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Changing Trends in Brain Imaging Technique for Pediatric Patients with Ventriculoperitoneal Shunts

Margaret J. Trost^{a,b}, Nathan Robison^{a,b}, Dean Coffey^{a,b}, Mary Rose Mamey^a, and R. Aaron Robison^{a,b}

^aChildren's Hospital Los Angeles, Los Angeles, CA, USA

^bUniversity of Southern California Keck School of Medicine, Los Angeles, CA, USA

Abstract

Background: Children with ventriculoperitoneal shunts (VPS) undergoing brain computed tomography (CT) for shunt malfunction evaluation are at risk for later malignancy due to radiation exposure. We aimed to determine if and how hospitals have adopted radiation-avoiding magnetic resonance imaging (MRI) techniques.

Methods: We performed a secondary analysis of the Pediatric Health Information System (PHIS) database. Children with VPS presenting to acute wards at 31 PHIS hospitals between January 1, 2007 and January 2, 2015 and receiving noncontrast neuroimaging on day of service 0/1 were included. Outcome measures were (1) incidence of MRI over time and (2) comparison of demographic characteristics between hospitals with MRI representing higher versus lower proportions (>15% or <15%) of total brain imaging.

Results: MRIs increased by 18.1% from 2007 to 2015. Hospitals were assigned to high-use ($n = 12$) or minimal-use ($n = 19$) MRI groups based on year 2014/2015 MRI percentages. The only identified difference was an older mean age in the high-use group (8.1 vs. 7.5 years; $p = 0.03$).

Conclusions: MRI is increasingly used to evaluate patients with VPS. Hospitals with more MRI use had older patients and no increase in cost or length of stay. Initiating local quality improvement projects may help identify barriers to MRI uptake and increase use.

Keywords

Shunt malfunction; Diagnostic imaging

Margaret Trost, Division of Hospital Medicine, Children's Hospital Los Angeles, 4650 Sunset Blvd., #94, Los Angeles, CA 90027 (USA), mtrost@chla.usc.edu.

Author Contributions

Dr. M.J. Trost coordinated and supervised the data collection, drafted the initial manuscript, and approved the final manuscript as submitted. Dr. M.R. Mamey assisted with statistical data analysis and edited the methods and results. Drs. N. Robison and D. Coffey contributed to the study design, carried out the data collection, reviewed and revised the manuscript, and approved the final manuscript as submitted. Dr. R.A. Robison critically reviewed and edited the manuscript.

Disclosure Statement

All authors have no conflicts of interest to disclose.

Introduction

Infant hydrocephalus occurs in approximately 1 in 1,000 births [1]. Ventriculoperitoneal shunting (VPS) to reduce intracranial pressure caused by hydrocephalus is the most commonly performed procedure by pediatric neurosurgeons [2]. Due in part to high rates of shunt failure, children with VPS continue to account for a disproportionate share of hospital days and up to USD 2 billion in US hospital charges annually [3]. Malfunction leading to recurrence of hydrocephalus has historically been diagnosed with brain computed tomography (CT), which rapidly provides information on ventricular size and shunt location but comes at the cost of radiation exposure. These unexpected scans are in addition to routine surveillance imaging that children receive to detect subclinical shunt failure. Retrospective population studies show an average of 1–2 cranial imaging studies a year, and implicate CT imaging of patients with VPS as a major source of radiation exposure [4, 5]. Ionizing radiation in children carries an approximately 10-fold risk of future malignancy compared to the same dose exposure in adults [6, 7]. Risk models applied to the CT scans performed in the year 2007 estimated that 4,000 cases of future cancers in pediatric and adult patients could be related to brain CTs performed in that single year [8]. In 2015, The Joint Commission issued new standards for brain imaging in children, highlighting concerns regarding radiation exposure [9].

The relatively recent development of rapid-sequence magnetic resonance imaging (MRI) techniques represents a promising alternative to brain CT [10]. Singlecenter studies have shown an increasing adoption of rapid-sequence MRI for the evaluation of VPS patients [11, 12]. Parker et al. [13] suggested that MRI for VPS procedures was increasing, but used the All Patient Refined Diagnosis Related Groups (APR-DRG) to define cases which may have missed initial imaging evaluation for a yet unknown diagnosis. Florin et al. [14] retrospectively followed 1,319 children for 10 years after shunt placement and found nearly half received CT during emergency department visits but saw almost no use of MRI. Fortyfour (79%) of 56 institutions surveyed by the American Society of Pediatric Neurosurgeons had a rapid-sequence MRI protocol to evaluate ventricle size, yet only 36 (64%) routinely used it [15].

The purpose of our study was to describe national trends at pediatric hospitals in MRI use for the evaluation of ventricular size in children with VPS and a clinical diagnosis of possible shunt malfunction. We hypothesized that MRI rates would increase, but that demographic or other differences would lead to high variability between hospitals.

Methods

Study Population

This study used data from the Pediatric Health Information System (PHIS), which includes comprehensive administrative data on demographic characteristics, diagnoses, and procedures using International Classification of Diseases, Ninth Edition, Clinical Modification (ICD-9-CM) codes from 48 children's hospitals in the USA. The PHIS was queried for encounters with any diagnosis code of VPS (V452) and a clinical transaction code for a brain CT scan or brain MRI at an inpatient, observation, or emergency department

visit from January 1, 2007 to January 1, 2015 ($n = 54,402$). A very small number of patient encounters ($n = 11$) had discharge dates in the calendar year 2015 and were grouped with the 2014 data. In order to select for encounters with clinical suspicion of shunt malfunction, encounters were included if the imaging occurred on day of service 0 or 1 ($n = 49,427$) and if the image was done without contrast ($n = 45,263$). Patients who received both CT and MRI on day 0 or 1 were assigned to the CT group. Encounters from 15 hospitals were excluded (data not reported), leaving a total cohort of 36,414 encounters and 31 hospitals included in the analysis. All study procedures were considered exempt by the Children's Hospital Los Angeles (CHLA) Institutional Review Board.

To compare hospital-level characteristics, certain variables available in the PHIS database were extracted. Demographics included age, race, insurance status, hospital region, and presence of complex chronic conditions (CCC), which are flagged in the PHIS based on the published CCC classification system [16]. For instance, the presence of a VPS flags as a "neurologic" CCC, which is why all encounters included in our analysis have this condition. Surgical complications are similarly defined by the presence of any one of over 100 ICD-9 codes. Outcome data included length of stay, cost, and 7-day readmissions. All patient-level data were aggregated at the hospital level for comparisons between hospital groups.

Statistical Analysis

Raw means of MRI percentages within each of the hospitals were first estimated across years (from 2007 to 2014/2015) and plotted to describe growth trajectories for each hospital (online suppl. Fig. 1; see www.karger.com/doi/10.1159/000485923 for all online suppl. material). Hospitals were subsequently assigned to one of two groups (high vs. minimal MRI use), based on the percentage of MRIs that the hospital had completed at year 2014/2015 since all of the hospitals had zero or close to zero MRIs performed in 2007. Given the nature of the data, a cutoff of 15% MRI use in 2014/2015 was set to allow for the natural groupings of the hospitals over time. Baseline demographic and clinical characteristics were reported and compared between high- and minimal-use MRI groups using independent samples t tests and χ^2 tests. An independent samples t test was also performed to determine MRI usage between the high- and low-use groups during the final year of the study. All analyses were conducted using SPSS, version 23 (IBM Corp.). All tests of hypotheses were two-tailed with type 1 error fixed at 0.05.

Results

Discharge data for a total of 36,414 patients were used within the 31 hospitals meeting the inclusion criteria. In the most recent year examined (2014/2015), 12 hospitals (38.7%) had >15% of encounters with MRI rather than CT ("high users"), while the remaining 19 hospitals (61.3%) used MRIs <15% of the time ("minimal users"). The overall cohort was 55% male, 55% White, and had a median age of 7.7 years (IQR 6.1–9.9). High-use hospitals had an older mean patient population (8.1 vs. 7.5 years, $p = 0.03$), but there were no other demographic differences between the groups. The need for operation and length of stay also did not vary between the groups (Table 1).

MRI usage increased from 1.7 to 19.8% for all discharges from 2007 to 2014/2015 (Fig. 1 a). The increase in MRI usage was due to change in practice at a minority of institutions. The use of an independent samples *t* test showed a statistically significant difference between the high-use (41.7%) and minimal-use (3.8%) hospitals ($t = -8.36$, $p < 0.001$) in the most recent year examined (Fig. 1 b).

Discussion

Recent recommendations by The Joint Commission promote ALARA (as low as reasonably achievable) radiation exposure standards [9] , raising awareness of imaging risks and the need for protocols to manage these risks. Our hypothesis that the diagnostic use of MRI in VPS patients in pediatric hospitals would increase over the study period was supported. However, this is attributable primarily to a significant change in practice at a minority of institutions.

These findings suggest that significant barriers still exist to the implementation of rapid-sequence MRI as a primary modality for VPS malfunction screening. Our analysis of demographics revealed patient age as the only identified difference between hospitals with higher and lower MRI use. With traditional MRI, younger patients often require sedation to limit motion artifact, which may lead practitioners to choose CT for faster results. However, fast MRI can be performed without sedation. Although we did exclude MRIs with contrast, some of the MRIs included may have been nonfast, which could have influenced this finding.

Due to the limitations of data available in an administrative database, there may also be unmeasured forces driving MRI adoption. Multiple barriers could be hypothesized, including use of programmable shunts (which typically require reprogramming after MRI), variability in resources (e.g., in the relative availability of MRI for emergency scans), as well as individual provider preferences and long-standing institutional practices. On the other hand, the finding that a minority (38.7%) of institutions with MRI accounts for >15% of the neuroimaging studies in this population suggests that barriers are surmountable, and the implementation of a reduced radiation exposure protocol as a national standard of care is feasible. In addition, there were no differences between groups in outcome measures of cost, length of stay, or readmission within 7 days (Table 1). This information could be applied at low-use hospitals to help overcome theoretical barriers.

Recent trends towards the use of low-dose CT for evaluation of children with hydrocephalus partially mitigate the effects of cranial CT imaging in this population and may influence practice patterns [17] . However, population studies suggest that even low-dose radiation exposure is associated with an incremental increase in malignancy risk [18, 19] . Thus, especially in a population where serial imaging is often required, even lower radiation dose limited-sequence CT modalities may result in a clinically relevant cumulative radiation exposure.

Our study used data extracted from the PHIS database. There are multiple advantages to this data source, including the size of the data set available and the ability to access a broad array

of institutions and regions. However, the study also has inherent limitations: patient-specific information is limited, and the level of encounter-specific detail available from the database varies by institution. For instance, it was not possible to assess which patients had programmable shunts, which we hypothesize is a significant factor in determining the likelihood of obtaining a screening CT versus MRI. In addition, use of the VPS ICD-9 code to identify our cohort could lead to selection bias. However, other studies have used this method when identifying VPS patients in large databases [20] .

In summary, our findings suggest that MRI rather than CT is gaining acceptance as a screening modality for children with VPS and suspected shunt malfunction at a minority of pediatric academic institutions. Hospitals with higher versus lower MRI use had no differences in overall costs, length of stay, or 7-day readmissions. Our findings also suggest that choice of MRI versus CT is at least partially related to patient age, and focused education to providers could increase the use of rapid-sequence MRI in younger populations. The reason for the observed variability between institutions is likely multifactorial, including both structural limitations to MRI use as well as historical precedent. Quality improvement efforts at individual centers can identify other barriers to the implementation of rapid-sequence MRI as a primary screening modality for suspected VPS failure in children.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Fig. 1.

a Number of MRIs and CTs performed from 2007 to 2014/2015. The raw number of encounters with CT decreased over time as MRI usage increased. **b** Trends in the proportion of MRI over time between high-usage (>15% at end of study period) and low-usage groups. The use of an independent samples *t* test showed a statistically significant difference between the high-use (41.7%) and minimal-use (3.8%) hospitals ($t = -8.36$, $p < 0.001$) in the most recent year examined.

Table 1.

Hospital-level descriptives: high versus low MRI use

Variable	Total sample (N=31)	% MRI use >15% (n = 12)	<15% (n = 19)	p value ^b
Male patients	55 (49 – 61)	55 (49 – 61)	56 (50 – 61)	0.36
Hispanic				
Hispanic	17 (0 – 66)	19 (2 – 66)	15 (0 – 55)	0.60
Non-Hispanic	61 (0 – 98)	61 (5 – 8)	61 (0 – 98)	0.96
Unknown	22 (0 – 98)	20 (0 – 90)	24 (0 – 98)	0.68
Race				
White	55 (21 – 88)	56 (21 – 81)	55 (28 – 88)	0.86
Black	17 (1 – 55)	19 (6 – 55)	16 (1 – 43)	0.52
Asian	1 (0 – 4)	1 (0 – 2)	1 (0 – 4)	0.69
Pacific Islander	1 (0 – 3)	1 (0)	2 (0 – 3)	0.49
American Indian	2 (0 – 2)	2 (0 – 2)	1 (0 – 1)	0.39
Other	10 (0 – 37)	12 (0 – 31)	8 (1 – 37)	0.36
Insurance				
Unknown	17 (0 – 44)	14 (0 – 40)	19 (0 – 44)	0.36
Commercial	27 (6 – 55)	28 (13 – 52)	26 (6 – 55)	0.79
Medicaid	48 (30 – 75)	50 (30 – 75)	46 (35 – 62)	0.44
TRICARE	2 (0 – 11)	2 (0 – 4)	3 (0 – 11)	0.29
Medicare	1 (0 – 13)	1 (0 – 2)	2 (0 – 13)	0.35
Other	5 (0 – 33)	7 (1 – 31)	5 (0 – 33)	0.48
Surgical complication	7 (3 – 14)	7 (4 – 14)	7 (3 – 13)	0.88
Complex chronic conditions ^a				
Cardiovascular	5 (2 – 8)	5 (3 – 7)	5 (2 – 8)	0.92
Gastrointestinal	16 (9 – 26)	15 (10 – 23)	16 (9 – 26)	0.32
Hematologic or immunologic	1 (0 – 4)	1 (1 – 4)	1 (0 – 3)	0.42
Malignancy	6 (2 – 14)	6 (2 – 14)	6 (2 – 14)	0.56
Metabolic	4 (1 – 10)	4 (2 – 5)	4 (1 – 10)	0.99
Neuromuscular	100	100	100	–

Variable	Total sample (N=31)	% MRI use >15% (n = 12)	<15% (n = 19)	^b p value
Congenital	7 (3 – 12)	8 (4 – 10)	7 (3 – 12)	0.44
Renal	7 (2 – 16)	8 (3 – 12)	6 (2 – 16)	0.12
Respiratory	5 (1 – 8)	5 (3 – 7)	5 (1 – 8)	0.45
Mean age (range), years	7.7 (6.1 – 9.9)	8.1 (6.5 – 9.9)	7.5 (6.1 – 8.8)	0.03
Hospital region, n (%)				
South	14 (45)	5 (42)	9 (47)	0.76
Midwest	9 (29)	4 (33)	5 (26)	0.68
West	7 (23)	3 (25)	4 (21)	0.80
Northeast	1 (3)	0 (0)	1 (5)	0.42

Values are mean % (range %) unless otherwise indicated. Data were aggregated at the hospital level, representing the mean (proportion) and variation within the high-use hospitals (>15% MRI use) compared to the low-use hospital group (<15% MRI use).

^aComplex chronic conditions are assigned in the database to patients with specific diagnoses within 9 organ systems.

^bIndependent samples *t* test (χ^2 test for hospital region).