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The low utility of routine cranial imaging after pediatric shunt revision

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OBJECTIVE Postoperative routine imaging is common after pediatric ventricular shunt revision, but the benefit of scanning in the absence of symptoms is questionable. In this study, the authors aimed to assess how often routine scanning results in a change in clinical management after shunt revision.

METHODS The records of a large, tertiary pediatric hospital were retrospectively reviewed for all consecutive cases of pediatric shunt revision between July 2013 and July 2018. Postoperative imaging was classified as routine (i.e., in the absence of symptoms, complications, or other direct indications) or nonroutine. Reinterventions within 30 days were assessed in these groups.

RESULTS Of 387 included shunt revisions performed in 232 patients, postoperative imaging was performed in 297 (77%), which was routine in 244 (63%) and nonroutine in 53 (14%). Ninety revisions (23%) underwent any shunt-related procedure after postoperative imaging, including shunt reprogramming (n = 35, 9%), shunt tap (n = 10, 3%), and a return to the operating room (OR; n = 58, 15%). Of the 244 cases receiving routine imaging, 241 did not undergo a change in clinical management solely based on routine imaging findings. The remaining 3 cases returned to the OR, accounting for 0.8% (95% CI 0.0%–1.7%) of all cases or 1.2% (95% CI 0.0%–2.6%) of cases that received routine imaging. Furthermore, 27 of 244 patients in this group returned to the OR for other reasons, namely complications (n = 12) or recurrent symptoms (n = 15); all arose after initial routine imaging.

CONCLUSIONS The authors found a low yield to routine imaging after pediatric shunt revision, with only 0.8% of cases undergoing a change in management based on routine imaging findings without corresponding clinical findings. Moreover, routine imaging without abnormal findings was no guarantee of an uneventful postoperative course. Clinical monitoring can be considered as an alternative in asymptomatic, uncomplicated patients.

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KEYWORDS computed tomography; hydrocephalus; magnetic resonance imaging; utility; ventriculoperitoneal shunt; radiography

Hydrocephalus is one of the most common neurosurgical pathologies with an estimated prevalence of 88 per 100,000 in the pediatric population.[1] Ventricular shunt placement, particularly ventriculoperitoneal (VP) shunting, remains a well-established treatment for this condition.[2] Despite advances in device technology and concentration of care in high-volume centers, long-term shunt failure rates remain high, and eventual revision surgery is necessary in up to 80% of children.[3–5] The need for reoperation is particularly high within the first 30 days after surgery, with reported rates ranging from 12% to 24%.[6–10] For these reasons, our institution has moved

ABBREVIATIONS NNS = number needed to scan; OR = operating room; VP = ventriculoperitoneal.
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away from shunt placement as the primary treatment for hydrocephalus in children, although shunt revisions remain common.

Many institutions routinely perform postoperative imaging of the head to assess shunt location and ventricle size after revision surgery. While this practice has obvious benefits in the setting of persistent symptoms, its utility in asymptomatic, uncomplicated patients is questionable. This is reflected in the lack of clear guidelines regarding optimal timing and indication for imaging in this setting. There is increasing advocacy for judicious and evidence-based imaging in neurosurgery, as opposed to a more traditional low-threshold scanning approach,[11] and different studies have questioned the utility of routine imaging in various neurosurgical conditions, including chronic subdural hematoma evacuation,[12,13] brain tumor resection,[14,15] tethered cord release,[16] and craniosynostosis reconstruction.[17] Similarly, for adult shunt revision, routine postoperative CT has been suggested to have low utility (management consequences in < 2% of cases) in asymptomatic patients.[18,19] It could be argued that routine postoperative imaging is more relevant in the pediatric population, since particularly young children could have greater difficulty communicating their symptoms, thus increasing the difficulty of monitoring on a clinical basis alone. However, no studies to date have been undertaken to evaluate this question. To address this gap in knowledge, we aimed to determine how often routine postoperative imaging led to a change in clinical management after ventricular shunt surgery in a pediatric population.

Methods

Data Acquisition

Under IRB approval from Boston Children's Hospital, all consecutive cases of shunt revision between July 2013 and July 2018 were collected from the records of a large, tertiary center for pediatric neurosurgery. While the majority of our patient population consisted of children, young adults (> 21 years of age) remaining in follow-up at our institution after an initial shunt placement in childhood were not excluded from the present study.

Data were collected on demographics, indications for shunt revision, shunt location, pre- and postoperative symptoms, intra- and postoperative imaging studies, surgical complications, and postoperative shunt-related procedures (i.e., shunt reprogramming, shunt taps, returns to the operating room [OR], and other procedures) within 30 days after the initial surgery. Cranial imaging studies were classified as CT, rapid-sequence MRI, or full MRI. Intraoperative imaging in our institution consists of head CT performed at the end of the surgical procedure, after closing the skin but before termination of anesthesia. Furthermore, shunt series radiograph studies were also collected.

At our institution, postoperative imaging is performed at the discretion of the attending neurosurgeon, and routine imaging studies within 48 hours after surgery are frequently ordered to assess the ventricles and the position of the catheter. Therefore, routine studies were defined as those performed in the absence of symptoms or other suspicion of pathology; all other imaging studies were regarded as nonroutine for the purpose of this investigation. The primary outcome of this study was the percentage of routine imaging studies that led to a change in clinical management. Furthermore, the number needed to scan (NNS) was derived to estimate how many patients would need to be routinely imaged in order to change management in one patient using the formula NNS = 1/(absolute risk reduction), as introduced by Wen et al.[20] Finally, we compared reintervention rates across imaging-stratified groups (routine imaging, nonroutine imaging, and no imaging), and 30-day reoperation rates were compared between groups. We hypothesized that in asymptomatic/uncomplicated patients, omitting routine imaging would not be associated with a higher need for reintervention within 30 days.

Statistical Analysis

R version 3.5.0 (The R Foundation) was used for data analysis. Categorical variables were expressed with counts and percentages, and continuous variables with median and interquartile range. Percentages are calculated based on the total number of shunt revisions unless otherwise indicated. The yield of routine imaging was estimated using percentages and 95% confidence intervals. The chi-square test was used to compare statistical differences between categorical variables; a p value of 0.05 was considered statistically significant.

Results

Population Characteristics

A total of 387 shunt revisions performed in 232 patients met inclusion criteria. The median patient age was 12.0 years (IQR 4.9–16.4 years); 39 revisions (10.1%) were performed in patients older than 21 years of age, and 238 revisions (61.5%) were performed in male patients. The shunt location was frontal (33.3%), occipital (63.3%), parietal (2.3%), or combined frontal and occipital (1.0%). Further baseline characteristics are outlined in Table 1. In 297 cases (76.7%), imaging was performed after surgery, including CT in 43 (11.1%), rapid-sequence MRI in 201 (51.9%), full MRI in 22 (5.7%), and shunt series radiography in 151 cases (39.0%). Moreover, 23 revisions (5.9%) included intraoperative CT scanning. A breakdown of routine versus nonroutine postoperative imaging is shown in Table 2. In total, 244 revisions included routine postoperative imaging; this constitutes 63.0% of all cases and 82.2% of cases in which imaging was performed. Broken down by modality, routine imaging constituted rapid-sequence MRI (n = 165, 42.6%), shunt series radiography (n = 133, 34.4%), CT (n = 23, 5.9%), and full MRI (n = 14, 3.6%).

Reinterventions After Routine Imaging

Of the 244 cases in which routine imaging was performed, 241 did not have a change in management triggered by routine imaging findings. The remaining 3 cases resulted in a return to the OR, accounting for 0.8% (95% CI 0.0%–1.7%) of all cases or 1.2% (95% CI 0.0%–2.6%) of cases that received routine imaging. Two of these studies were CT and 1 was rapid-sequence MRI. Notably, of 133 routine shunt series, none (95% CI 0.0%–2.7%) led to

TABLE 1. Baseline characteristics of 387 shunt revisions performed in 232 patients

	Value
Total no. of revisions	387
Male sex	238 (61.5)
Median age, yrs (IQR)	12.00 (4.9–16.4)
Cause of hydrocephalus	
Chiari malformation	15 (3.9)
Neural tube defect	59 (15.2)
Other congenital	109 (28.2)
Posthemorrhagic	87 (22.5)
Tumor	54 (14.0)
Postinfection/inflammation	18 (4.7)
Posthemispherectomy	5 (1.3)
Miscellaneous	13 (3.4)
Unknown	27 (7.0)
Indication for revision	
Shunt blockage	66 (17.1)
Shunt disconnection	39 (10.1)
Shunt migration/malpositioning	8 (2.1)
Shunt infection	17 (4.4)
Mechanical or unspecified shunt malfunction	178 (46.0)
Miscellaneous	66 (17.1)
Shunt location	
Frontal	129 (33.3)
Occipital	245 (63.3)
Parietal	9 (2.3)
Frontal & occipital	4 (1.0)
Received postop imaging	297 (76.7)
Received intraop imaging*	24 (6.2)

Values represent the number of shunt revisions (%) unless indicated otherwise.
* All intraoperative imaging was CT.

TABLE 2. Overview of postoperative imaging modalities

	Total, n (%)	Routine, n (%)	Nonroutine, n (%)
All shunt revisions	387 (100.0)		
Imaging type			
Any imaging	297 (76.7)	244 (63.0)	53 (13.7)
Rapid-sequence MRI	201 (51.9)	165 (42.6)	36 (9.3)
Full MRI	22 (5.7)	14 (3.6)	8 (2.1)
CT	43 (11.1)	23 (5.9)	20 (5.2)
Shunt series radiography	151 (39.0)	133 (34.4)	18 (4.7)

a change in management. Figure 1 is a flowchart providing an overview of how all cases were identified. Based on this, the NNS was estimated to be 81.3 (95% CI 38.5 to ∞).

In addition to the 3 cases that required a return to the OR because of findings on routine imaging, 27 of the 244 returned to the OR for other reasons, namely postoperative complications (n = 12) or recurrence of symptoms before (n = 6) or after (n = 9) discharge (Table 3); all complications and recurrent symptoms related to these revisions arose in patients after initial routine imaging. Complications included a positive CSF culture (n = 8), skin breakdown (n = 1), hemorrhage (n = 1), CSF leakage (n = 1), and a disconnected distal shunt (n = 1, discovered during physical examination in an asymptomatic patient). Of note, in 20 of 244 cases (8.2%) in which routine imaging demonstrated no increased ventricle size, catheter malposition, or other abnormal findings, a return to the OR was ultimately still necessary due to recurring symptoms or delayed complications, indicating that a routine imaging study with no abnormal findings did not guarantee an uneventful postoperative course.

Nonoperative shunt-related procedures within 30 days after surgery in the routine imaging group included shunt reprogramming in 27 of 244 cases (11.1%) and shunt tapping in 5 of 244 cases (2.0%). The majority of shunt reprogramming was performed to correct unintentional adjustment by MRI (n = 19), while other indications included recurring symptoms (n = 5) or intentional initial overdrainage with planned postoperative readjustment (n = 3). Shunt taps were performed in the setting of recurrent symptoms (n = 4) or monitoring after positive CSF culture (n = 1). In total, 52 of 244 cases (21.3%) in the routine imaging group involved ≥ 1 shunt-related procedure within 30 days after surgery, either operative, nonoperative, or both.

Reinterventions Across Groups

When comparing imaging groups, return to the OR occurred in 37.8% of the nonroutine imaging group, 12.3% of the routine imaging group, and 8.9% of the no-imaging group ($p = 0.46$ for routine imaging vs no imaging). Table 3 displays the reasons for return to the OR across these groups. Of all shunt revision cases (n = 387), 58 (15.0%) required a return to the OR within 30 days, while 35 (9.0%) required shunt reprogramming and 10 (2.6%) required shunt tapping. Overall, 90 of 387 cases (23.3%) had ≥ 1 reintervention.

Discussion

This study analyzed 387 cases of pediatric shunt revision and found that postoperative imaging in the absence of symptoms or other clinical indications triggered a management change in only 3 cases (0.8%). Moreover, a routine imaging study without abnormal findings did not guarantee an uncomplicated postoperative course. These findings indicate that the utility of routine postoperative imaging in this pediatric population is low.

Two previous studies investigated the yield of routine CT after VP shunt placement in adults; both suggested a < 2% rate of management change based on CT findings in asymptomatic patients.[18,19] Our study does not support the hypothesis that routine imaging has more benefit in children because of a less reliable clinical examination. Following increasing awareness of the importance of reducing the diagnostic radiation burden in children, alternatives to CT such as rapid-sequence MRI have gained popularity in

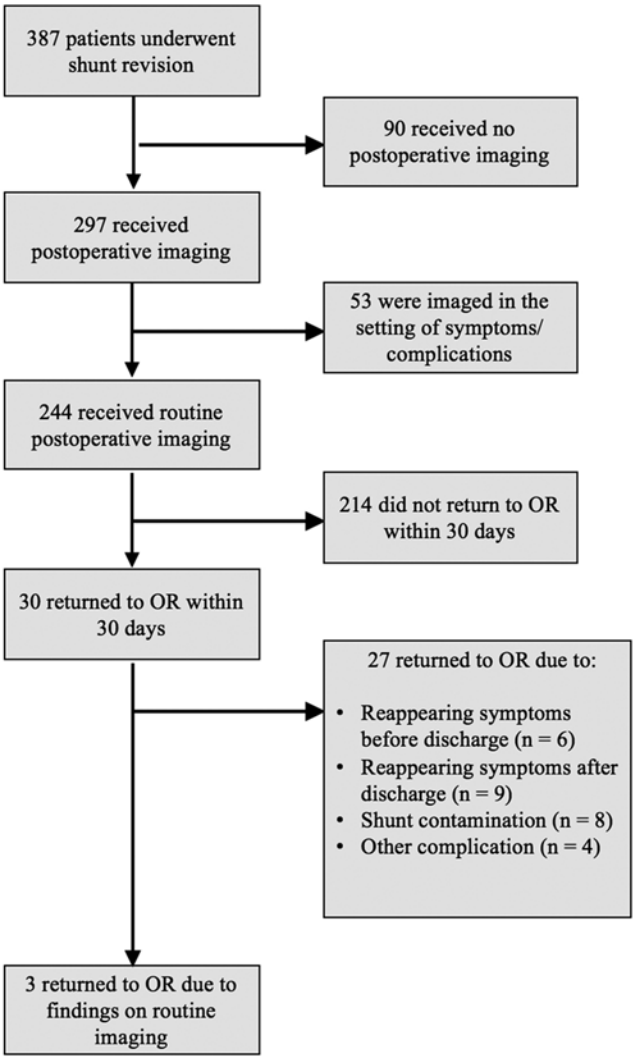

FIG. 1. Flowchart providing an overview of all 387 included shunt revisions performed in 232 patients based on routine imaging and the subsequent postoperative course.

the evaluation of these patients in recent years. Although providing a clear benefit over CT, the present study suggests that the yield of rapid-sequence MRI is still low, with only 1 management change in 165 asymptomatic patients in whom imaging was performed. Similarly, 133 routine radiography shunt series led to no management changes; while it is not possible to provide a formal NNS calculation for this proportion, our results are unable to support any benefit to routine shunt series, at least based on the present data. Lastly, while the previous studies looked almost exclusively at frontal shunt placement surgery, the majority of cases in the present series involved occipital shunt placement, which might be associated with a higher rate of return to the OR based on previous series.[18]

The rate of return to the OR within 30 days in our series was 15%. This is comparable with reoperation rates in the literature; an analysis of 2891 shunt revisions in a representative, population-based prospective registry reported a shunt failure rate of 14% within 30 days.[10] In the present series, the revision rate was understandably much higher in the subgroup of revisions in patients who continued to have symptoms after surgery and at the point of imaging (20/53 revisions, 37.8%). On the other hand, reoperation rates in the routine imaging and no-imaging groups were comparable (8.9% for no imaging vs 12.3% for routine imaging, $p = 0.46$). This suggests that omitting routine imaging in asymptomatic patients did not ultimately lead to a greater need for return to the OR before or after discharge. The relatively high revision rates for VP systems in general have led our institution to move toward endoscopic third ventriculostomy/choroid plexus cauterization (ETV/CPC) as a primary treatment for hydrocephalus in children younger than 2 years of age.[21] Between 2008 and 2019, of approximately 300 children with primary hydrocephalus, roughly 230 were treated with ETV/CPC, compared with around 70 primary VP shunt insertions. This has contributed to the relatively low number of VP shunt revisions in our institution over the study period; these revisions now constitute < 10% of our annual pediatric case volume.

When looking at reinterventions other than a return to the OR, we found that these were not influenced by findings on routine imaging. Shunt reprogramming was particularly frequent but was not performed in the case of abnormal MRI findings if the patient was asymptomatic. On the contrary, performing MRI can increase the need for shunt reprogramming through inadvertent magnetic adjustment of the valve.[22] For this reason, our institution has recently shifted to programmable valves that resist such changes.

The 3 revisions that required a return to the OR based on findings on routine imaging were all notably complex and irregular cases. Case 1 concerned a 19-year-old male with a history of Chiari type II malformation and profound scoliosis (Fig. 2A), which prevented regular positioning on the operating table and made intraoperative CT impossible. After a postoperative CT scan that was obtained within 3 hours after surgery showed catheter malpositioning, the patient was taken back to the OR for revision. This timing may have been too early for headaches to develop, and it is possible that had imaging been delayed, the malpositioning would have been detected in the setting of symptoms. However, in the retrospective setting of our study, it is not possible to know this with certainty. Case 2 concerned a 5-year-old female with a history of Chiari type II malformation and myelomeningocele who underwent shunt revision; intraoperative CT was obtained after skin closure but before terminating anesthesia. The scan showed the new catheter traversing the ventricle and extending into the prepontine cistern (Fig. 2B). At this point, the patient's head was reopened and the catheter revised, after which a repeat CT scan showed good positioning (Fig. 2C). Since the patient was still under anesthesia when CT was performed, no symptoms could have been detected at that point. While this is arguably not a routine scan, we chose to classify it as such because the operative report revealed no obvious complications or direct reasons to obtain imaging. Moreover, we aimed to make a conservative estimation. Had this case been classified as a nonroutine scan, the yield of routine imaging in our cohort would be lower still, with 2 cases representing 0.5% of all

TABLE 3. Reasons for return to the OR within 30 days after revision

	Total, n (%)	Nonroutine Imaging, n (%)	Routine Imaging, n (%)*	No Imaging, n (%)
All shunt revisions	387 (100.0)	53 (100.0)	244 (100.0)	90 (100.0)
Returned to OR	58 (15.0)	20 (37.8)	30 (12.3)	8 (8.9)
Persistent symptoms	19 (4.9)	19 (35.8)	0	0
Recurring symptoms	21 (5.4)	1 (1.9)	15 (6.1)	5 (5.6)
Before discharge	7 (1.8)	1 (1.9)	6 (2.5)	0
After discharge	14 (3.6)	0	9 (3.7)	5 (5.6)
Shunt contamination	10 (2.6)	0	8 (3.3)	2 (2.2)
Other complications	5 (1.3)	0	4 (1.6)	1 (1.1)
Imaging finding in asymptomatic pt	3 (0.8)	NA	3 (1.2)	NA

NA = not applicable; pt = patient.
* Routine postoperative imaging is defined as imaging in the absence of symptoms or (suspicion of) complications.

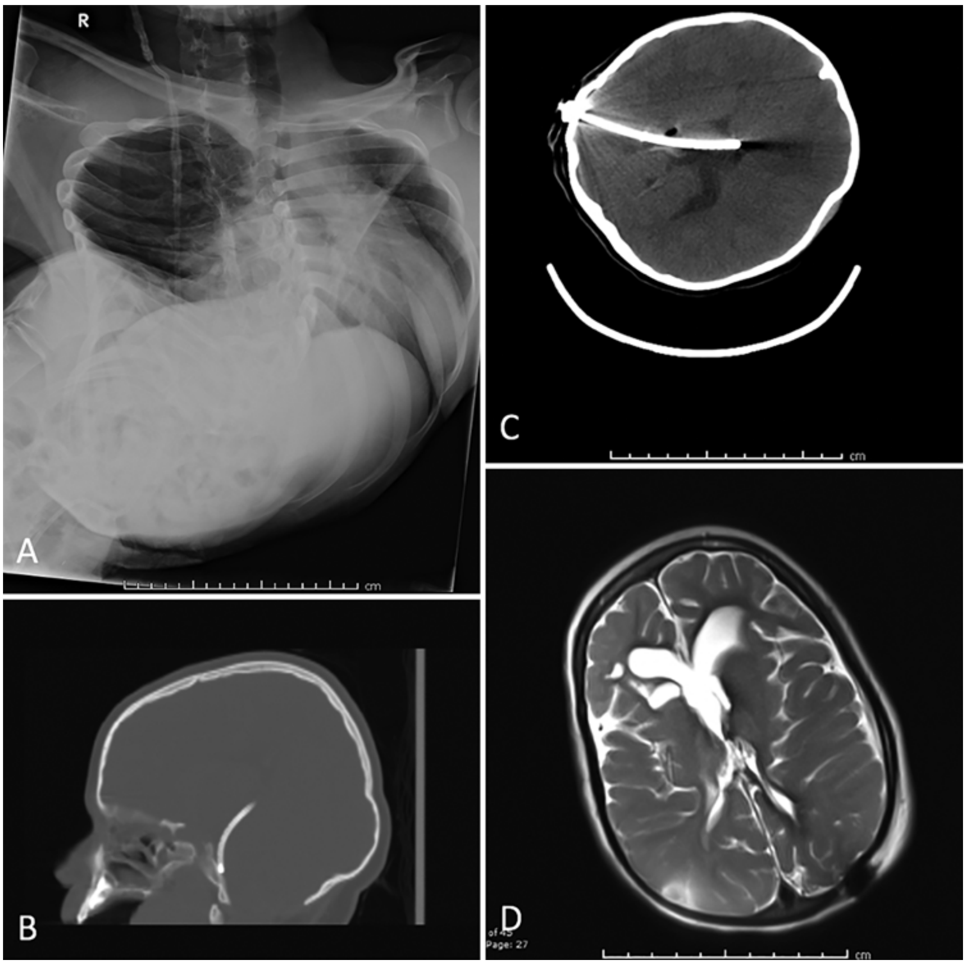

FIG. 2. Case illustrations. **A:** Case 1. Severe scoliosis in a 19-year-old male complicated positioning on the operating table and made intraoperative CT scanning impossible. CT scan obtained immediately postoperatively showing a malpositioned catheter, after which the shunt was revised and repositioned correctly (CT not shown). **B and C:** Case 2. Intraoperative sagittal CT scan (B) obtained after replacing a 5-cm catheter with a 10-cm catheter in a 5-year-old female, showing the new catheter extending into the prepontine cistern; after revision, correct positioning was observed on axial CT (C). **D:** Case 3. A 12-year-old female with noncommunicating hydrocephalus underwent revision, with a postoperative axial MR image (D) showing the left catheter in place but incorrect positioning of the right catheter. Despite good clinical status, the patient was taken back to the OR based on the surgeon's experience with previous episodes of shunt malfunction in this patient, and the catheter was correctly positioned (not shown).

cases or 0.8% of cases undergoing a routine scan. Case 3 concerned a 12-year-old female with a history of noncommunicating hydrocephalus after teratoma resection in infancy; she underwent revision of bilateral occipital shunts connected to a single valve. Postoperatively, rapid-sequence MRI showed the left catheter in place while the right one traversed the ventricle and extended into the subarachnoid space (Fig. 2D). Despite a lack of symptoms, it was decided to return the patient to the OR, given that the lateral ventricles did not communicate; this decision was partly based on the surgeon's experience with the clinical course of prior episodes in this patient.

Examination of these cases suggests that while postoperative imaging appears to have no utility after routine or noncomplex shunt revision, it could still offer benefits in highly complex cases of patients with significant comorbidities that make shunt placement more difficult. Patients with Chiari type II malformation might form a risk group, given their deviating anatomy and sensitivity to malfunction, potentially resulting in loss of vital functions. However, our small sample size prevents definitive conclusions regarding risk groups. In the discussed cases, it is not possible to say in retrospect what would have happened had imaging been delayed. We believe that performing low-threshold postoperative imaging in an asymptomatic but highly complex case is a question of individual judgment, and the attending surgeon's experience and knowledge of the patient's history should be central in this process.

There is an increasing awareness of the need to critically assess the utility of routine diagnostic practices in neurosurgery. For instance, a recent randomized trial by Schucht et al.[13] showed no benefit for routine CT after chronic subdural hematoma, confirming findings by previous retrospective investigations.[12] In pediatric neurosurgery, utility of routine postoperative imaging has been investigated in several other indications. A study evaluating routine MRI after tethered cord release found no benefit in uncomplicated patients.[16] Another investigation evaluating routine CT after cranial vault reconstruction for craniosynostosis[17] also showed no benefit in uncomplicated patients. Interestingly, in that series, 2 of 7 patients who required postoperative shunt placement after synostosis surgery had findings of malfunction on postoperative CT. However, those patients also showed clinical signs of shunt malfunction.[17]

When obtaining imaging studies, ideally, the potential diagnostic, prognostic, and therapeutic benefits of imaging should be weighed against its (potential) harms.[11] CT scans and radiographs expose children to radiation, potentially increasing the risk of carcinogenesis in the long term.[23] MRI and rapid-sequence MRI can cause shunt valve adjustments, necessitating reprogramming.[22] Moreover, these imaging modalities are associated with costs that can burden patients and the healthcare system. Because rapid-sequence MRI does not currently have its own Current Procedural Terminology code, it is usually billed either as full MRI or as CT; the latter is the case in our institution.[24] The median cost of CT and MRI in the United States in 2015 was around $2000 and $3000, respectively;[25] a rough estimate based on these numbers would place the total cost of routine postoperative imaging in this series around $418,000, excluding costs incurred by intraoperative CTs, shunt series, or shunt reprogramming after inadvertent adjustment by MRI. Lastly, identifying nonessential procedures which consume time and manpower can help streamline care in a burdened healthcare situation. These arguments underline the previously described importance of judicious use of imaging studies.[11]

Strengths and Limitations

The main strength of this study is its large sample size, which is especially important when estimating the incidence of rare outcomes. Furthermore, the study was conducted at one of the largest pediatric neurosurgery centers in the United States, with considerable expertise in shunt revision in complex cases. On the other hand, this study should be interpreted in light of its retrospective nature. The imaging policy after shunt revision was not formally standardized over the study period, resulting in heterogeneity in terms of imaging modalities in the investigated population. Rather than evaluate a certain protocol, we aimed to investigate real-life practice. We also did not assess the role of intraoperative neuronavigation for catheter placement. While the impact of neuronavigation on the need for postoperative imaging could be a valuable avenue for future research, the aim of the present study was to quantify and determine the benefit of routine postoperative imaging in the entire population. Lastly, our study exclusively investigated shunt revision; its conclusions cannot be extrapolated to initial shunt placement procedures where postoperative imaging may have more utility, particularly given the need for a radiological baseline for future studies. If obtaining a new baseline is desired, we believe this would justify imaging. However, this could also be done in the outpatient setting 2 to 4 weeks after surgery, rather than immediately after surgery.

Conclusions

In this study, we sought to determine the yield of routine imaging after ventricular shunt revision. Our data have shown that this practice had clinical consequences in only 0.8% of cases, demonstrating low utility. Clinical monitoring could be considered as an alternative in asymptomatic, uncomplicated patients.

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Disclosures

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

Conception and design: Proctor, Hulsbergen, McAvoy, Gormley, Warf. Acquisition of data: Hulsbergen, Siddi, McAvoy, Lynch, Karsten, Stopa, Ashby, McNulty, Stone. Analysis and interpretation of data: Proctor, Hulsbergen, Siddi. Drafting the article: Hulsbergen. Critically revising the article: Proctor, Hulsbergen, Siddi, McAvoy, Lynch, Karsten, Broekman, Gormley, Stone, Warf. Approved the final version of the manuscript on behalf of all authors: Proctor. Statistical analysis: Hulsbergen. Administrative/technical/material support: Proctor, Stopa. Study supervision: Proctor, Broekman, Gormley, Warf.

Supplemental Information

Previous Presentations

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