Risk of radiation-induced malignancies from CT scanning in children who underwent shunt treatment before 6 years of age: a retrospective cohort study with a minimum 10-year follow-up

Clinical article

Ian K. White, M.D.,¹ Kashif A. Shaikh, M.D.,¹ Reilin J. Moore, B.A.,¹ Carl L. Bullis, M.D.,¹ MairaJ T. Sami, M.D.,¹ Thomas J. Gianaris, M.D.,¹ and Daniel H. Fulkerson, M.D.²

¹Department of Neurosurgery, Indiana University School of Medicine; and ²Department of Neurosurgery, Division of Pediatric Neurosurgery, Indiana University School of Medicine, Goodman Campbell Brain and Spine, Indianapolis, Indiana

Object. A number of mathematical models predict the risk of future cancer from the ionizing radiation exposure of CT scanning. The predictions are alarming. Some models predict 29,000 future cancers and 14,500 deaths in the US will be directly caused by 1 year’s worth of CT scanning. However, there are very few clinical data to justify or refute these claims. Young children are theoretically highly susceptible to the damaging effects of radiation. In this study, the authors examined children who underwent CSF shunt placement before 6 years of age. The authors chose to study shunt-treated patients with the assumption that these patients would undergo future imaging, facilitating surveillance. They chose a study period of 1991–2001 to allow more than 10 years of follow-up data.

Methods. The authors studied 104 consecutive children who underwent CSF shunt placement prior to 6 years of age and who had at least 10 years of follow-up data. Sixty-two of these patients underwent shunt placement prior to 1 year of age. The age at the initial scanning session, the number of future CT scanning sessions, diagnosis, and results of any future studies were recorded. The age-specific radiation dose was calculated for children younger than 1 year. Children younger than 1 year at the time of shunt placement were evaluated separately, based on the assumption that they represented the highest risk cohort. The authors examined all data for any evidence of future leukemia or head/neck tumor (benign or malignant).

Results. These children underwent a total of 1584 CT scanning sessions over a follow-up period of 1622 person-years. A total of 517 scanning sessions were performed prior to 6 years of age, including 260 in the 1st year of life. Children who underwent shunt placement before 1 year of age underwent an average of 16.3 ± 13.5 CT sessions (range 1–41). Children undergoing placement between 1 and 6 years of age received an average of 14.1 ± 12.5 CT studies (range 5–52). There were no subsequent tumors (benign or malignant) or leukemia detected.

Conclusions. Previously published models predict a significant number of future cancers directly caused by CT scanning. However, there are very few published clinical data. In the authors’ study, zero future radiation-induced malignancies were detected after routine CT scanning in a high-risk group. While the authors do not consider their single-institution study adequate to define the actual risk, their data suggest that the overall risk is low. The authors hope this study encourages future collaborative efforts to define the actual risk to patients.

Head CT scanning accounts for approximately 50% of all CT scanning.¹⁵,²²,²⁸ With these increasing numbers, there is growing concern about the possibility of cancer due to the exposure. This concern is heightened in young children, who are potentially more susceptible to the damaging effects of radiation.

The National Academies’ Biological Effects of Ionizing Radiation (BEIR) VII report related the risk of cancer with radiation exposure from military sources (Japanese

Abbreviation used in this paper: BEIR VII = Biological Effects of Ionizing Radiation VII.
Malignancy risk of CT scanning

patients exposed to nuclear fallout in World War II), therapeutic radiation treatment (treatment of tinea capitis), and nuclear facility workers. Various models and anthropomorphic phantom simulations provide estimates for the effective radiation dose to organs based on the type of CT scanning study. Authors have then correlated the radiation dose from simulations to similar doses from the BEIR VII report to calculate a mathematical estimate of the lifetime attributable risk of cancer development.

These models estimate a large number of future cancers attributable to CT scanning. One study estimated that 29,000 future cancers and 14,500 deaths will be caused by 1 year of CT scanning in the US alone. Others estimated that 2% of all future cancers will be directly caused by CT scanning. These estimates carry substantial potential clinical and medicolegal costs.

While the models are alarming, there is a lack of clinical data to either confirm or refute the estimates. Pediatric neurosurgeons routinely use CT scanning in the care of their patients. In particular, children with CSF shunts are often subjected to multiple scanning sessions, often beginning in infancy. Very young children are at the highest theoretical risk of secondary malignancy after radiation exposure. Unfortunately, children who undergo shunt placement at very young ages are also at the highest risk for shunt problems and may undergo the most scanning procedures.

In this study, we examined a cohort of 104 children who received an initial CSF shunt before 6 years of age (≤ 71 months) between 1991 and 2001. This period was chosen to allow a minimum of 10 years of follow-up data. We analyzed children undergoing shunt placement before 1 year of age separately, as we considered these patients to be in the highest risk group. A review was performed to evaluate any evidence of future tumors (benign or malignant) or leukemia. We included patients who underwent shunt placement for hydrocephalus secondary to a primary tumor, but we excluded any patient who received subsequent therapeutic radiation treatment. In tumor patients, we evaluated for a new or secondary cancer.

Methods

We performed a retrospective review of all patients who underwent CSF shunt placement at Riley Hospital for Children (Indianapolis, IN) between 1991 and 2001. The study began after approval was obtained from the Indiana University School of Medicine Institutional Review Board. We identified all patients who received an initial shunt before they were 6 years of age (≤ 71 months). We reviewed all relevant clinical and radiology reports. We excluded patients who did not have follow-up for the requisite 10 years (n = 42). Any deaths of shunt-treated patients were reviewed for suggestion of cancer. While we included children who were undergoing shunt placement for a presenting brain tumor, we excluded any receiving subsequent therapeutic radiation treatment.

Data points included age at the initial CT scanning session, number of CT scanning sessions, diagnosis, and follow-up clinical data, including specific searches for any subsequent diagnosis of tumor or leukemia. We prepared a statistical analysis for any subsequent tumors identified based on the number of CT scanning sessions, radiation exposure estimates, age at first scan, and diagnosis.

The radiation exposure for children younger than 1 year was estimated based on the output recorded from the CT scanner. We calculated the radiation dose per patient based on this output as described in previous publications. The actual tissue dose was not calculated, as this dose is based on variables (distance from the radiation source, size of the patient, and different tissue thicknesses), which were not available in a retrospective review.

We estimated surveillance for any subsequent tumors from follow-up clinical and radiological data. Any future laboratory or radiological study was reviewed. We assumed that any symptomatic tumors would be identified on clinical notes. While we only included subsequent CT scanning sessions in the data, we reviewed any other available imaging studies (such as MRI) for any evidence of asymptomatic tumors.

Results

Children Undergoing Shunt Placement in the 1st Year of Life

We identified 62 patients meeting the entry criteria who underwent shunt placement in the 1st year of life. The demographics and results are shown in Table 1.

The average age at the first CT scanning session was 4.2 ± 4.5 months (range 1 day–12 months). The average number of total scanning sessions per patient in the 1st year of life was 4.2 ± 4.2 (range 1–18). The total number of head CT scanning sessions per patient performed throughout the follow-up period was 16.3 ± 13.5 (range 1–41). Table 1 lists the number of scanning sessions by diagnosis in total and in the 1st year of life.

We calculated the age-specific radiation dose based on the criteria described by Pearce et al. The estimated average radiation dose per patient was 321 mGy to the brain (range 70–1400 mGy) and 92 mGy to the bone marrow of the skull (range 20–400 mGy).

The average length of follow-up was 16.0 ± 3.1 years (range 10–21 years). There was a total of 989 person-years of data. There were no subsequent cases of benign or malignant brain, ocular, or thyroid tumors. There were no leukemias or any other tumors discovered in the follow-up period.

Children Undergoing Shunt Placement at Ages 1–6 Years (≤ 71 Months)

Forty-two children received an initial shunt between 1 and 6 years of age and met the study entry criteria. The demographics and results are shown in Table 2.

These children had a total of 257 CT scanning sessions prior to 6 years of age. The average number of scanning sessions per patient prior to 6 years of age was 6.1 ± 6.3 (range 0–32). These children have had a total of 592 scanning sessions to date (average per patient 14.1 ± 12.5; range 5–52).

Follow-up data were available for all patients for at least 10 years. The average length of follow-up was 15.1
± 3.7 years. There was a total of 633 person-years of data. There were no cases of new benign or malignant brain, ocular, or thyroid tumors. There were no leukemias or any other tumors discovered in the follow-up period.

Discussion

Ionizing radiation is a known risk factor for the development of cancer.5,10,13,19,23,25,30–33,36,37 There is an increasing and justifiable concern among physicians and the public about the possibility of cancers caused by medical diagnostic tests. The use of CT scanning has increased dramatically over the past few decades, with an estimated 72 million scans performed annually in the US.3

The risk of a CT-induced malignancy is based on phantom models estimating a tissue radiation dose for a given scan.15 This estimated dose is then compared with known actuarial data, such as the National Academies Research Council’s BEIR VII report.10 This report estimates the future risk of cancer based on the incidence in patients with known exposure to radiation: Japanese survivors after nuclear bombing, nuclear industry workers, and patients exposed to therapeutic radiation for medical treatment (for example, tinea capitis).6,8,30 Multiple authors have then extrapolated the expected risk of future cancer from CT scanning by equating the phantom model doses to the known risk reported in the BEIR VII report.1,3,7,9,11,12,14,18,21,22,28,34

These models predict an alarming number of future cancers. Berrington de González et al. predicted 29,000 future cancers and 14,500 future deaths in the US caused by 1 year of CT scanning.7 Chodick et al. estimated 9.5 excess lifetime deaths for 1 year of pediatric CT scanning in Israel.9 Koral et al. estimated 1 excess lifetime death per 97 pediatric patients.21 Brenner et al. estimated 500 future deaths annually directly attributable to CT scanning in children younger than 15 years.7 Stein et al. predicted a lifetime risk of developing cancer of 0.22% after one CT scanning session in a child younger than 1 year of age.35

There are studies that show a correlation of cancers with therapeutic radiation. There is a link between breast cancer and diagnostic radiography in young women.6,13 Hammer et al. examined 92,957 children who underwent diagnostic radiography between 1976 and 2003. They did not find an increase in cancer incidence, although the radiation doses from radiography are lower than those from CT scanning.16 In the largest study to date, Pearce et al. reviewed more than 170,000 patients who underwent CT scanning in the National Health Service centers in Great Britain.29 They correlated the radiation dose from multiple scanning sessions to an increased risk of brain tumors and leukemia. The relative risk of brain cancer in patients with a cumulative dose of 50–74 mGy was 2.82 compared with those who received less than 5 mGy. The relative risk of leukemia for those with a cumulative dose of at least 30 mGy was 3.18 compared with the lower dose. The study had a number of built-in assumptions. The authors relied on a 2- to 5-year exclusion period, with the thought that any tumors after this period were related to scanning. The authors also assumed that cancers caused by CT scanning occur within 10 years of exposure.

Children may be particularly susceptible to the damaging effects of radiation.39,13,20,27,31,35 It makes intuitive sense that developing tissue is more sensitive. Indeed,
Malignancy risk of CT scanning

TABLE 2: Demographics of 42 children undergoing shunt placement between 1 and 6 years (≤ 71 months) of age

<table>
<thead>
<tr>
<th>Parameter</th>
<th>No. of Patients</th>
<th>Mean No. of Head CT Sessions Prior to Age 6 Yrs (range)</th>
<th>Mean Total No. of Head CT Sessions (range)</th>
<th>Mean ± SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>diagnosis</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>congenital hydrocephalus</td>
<td>19</td>
<td>6.5 (0–32)</td>
<td>13.8 (1–52)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>tumor/leukemia</td>
<td>6</td>
<td>7.8 (2–18)</td>
<td>12.3 (4–22)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>trauma</td>
<td>5</td>
<td>6.4 (2–11)</td>
<td>10.8 (4–17)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>vascular/IVH</td>
<td>5</td>
<td>7.4 (1–16)</td>
<td>20.0 (5–44)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>skull deformity</td>
<td>4</td>
<td>3.8 (1–5)</td>
<td>8.5 (1–12)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>other*</td>
<td>3</td>
<td>1.0 (0–2)</td>
<td>22.3 (5–45)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>age at shunt insertion (mos)</td>
<td></td>
<td>30.1 ± 15.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>no. of CT sessions prior to age 6 yrs/patient</td>
<td></td>
<td>6.1 ± 6.3</td>
<td>0–32</td>
<td></td>
<td></td>
</tr>
<tr>
<td>total no. of CT sessions/patient</td>
<td></td>
<td>14.1 ± 12.5</td>
<td>5–52</td>
<td></td>
<td></td>
</tr>
<tr>
<td>future malignancy</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>benign brain/skull tumor</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>malignant brain/skull tumor</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ocular tumor</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>secondary leukemia†</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>thyroid malignancy</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>other malignancy</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Includes 2 patients with shunt secondary to arachnoid cysts and 1 patient with postinfectious hydrocephalus.
† One patient received a shunt for hydrocephalus for an initial diagnosis of leukemia. This patient did not have a second or subsequent diagnosis of a different malignancy. No other patient developed leukemia.

Prenatal exposure to radiation has been shown to increase childhood malignancy.4,5 A CT scanning session delivers a higher effective radiation dose to a child than an adult.2,17,28,35 The effective dose in a child younger than 1 year is double that of adults; this dose is 4-fold higher in a newborn.26 In addition, children presumably have a longer life expectancy and thus more time to develop cancers compared with adults.

With these considerations, we consider a child requiring a CSF shunt at a young age to represent a high-risk group for CT-induced malignancy. This risk may be magnified in children undergoing shunt placement in the 1st year of life. Unfortunately, these children are also at the highest risk for shunt problems. They often require multiple scanning sessions throughout their life. With this in mind, we studied 104 children who underwent shunt placement before 6 years of age with 1022 person-years follow-up. We chose the inclusion dates to allow at least 10 years of follow-up data, as the risk of development of cancer following ionizing radiation exposure is considered greatest in the 1st decade.29

We consider children undergoing shunt placement before 1 year of age to be at the highest risk. These 62 children were analyzed separately. These children underwent a total of 260 head CT scanning sessions in the 1st year of life. Using the estimates of Stein et al. and Brenner et al., there is an 18%–57% chance that at least one of our patients would develop cancer in the follow-up period from the scans in the 1st year alone. Each of our patients has been monitored for at least 10 years (mean 16.0 ± 3.1 years), for a total of 989 person-years. To date, there are no subsequent radiation-induced malignancies or benign tumors discovered in our patient population.

Our total study group included 104 children who underwent 517 CT scanning sessions prior to 6 years of age, with 10 years of follow-up data. Using the estimates of Stein et al., 1 radiation-induced malignancy should be identified for every 454 scanning sessions.35 Using this estimation, there is a 113% chance that at least 1 subsequent malignancy should be found in our study group. The model published by Brenner et al. estimates 1 additional malignancy per roughly 1428 scans.7 Based on this, we had an estimated 36% chance of detecting a radiation-induced cancer in just the scanning sessions performed prior to 6 years of age. The odds increase if we include all 1584 scanning sessions performed to date in the study group, although some of these CT sessions are more recent and thus are within 10 years. No subsequent tumors or new cancers were identified in 1622 person-years of follow-up.

One of the challenges in examining the “risk” of radiation-induced tumors is detection. We assumed that we would discover any symptomatic tumors based on clinical follow-up. However, there is the challenge of identifying occult or asymptomatic tumors. We chose shunt-treated patients as the study group with the assumption that they would undergo multiple future scanning sessions. While we did not have a standardized follow-up protocol during the study period, most patients underwent scanning on at least a yearly basis for shunt maintenance. We acknowledge that a noncontrasted head CT study ordered for shunt evaluation may not detect a subtle lesion.
available, we reviewed any other imaging studies including MRI.

The mathematical models predict that our total number of CT scanning sessions (1584) will generate 1.1–3.5 subsequent radiation-induced malignancies. While there were no subsequent cancers in our study group, we encourage prudence with exposing children to radiation. Radiology teams continue to enhance CT protocols to reduce the effective organ dose of radiation. At our institution (as in others), we have developed a protocol for limited T2-weighted MR images for surveillance imaging. These limited-view MR images demonstrate the ventricles and brain parenchyma in multiple planes without ionizing radiation. While the detail is not as robust as a standard MR study, the acquisition time and cost to the patient are comparable to a head CT scanning session. Head ultrasound images are also used liberally in children with an open fontanelle.

Computed tomography scanning is an important diagnostic tool for the neurosurgeon. It is quick and readily available. While we feel that prudence dictates limiting a child’s exposure to radiation, we are concerned that the alarming mathematical estimates may overestimate the actual risk. We also feel that these estimates may lead to undeserved clinical and medicolegal costs.

**Study Limitations**

We made a number of assumptions related to the detection of future malignancies. We assumed that shunt-treated children would receive follow-up scans. However, the number of scans in our population is quite variable. Most CT scanning for shunt evaluation is performed without contrast. This may be inadequate to detect an incidental tumor. We assumed that children with symptomatic malignancies would be identified in clinical follow-up and treated at our institution.

The larger population studies are limited by significant assumptions built into the design. In contrast, our study is limited by relatively small numbers of patients. Our strategy was to examine the group we felt was at the highest risk. Despite almost 1622 patient-years of follow-up, this study still is underpowered to detect a possibly rare occurrence. In the study by Pearce et al., 1 new tumor should be detected for 10,000 scanning sessions. Clearly, many more patients would need to be studied to detect this rare of an occurrence. Therefore, this study should be read not as definitive, but as a call for collaboration with multiple institutions.

**Conclusions**

Risk estimates for CT-induced cancers are alarming and mandate careful, coordinated study by pediatric neuroradiologists. In a study group of 104 of the highest risk children followed for a total of 1622 patient-years, we found zero subsequent cancers despite a high number of CT scanning sessions. We encourage prudence with ordering scans. However, we feel that the long-term risk is low and is usually outweighed by the immediate benefit of the study.

**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: Fulkerson, White. Acquisition of data: White, Shaikh, Moore, Bullis, Sami, Gianaris. Analysis and interpretation of data: Fulkerson, Moore. Drafting the article: Fulkerson, White. 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: Fulkerson. Study supervision: Fulkerson.

**References**

Malignancy risk of CT scanning


---

Manuscript submitted October 13, 2012. Accepted February 12, 2014. Please include this information when citing this paper; published online March 14, 2014; DOI: 10.3171/2014.2.PEDS12508. Address correspondence to: Daniel H. Fulkerson, M.D., Indiana University School of Medicine, Goodman Campbell Brain and Spine, Riley Hospital for Children, 702 Barnhill Dr. #1134, Indianapolis, IN 46202. email: dfulkers@iupui.edu.