapid-sequence MRI were similar among those institutions with a rapid-sequence MRI protocol and those without a protocol: lack of emergency access to MRI facilities, lack of staffing for MRI facilities during nights and weekends, and inability to obtain reimbursement from third-party payers for rapid-sequence MRI.

Based on survey responses, the availability of rapid-sequence MRI protocols is relatively new in many institutions and rapid-sequence MRI use is rapidly increasing. Sixty-six percent of institutions have used a rapid-sequence MRI protocol for less than 5 years and 89% have had a rapid-sequence MRI protocol for less than 10 years. Ideally, within another 5 years, all institutions caring for pediatric neurosurgical patients will use rapid-sequence MRI in lieu of CT for cerebral ventricle evaluation.

Study Limitations

The present study is limited by a 55% survey response rate, and further does not reflect the practices at pediatric neurosurgical services and hospitals not staffed by members or candidate members of the American Society of Pediatric Neurosurgeons. Conceivably, the nonreturned surveys (45%) could be from sites that do not use rapid-sequence MRI, and thus the reported results could be skewed. Responses received were not validated directly with the respondents’ institutions to assure accuracy. Questions regarding barriers to rapid-sequence MRI were subjective in nature, and the survey instrument has not been previously validated.

Clinical Rapid-Sequence MRI

Most reports of clinical rapid-sequence MRI use have focused on the evaluation of hydrocephalus. However, other pathologies may be successfully screened, evaluated, and/or followed using rapid-sequence MRI, including tumors, inflammatory/demyelinating lesions, hemorrhage in children and adults, macrocephaly, intracranial cysts, Chiari malformations, congenital abnormalities, and traumas. For trauma patients, rapid-sequence MRI has been used primarily for follow-up imaging. Additionally, in 1 study 13 of 64 patients with minor TBI underwent initial evaluation with rapid-sequence MRI and none were subsequently noted to have a missed lesion.

Traumatic brain injury is a potential area for expanded rapid-sequence MRI use. The present survey demonstrated that more than 96% of institutions continue to rely on noncontrast head CT scanning in the evaluation of nonpenetrating TBI in children. The sensitivity and specificity of rapid-sequence MRI for various findings that influence the medical and surgical management of cranial trauma have yet to be firmly established. One clearly established disadvantage of MRI in comparison with CT for the evaluation of cranial trauma, however, is insensitivity to nondisplaced skull fractures, which do not typically alter clinical management. Conversely, rapid-sequence MRI is effective in demonstrating many clinically relevant findings, such as parenchymal or extraxial hemorrhage and mass effect, and in our experience, sinus opacification sometimes associated with skull base fractures.

Other potential drawbacks of using rapid-sequence MRI include the need for a parent or health care profes-
### TABLE 1: Survey questions

<table>
<thead>
<tr>
<th>Question</th>
<th>Options</th>
</tr>
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<tbody>
<tr>
<td>Does your institution have a “quick brain/vent check” MR imaging protocol to evaluate the ventricle size in pediatric patients?</td>
<td>yes, no, unsure</td>
</tr>
<tr>
<td>How long has your institution utilized “quick brain/vent check” MR imaging?</td>
<td>&lt; 5 years, 5–10 years, &gt; 10 years, unsure</td>
</tr>
<tr>
<td>At your institution, what are the primary sequence(s) obtained for the “quick brain/vent check” MR imaging protocol? (e.g., T2 axial, T1, DWI)</td>
<td></td>
</tr>
<tr>
<td>Is sedation used to obtain “quick brain/vent check” protocol MR imaging?</td>
<td>never, rarely (&lt; 5% of studies), occasionally (5–49% of studies), frequently (50–99% of studies), always (100% of studies), unsure</td>
</tr>
<tr>
<td>If you have encountered obstacles to implementation of “quick brain/vent check” MR imaging what are/were they (check all that apply)?</td>
<td>unable to reimburse “quick brain/vent check” study, lack of emergency access to MR imaging facilities, lack of staffing for MR imaging facilities, lack of administrative support, have not attempted to implement, unsure, other, if other (please specify)</td>
</tr>
<tr>
<td>If “quick brain/vent check” is not reimbursed, has an effort been made by your institution to change reimbursement policy?</td>
<td>not applicable, yes, no, unsure, if yes (please specify)</td>
</tr>
<tr>
<td>At your institution, what is the preferred method of evaluating ventricle size in patients with an existing ventriculoperitoneal shunt?</td>
<td>CT, quick brain/vent check MRI, standard MRI, other, if other (please specify)</td>
</tr>
<tr>
<td>At your institution, what is the preferred method of evaluating the brain in patients with a GCS of 14 or 15 with non-penetrating traumatic brain injury?</td>
<td>CT, quick brain/vent check MRI, standard MRI, other, if other (please specify)</td>
</tr>
<tr>
<td>At your institution, does a CT brain imaging protocol exist to reduce radiation exposure in pediatric patients?</td>
<td>yes, no, unsure</td>
</tr>
</tbody>
</table>
Rapid-sequence MRI use in North America

Fig. 1. Graphs of rapid-sequence MRI use characteristics of institutions with a quick-brain MRI protocol. The graphs show responses to the following survey questions: "How long has your institution utilized "quick brain/vent check" MR imaging?" (A); "At your institution, what are the primary sequence(s) obtained for the "quick brain/vent check" MR imaging protocol? (e.g. T2 axial, T1, DWI)" (B); and "Is sedation used to obtain "quick brain/vent check" protocol MR imaging?" (C). Note that no institution reported the use of diffusion weighted imaging as part of their rapid-sequence MRI protocol.

Adoption and utilization of rapid-sequence MRI protocols in the US and Canada are increasing. Key obstacles to widespread utilization of rapid-sequence MRI are lack of emergency or off-hour MRI availability, lack of available MRI technicians to perform these studies, and barriers to study reimbursement. Quantification of rapid-sequence MRI use in the US and Canada and objective identification of barriers to adoption and routine use are important to influence institutional and governmental policies regarding this important imaging technique. Expanded use of MRI offers the potential of minimizing the adverse effects of radiation exposure in children.

Conclusions

Adoption and utilization of rapid-sequence MRI protocols in the US and Canada are increasing. Key obstacles to widespread utilization of rapid-sequence MRI are lack of emergency or off-hour MRI availability, lack of available MRI technicians to perform these studies, and barriers to study reimbursement. Quantification of rapid-sequence MRI use in the US and Canada and objective identification of barriers to adoption and routine use are important to influence institutional and governmental policies regarding this important imaging technique. Expanded use of MRI offers the potential of minimizing the adverse effects of radiation exposure in children.

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Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author contributions to the study and manuscript preparation include the following. Conception and design: all authors. Acquisition of data: Thompson. Analysis and interpretation of data: Thompson. Drafting the article: all authors. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Selden. Study supervision: Selden.

References


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