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CASE FOR DISCUSSION

Cumulative diagnostic radiation exposure in children with ventriculoperitoneal shunts: a review

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Abstract
Introduction Children may be more vulnerable to diagnostic radiation exposure because of the increased dose–volume ratio and the increased lifetime risk per unit dose of radiation from early exposure. Moreover, recent radiological literature suggests that exposure to ionizing radiation from imaging studies may play a role in the later development of malignancies.
Materials and Methods We review the literature and present two illustrative clinical examples of children (each child developed head and neck malignancies during their late teen years) with hydrocephalus requiring multiple cerebrospinal fluid (CSF) shunt revisions and diagnostic computerized tomography (CT) scans throughout their life.
Discussion The literature reviewed suggests that children are more prone to diagnostic radiation exposure. Although it is not possible to prove that the multiple diagnostic studies result in malignancies, our review of the literature and illustrative cases describing malignancy risk and radiation exposure should give clinicians pause when considering requesting multiple diagnostic CT studies in children during the evaluation of possible CSF shunt dysfunction. Alternative tests such as "shunt MRI" protocols should be considered for patients and used whenever possible to minimize exposure to ionizing radiation.

Keywords Pediatric · Diagnostic · Induced malignancy · Hydrocephalus

Introduction

The recent radiological literature suggests that exposure to ionizing radiation from imaging studies may play a role in the later development of malignancies, particularly in children [2–16, 18, 21, 23, 24, 26, 31, 32, 35, 36–39]. Children are more vulnerable because of the increased dose–volume ratio and the increased lifetime risk per unit dose of radiation from early exposure [5–8, 10, 11, 13, 15, 19, 20, 22, 25, 29, 30, 34]. Although increased recognition of this potential problem has led to the generalized adoption of protocols to minimize radiation exposure while maintaining imaging quality, repetitive diagnostic imaging, particularly with computerized tomography (CT), likely carries cumulative risk of inducing malignancy. We review this literature and present two illustrative examples of shunted hydrocephalic children who developed malignancies of the head and neck later in childhood.

Materials and methods

A PubMed online search was performed to try and identify reported cases or reviews in the English language literature

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using the following search terms: "induced malignancy, induced tumor, pediatric CT, radiation-induced tumor, diagnostic CT, case report, and radiation risk." Additionally, we present two illustrative cases of patients (one each at Children's Hospital, St. Louis, MO, USA and Children's Hospital, Birmingham, AL, USA) with a history of shunted hydrocephalus who presented with newly diagnosed head and neck malignancies. To specify the amount of radiation received, medical records were retrospectively reviewed to ascertain lifetime exposure to diagnostic ionizing radiation (skull films and head CT scans). Cumulative doses of radiation were estimated based on the CT protocols utilized at the time at each institution. Effective doses for each patient were calculated using published factors for pediatric cases, adjusting for the age of the patient at the time of each scan [5–8]. The CT scanners used at both institutions changed over the years for each patient, and the majority of scans obtained preceded our current special techniques for minimizing radiation for pediatric cases. The effective dose calculated for a single scan using those techniques is 160 mrems. The age-adjusted effective dose from each scan was calculated using published factors (Table 1), then summed for a total lifetime effective dose for each patient.

Illustrative cases

Case 1

This was a then 18-year-old Caucasian male diagnosed with cerebral palsy and hydrocephalus as an infant. At 3 weeks of age, a ventriculoperitoneal shunt was inserted. He suffered from frequent severe headaches and has undergone 23 ventriculoperitoneal shunt revisions to date. His headaches were described as dull, non-positional, and not associated with nausea or vomiting. An endoscopic third ventriculostomy had been performed in the past but ultimately failed. There was no family history of migraines. Intracranial pressure monitoring has been performed twice in this boy during the workup of shunt failures. Each revision has been preceded by CT imaging of the head; at the institution where he received most of his neurosurgical care, he has undergone a total of 23 head CTs and 25 plain skull radiographs prior to the age of 17. It is also likely that other studies were performed at other emergency rooms but are not included because that could not be accurately tallied.

Recent physical examination revealed a tall rotund boy in no apparent distress. Extraocular muscles were intact; with visual acuity corrected to 20/20 on the right and 20/25 on the left. Pupils were 4 mm and reactive, no afferent pupillary defect is present. An exotropia of 35 prism diopters was noted. There was a mild spastic right hemiparesis. Sensation and proprioception were within normal limits in all major dermatomes tested. This patient ambulated without assistance, with a mildly hemiparetic gait. There were no birthmarks over the craniosacral axis. Papilledema has not been documented although revision of his shunt has in the majority of cases resulted in temporary relief of headache. At the age of 17, he developed a progressively enlarging neck mass in the high cervical region of his shunt tract. A supraclavicular lymph node biopsy confirmed Hodgkin's lymphoma, which has responded successfully to treatment.

Table 1 Age-adjusted factors used to estimate effective dose for head CTs in both case illustrations. Baseline effective dose calculated for one scan is 160 mrems

Age	Factor
Newborn	2.5
1 year	2.2
5 years	1.7
10 years	1.3
15 years	1.1
Adult	1.0

Case 2

This patient initially presented as an infant with intraventricular hemorrhage and had a ventriculoperitoneal shunt placed at 2 months of age. He subsequently underwent 13 ventriculoperitoneal and ventriculoatrial shunt revisions, culminating in a complex bilateral shunt system. A review of his radiology records disclosed a minimum of 14 head CT scans performed prior to the age of 15. He presented to neurosurgery clinic at the age of 19 after a 3 year hiatus from his last shunt revision complaining of morning headaches. His neurologic examination revealed an ambulatory, interactive young man. His cranial nerve examination and fundoscopic examination were normal. He had a partial right homonymous hemianopsia and a subtle right hemiparesis. A CT scan demonstrated a new mass in the left parieto-occipital region, which was subtotally resected. Despite aggressive resection and fractionated cranial irradiation, the gliosarcoma recurred rapidly and the patient expired in home hospice care.

Radiation exposure to cases

Both patients presented in infancy with intraventricular hemorrhage of prematurity and underwent multiple cerebrospinal fluid shunt revisions. Throughout their lives, both patients were plagued with multiple shunt malfunctions necessitating frequent diagnostic imaging and shunt revisions. The first patient underwent a minimum of 23 CT scans of the head, with a cumulative radiation dose estimated at 3,800 mrems. In the first case, Hodgkin's lymphoma was identified in the soft tissues of the neck surrounding the distally tunneled shunt catheter as an incidental finding. A supraclavicular lymph node biopsy was performed, confirming the diagnosis of Hodgkin's lymphoma. In the second case, the patient presented to the clinic with headaches and nausea suggestive of shunt malfunction. A head CT, obtained to assess the ventricular system, demonstrated an unexpected mass in the left lateral ventricle and deep parietal lobe. This mass was not present on prior CT images. The mass was subtotally resected. The biopsy demonstrated a highly malignant, poorly differentiated gliosarcoma. Three years prior to the diagnosis of the new mass, this patient had undergone a minimum of 14 CT scans of the head, with a cumulative effective radiation dose estimated at 4,100 mrems. Both patients underwent routine CT imaging of the brain for their shunted hydrocephalus from the time of shunt placement (perinatally) until the present time at routine intervals for clinic visits (approximately every 6 months until age of 5 years then every 1 year). Additionally, each patient underwent CT imaging and radiographs of their shunt systems each time shunt malfunction was evaluated.

Discussion

Calculating the lifetime effective radiation dose that each child received from diagnostic CT imaging is fraught with methodological difficulty due to the long time span (1983–2003) during which the patients underwent imaging, the different CT scanners in use over time (even at the same institutions), and variability in the techniques employed. Furthermore, records from other health care facilities where both of the patients also undoubtedly underwent diagnostic radiological imaging were not available for dose estimation. For the purposes of this study, we have only calculated an estimated effective lifetime dose based on the number of CT scans confirmed to have been performed, assuming the technique used (kmV, etc) was similar to that employed at both institutions in typical adult head CT scans from the 1980s and early 1990s. Newer, age-adjusted techniques are currently employed at the radiology departments at both institutions for diagnostic imaging in all pediatric patients.

While we cannot prove that childhood exposure to CT imaging induced the malignancies in these two cases, it is not unreasonable to suspect a causative role. Both malignancies occurred within the fields exposed to ionizing radiation, and each patient received a cumulative dose of radiation (>4 rem) approximating that seen in the cohort of Hiroshima atomic bomb survivors (5–20 rem) with documented elevated background cancer risks [7, 17, 26, 32, 35]. Many reports exist of malignancies induced in adults from high-dose therapeutic irradiation [3, 9, 16, 18, 24], and it stands to reason that frequent lower doses of ionizing radiation delivered during childhood may also lead to neoplastic transformation. Lifetime cancer mortality risks attributable to pediatric diagnostic radiation exposure are estimated to be considerably higher than in adults. One recent study used population-based estimates of the relative risk of developing a neoplasm from a single diagnostic CT examination to put the odds at 1 in 1,500 per head CT (0.07%) and 1 in 550 per abdominal CT (0.18%) in 1 year olds [3]. By this estimate, the lifetime risk of developing a malignancy increases to 1% after 15 head CT scans early in life.

Physicians and other pediatric health care providers, CT technicians, CT manufacturers, and medical and governmental organizations share the responsibility to minimize radiation exposure to children. Improved communication between radiologists and clinical health care providers regarding the need for CT examination and the techniques used can help minimize radiation exposure. Exposure parameters for pediatric CT should be adjusted based on patient size, the smallest necessary region scanned, and scan resolution (e.g., lower quality scans at lower mA can still be diagnostic). Cranial ultrasound should be used whenever possible in younger patients with open fontanelles. The current medicolegal environment in the US applies pressure to physicians to order tests even when the pretest probability of a positive finding is quite low. When faced with the frequent clinical situation of "rule out shunt failure" in pediatric hydrocephalus patients, emergency room physicians and neurosurgeons should be aware of the potential risks of ionizing radiation from diagnostic imaging. Instead of reflexively ordering the "CT and shunt series," physicians managing children with hydrocephalus should carefully weigh the real need for imaging data in the clinical decision-making process, tempered against the reality of practicing "defensive medicine."

Recent reports of the utility of fast-sequence magnetic resonance imaging (MRI) scans to assess the ventricular system for shunt function are encouraging [1, 27, 28]. Advantages of fast-sequence MRI include the lack of ionizing radiation, high resolution imaging of the ventricular system, and usually do not require sedation. The main disadvantages are the difficulty in visualizing the shunt catheters and the availability of time in the MRI unit. Many radiology departments, including our institutions, have made steps to accommodate requests for "rapid sequence shunt MRI" scans by inserting the add-on cases in between longer scheduled studies. Because of the potential risks of pediatric diagnostic CT, "shunt MRI" protocols should be considered for these patients and used whenever possible to minimize exposure to ionizing radiation. Radiation-induced carcinogenesis is most likely due to gene mutations that lead to errors in DNA repair and synthesis [33]. Minimizing patient exposure to radiation with routine radiological tests is desirable with the potential for tissue damage at the molecular level and subsequent risk of cancer.

Conclusions

The clinician should be aware of potential risks while ordering "routine" CT imaging for the evaluation of shunted hydrocephalus. Our hopes are that these case reports enhance the awareness of the readership to this potential problem.

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