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The Burden of Ionizing Radiation Studies in Children with Ventricular Shunts

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Objectives To quantify the number of shunt-related imaging studies that patients with ventricular shunts undergo and to calculate the proportion of computed tomography (CT) scans associated with a surgical intervention.

Study design Retrospective longitudinal cohort analysis of patients up to age 22 years with a shunt placed January 2002 through December 2003 at a pediatric hospital. Primary outcome was the number of head CT scans, shunt series radiograph, skull radiographs, nuclear medicine, and brain magnetic resonance imaging studies for 10 years following shunt placement. Secondary outcome was surgical interventions performed within 7 days of a head CT. Descriptive statistics were used for analysis.

Results Patients (n = 130) followed over 10 years comprised the study cohort. The most common reasons for shunt placement were congenital hydrocephalus (30%), obstructive hydrocephalus (19%), and atraumatic hemorrhage (18%), and 97% of shunts were ventriculoperitoneal. Patients underwent a median of 8.5 head CTs, 3.0 shunt series radiographs, 1.0 skull radiographs, 0 nuclear medicine studies, and 1.0 brain magnetic resonance imaging scans over the 10 years following shunt placement. The frequency of head CT scans was greatest in the first year after shunt placement (median 2.0 CTs). Of 1411 head CTs in the cohort, 237 resulted in surgical intervention within 7 days (17%, 95% CI 15%-19%).

Conclusions Children with ventricular shunts have been exposed to large numbers of imaging studies that deliver radiation and most do not result in a surgical procedure. This suggests a need to improve the process of evaluating for ventricular shunt malfunction and minimize radiation exposure. *(J Pediatr 2017;182:210-6).*

Recent epidemiologic data demonstrate that children who undergo computed tomography (CT) of the head have a quantifiably increased risk of leukemia and the risk increases with the number of imaging examinations.[1,2] Currently, the recommended diagnostic evaluation for shunt malfunction includes CT of the head to evaluate for ventriculomegaly and plain radiographs to evaluate for shunt disconnection.[3-5] Because symptoms of a shunt malfunction often are nonspecific, the decision to evaluate for a malfunction in these children can pose a challenge to practitioners. In addition, history and examination findings can be subtle and overlap with many other diagnoses, which contributes to the complexity of accurate diagnosis and frequent visits to the emergency department (ED).[6-8] Therefore, physicians often have a low threshold to evaluate for a shunt malfunction because an untreated malfunction can be life threatening.[3,6,7,9]

Ventricular shunt malfunctions, or failures, are relatively common, with up to 87.5% of shunts failing by 10 years.[10] Because CT and shunt radiographs are the currently recommended initial evaluation for malfunction, patients with ventricular shunts may be at risk for repeated exposure to ionizing radiation. A recent study evaluated CT usage for pediatric patients with ventricular shunts.[11] This study, however, was limited to exposures in the pediatric ED and did not account for other imaging studies that confer radiation. Thus, the primary objective of this study was to quantify the number of shunt-related imaging studies that children with ventricular shunts undergo during a 10-year period following shunt placement with specific attention to those that expose patients to ionizing radiation. The secondary objective was to determine the proportion of CT scans associated with a surgical shunt intervention.

Methods

We performed a retrospective longitudinal cohort analysis of patients 22 years of age or younger with ventricular shunts placed from January 1, 2002, to

CPT	Current Procedural Terminology
CT	Computed tomography
ED	Emergency department
ICD-9-CM	*International Classification of Diseases, Ninth Revision, Clinical Modification*
MRI	Magnetic resonance imaging
rsMRI	Rapid sequence magnetic resonance imaging

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Supported by the National Institutes of Health (UL1-TR-000005). The authors declare no conflicts of interest.

http://dx.doi.org10.1016/j.jpeds.2016.11.051

December 31, 2003, at a tertiary care children's hospital, which is part of a large integrated health network consisting of 15 hospitals and the only children's hospital servicing the region. Patients were identified by use of the *International Classification of Diseases*, *Ninth Revision, Clinical Modification* (ICD-9-CM) procedure and Current Procedural Terminology (CPT) billing codes for ventricular shunt placement (ICD-9-CM codes 02.22, 02.31, 02.32, 02.33, 02.34, 02.35, and 02.39 and CPT codes 62220 and 62223).

We included patient data for up to 10 years after their shunt placement. If before the 10-year study follow-up period, the shunt was removed and not replaced; the patient died or was transferred to adult neurosurgical care (defined at our hospital as after 22 years of age); or there was evidence that the patient moved outside of the Pittsburgh area or outside the hospital network, we excluded the patient from the final study cohort. We verified dates of death through death or autopsy notes, or the date of death recorded in the hospital system. For patients with transitions to outside the practice area, departure date was estimated as 1 year after the last documented note in the electronic record.

Patient demographics included age at shunt placement, sex, race, and type of shunt. We determined the reason for initial shunt placement based on the ICD-9-CM diagnosis codes assigned at the time of shunt placement. Shunts were categorized as primary or secondary, because shunt survival rate has been shown to decrease with each subsequent shunt revision.[12] A primary shunt was defined as a shunt placed in a child with no previous ventricular shunts at the time of the initial procedure. A secondary shunt was defined as any new shunt placed after removal of a previous shunt. Operative records were reviewed to confirm that a shunt was placed or replaced. The study was approved by our university's institutional review board as meeting the exception from informed consent.

Outcome Variables

The primary outcome measure was the number of head CTs, shunt series and skull series radiographs, with each "series" counted as a single study, nuclear medicine studies, and complete brain magnetic resonance imaging (MRI) examinations performed during the 10 years following shunt placement. Imaging studies were identified with the use of CPT billing codes. Because a patient may not always have sought care at the pediatric hospital during the study period, we included imaging done at any of the 15 hospitals within the health system, which share an electronic medical record. We initially identified all imaging studies for our cohort and subsequently excluded those we determined a priori not to be associated with ventricular shunt imaging (eg, abdominal CT, chest radiograph). All head CTs, despite the indication for the scan, were included in the study. Rapid sequence magnetic resonance imaging (rsMRI) was not introduced at our institution until 2010, and all MRI examinations in our study were coded as a single variable.

We defined surgical interventions as a shunt revision, shunt removal, shunt replacement, or shunt externalization (ICD-9-CM procedure codes 02.22, 02.31, 02.32, 02.33, 02.34, 02.35, 02.39, 02.42, 02.43, and 54.95 and CPT codes 62160, 62190, 62192, 62200, 62201, 62220, 62223, 62225, 62230, 62256, and 62258) occurring within 7 days of the patient having a head CT scan performed. There is conflicting opinion regarding the number of days after a CT when an intervention occurs as a result of the imaging findings. Based on the neurosurgical literature, this range can be several days to 1 month.[3,13] A priori, we determined in consultation with our neurosurgical group that 7 days was a conservative estimate of the time frame when a surgical procedure would have taken place based on head CT imaging. Surgical interventions within this time frame were classified as binary (yes/no) as to not overestimate the number of procedures.

Statistical Analyses

We used summary statistics to describe the patient and hospital characteristics, including medians with IQRs as well as proportions with 95% CIs. We compared continuous variables using the Mann-Whitney *U* test and the Fisher exact test for categorical variables. We used a zero-inflated negative binomial regression to evaluate patient counts of CT use across years after shunt placement. We used SPSS Statistics for Windows, Version 22.0 (IBM Corp, Armonk, New York) and Stat, Version 14 (StatCorp, College Station, Texas) for all statistical analysis.

Results

There were 178 patients with ventricular shunts placed between January 1, 2002, and December 31, 2003. There were 130 patients (73%) who remained in the study for 10 years and comprised the final study cohort (**Figure 1**). All patients in the final cohort were younger than 12 years of age, given the follow-up period of 10 years and the transition to adult neurosurgical care occurring at 22 years. The median age was 1.1 years (IQR 0.2-4.7) in the final study cohort and 77% of patients were younger than 5 years of age (**Table I**). Most patients were male (61%) and white, non-Hispanic (85%). The most common reason for shunt placement was congenital hydrocephalus (30%), obstructive hydrocephalus (19%), and atraumatic hemorrhage (18%), and 97% of shunts were ventriculoperitoneal. The majority of shunts were considered primary (86%). Patients not in the study for 10 years (n = 48) were older at time of shunt placement (median age 13.7 years vs 1.1 years in primary cohort, $P < .001$), had a greater percentage of secondary shunts placed (37.5% vs 13.8% in primary cohort, $P < .001$), and were less likely to have atraumatic intraventricular hemorrhage as the cause of shunt placement (2.1% vs 17.7% in primary cohort; atraumatic hemorrhage vs all other diagnoses combined $P = .005$).

Imaging Studies

During the 10 years after shunt placement, patients had a median of 8.5 head CTs (IQR 4.0-15.0), 3.0 shunt series radiographs (IQR 1.0-6.0), 1.0 skull radiographs (IQR 0-2.3), 0 nuclear medicine studies (IQR 0-1.3), and 1.0 brain MRIs (IQR 0-3.0) (**Figure 2**). The frequency of head CTs was