Low-dose head computed tomography in children: a single institutional experience in pediatric radiation risk reduction

Clinical article

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Object. In this study, the authors describe their experience with a low-dose head CT protocol for a preselected neurosurgical population at a dedicated pediatric hospital (Seattle Children's Hospital), the largest number of patients with this protocol reported to date.

Methods. All low-dose head CT scans between October 2011 and November 2012 were reviewed. Two different low-dose radiation dosages were used, at one-half or one-quarter the dose of a standard head CT scan, based on patient characteristics agreed upon by the neurosurgery and radiology departments. Patient information was also recorded, including diagnosis and indication for CT scan.

Results. Six hundred twenty-four low-dose head CT procedures were performed within the 12-month study period. Although indications for the CT scans varied, the most common reason was to evaluate the ventricles and catheter placement in hydrocephalic patients with shunts (70%), followed by postoperative craniostomy imaging (12%). These scans provided adequate diagnostic imaging, and no patient required a follow-up full-dose CT scan as a result of poor image quality on a low-dose CT scan. Overall physician comfort and satisfaction with interpretation of the images was high. An additional 2150 full-dose head CT scans were performed during the same 12-month time period, making the total number of CT scans 2774. This value compares to 3730 full-dose head CT scans obtained during the year prior to the study when low-dose CT and rapid-sequence MRI was not a reliable option at Seattle Children's Hospital. Thus, over a 1-year period, 22% of the total CT scans were able to be converted to low-dose scans, and full-dose CT scans were able to be reduced by 42%.

Conclusions. The implementation of a low-dose head CT protocol substantially reduced the amount of ionizing radiation exposure in a preselected population of pediatric neurosurgical patients. Image quality and diagnostic utility were not significantly compromised.

(<http://thejns.org/doi/abs/10.3171/2013.7.PEDS12631>)

KEY WORDS • low dose • computed tomography • radiation • risk reduction

THE incidence of CT scan use is drastically on the rise, with approximately 70 million CT scans performed in the US each year.^{1,3,4} The largest increase in CT scan use, however, has been in the diagnosis of pediatric disorders.^{7,11} Approximately 4 million pediatric CT scans are performed annually, 25% of which are head CT scans. The advantages of head CT scans are multi-fold and involve a fast and relatively inexpensive way to obtain a detailed evaluation of the brain parenchyma, ventricles, and calvaria. However, CT scans necessarily expose the patient to ionizing radiation, increasing the statistical risk of developing cancer later in life. This risk

is particularly increased in children due to longer remaining life expectancy and thinner, less dense skulls that offer less shielding than the adult calvaria.

A recent study has evaluated the cancer risk of leukemia and brain tumors in patients receiving head CT scans. Pearce et al.⁹ concluded that the risk of leukemia and brain tumors is almost 3 times greater in those patients who received a cumulative dose of 50–60 mGy (approximately 2–3 head CT scans at common CT dose settings). This is equivalent to 1 excess case of leukemia and brain tumor in 10 years per 10,000 head CT scans performed in patients younger than 10 years.⁹ As approximately 1 million head CT scans are performed in the pediatric population annually, this statistically extrapolates to an extra 100 radiation-induced hematogenous or brain

Abbreviation used in this paper: ICH = intracerebral hemorrhage.

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cancers over the next 10 years. In addition, as more premature children are surviving with chronic neurosurgical conditions, these numbers will likely increase.

By reducing the radiation dose of a head CT scan or performing rapid-sequence MRI, one can obtain the critical diagnostic information needed in a preselected group of patients (such as those with shunted hydrocephalus or craniosynostosis) while minimizing the cumulative ionizing radiation dose these patients receive. Our center's patient series with rapid-sequence MRI, as well as others, have been described previously.^{5,8} We describe our experience with a low-dose head CT protocol for a preselected neurosurgical population at a dedicated pediatric hospital, the largest number of patients with this protocol reported to date.

Methods

Study Population and Criteria

This study was approved by the hospital's institutional review board. A retrospective review of prospectively collected data was performed on all patients who received a low-dose head CT scan between October 2011 and November 2012. Two different radiation dosages were used at approximately one-half or one-quarter the dose of a standard head CT scan, based on patient characteristics agreed upon by the neurosurgery and radiology departments. These criteria are listed below and in Table 1. Patient information, including diagnosis and indication for CT scan, was recorded. Patients eligible for a "half-dose" protocol included: 1) patients with shunted hydrocephalus presenting for routine follow-up, presenting to the emergency room with concerns for shunt malfunction, or receiving a "routine" postoperative scan for catheter placement verification; 2) all patients receiving a preoperative head CT scan with fine slices for a shunt, tumor, or other procedure requiring neuronavigation; 3) postoperative craniotomy patients receiving imaging to identify postoperative concerns including hemorrhage (with a previous full-dose head CT scan or MR image in our database); and 4) follow-up of a known ICH (with a previous full-dose head CT scan or MR image in our database). Patients eligible for the "quarter-dose" CT protocol included: 1) routine postoperative head CT scans for craniosynostosis patients after either endoscopic or open

repair in which the calvaria was the primary objective of radiographic evaluation; and 2) follow-up of a bone-only skull lesion.

Radiological Specifications

To perform "half-dose" and "quarter-dose" low-dose head CT scans, we decreased the tube current (and thus the dose in mAs) by approximately 50% and 75%, respectively, compared with standard head CT. The absolute reduction was calculated based on the patient's age (Table 2). Because the relationship between tube current and radiation dose is linear, decreasing the tube current by 50%–75% will essentially decrease the radiation dose by 50%–75%. However, with other scanning parameters held constant (pitch, peak kilovoltage, gantry cycle time, and slice number and thickness), a reduction in tube current also increases image noise. Because noise is the principle determinant of image quality and diagnostic yield, we implemented a postprocessing software package (Neuro 3D Filter N2, GE Healthcare) that creates average and maximum intensity projection images to reduce noise and improve image quality at lower CT doses (Fig. 1). All scans were reviewed by pediatric neuroradiologists for image quality and diagnostic yield.

Results

We performed 624 low-dose head CT procedures within the 12-month study period, or an average of 52 low-dose scans per month (range 28–71 scans/month). Although indications for the CT scans varied (Table 3), the most common reason was to evaluate the ventricles and catheter placement in patients with shunted hydrocephalus (70%), followed by postoperative craniosynostosis imaging (12%). These scans provided adequate diagnostic imaging and no patient required a follow-up full-dose CT scan due to low-dose CT image quality. Overall physician comfort and satisfaction with interpretation of the images was high as indicated in the survey analysis of all of the pediatric neurosurgeons and craniofacial plastic surgeons at Seattle Children's Hospital, as well as 3 pediatric neuroradiologists (Table 4). All (4 pediatric neurosurgeons, 3 pediatric craniofacial plastic surgeons, and 3 pediatric radiologists) strongly agreed that the current quality of images provided the information needed to evaluate hydrocephalus, skull and face bones, and ICH in our selected

TABLE 1: Inclusion criteria to obtain a low-dose head CT scan

Dose	Inclusion Criteria
half	1) shunted hydrocephalic patients presenting for routine follow-up, presenting to the emergency room over concern for ventriculoperitoneal shunt malfunction, or receiving a routine postop scan for catheter placement verification; 2) all patients receiving a preop CT scan w/ fine slices for shunt, tumor, or other procedure needing neuronavigation;* 3) postop craniotomy patients;* 4) follow-up of a known ICH*
quarter	1) routine postop CT scans (& follow-up if deemed necessary) for craniosynostosis patients after either endoscopic or open repair where the skull bones were the primary object of radiographic evaluation; 2) follow-up of a bone-only skull lesion

* All patients had a full-dose head CT scan or MR image in the database for reference.

TABLE 2: Radiation specifics for full-, half-, and quarter-dose CT scans*

Dose	Age (yrs)	mA	Scan Time (sec)	Total mAs
full				
	<2	310	0.4	124
	2–15	335	0.5	168
	>15	300	0.8	240
half				
	<2	155	0.4	62
	2–15	170	0.5	85
	>15	240	0.5	120
quarter				
	<2	75	0.4	30
	2–15	75	0.5	37.5
	>15	85	0.5	42.5

* All scans used a pitch of 0.969 and 120 kV. The tube current (and thus the dose in mA) is decreased by approximately 50% and 75%, respectively, compared to standard head CT. Other scanning parameters including pitch, peak kilovoltage, gantry cycle time, slice number and thickness, and others were held constant.

patient population. Additionally, the overall satisfaction with the image quality was high and all supported the continued use of low-dose head CT at Seattle Children's Hospital.

An additional 2150 full-dose head CT scans were performed during the same 12-month period, making the total number of CT scans 2774. This number compares to 3730 full-dose head CT scans from the year prior to the study when low-dose CT and rapid sequence MRI was not a reliable option at Seattle Children's Hospital. Thus, over a 1-year period we were able to convert 22% of the total CT scans to low-dose and reduce the total number of full-dose CT scans by 42%.

Discussion

The risks of ionizing radiation have been recently emphasized in both the scientific literature and in the popular press.^{1–4} The pediatric neurosurgical population is at considerable risk for radiation-induced disease due to chronic neurosurgical conditions requiring repeated cranial imaging, most often using CT. Previous studies have demonstrated that a patient with shunted hydrocephalus receives an average of 2 head CT scans per year for surveillance purposes alone.⁹

Additionally, our institution utilizes frameless stereotaxy for image-guided placement of nearly all of our proximal shunt catheters, with improved results.⁶ Thus, we often require an additional scan beyond that required for the diagnosis of shunt failure. The benefit of reduced radiation is substantial in such patients, as these patients are well within the 50–60 mGy range associated with at least a 3-fold increased risk of brain and hematogenous malignancy.

To this end, we have adopted the “as low as reasonably achievable” radiation dosing strategy to minimize the impact of ionizing radiation by implementing and developing both a low-dose head CT protocol and a rapid-sequence MRI protocol. These protocols have provided adequate diagnostic imaging in preselected situations such as ventricular size and catheter location in preoperative and postoperative ventriculoperitoneal shunting, evaluation for edema and hematoma after craniotomy, follow-up of traumatic intracranial hematoma, and others (Table 3). While rapid-sequence MRI has significantly diminished the number of head CT scans administered to patients with shunted hydrocephalus, many hospitals

FIG. 1. Diagnostic acceptability of low-dose CT studies. Axial standard-dose (A), low-dose (B), and low-dose filtered (C) head CT studies obtained in a 3-year-old girl.

TABLE 3: Indications and quantification of the various pathologies for which low-dose head CT scans were obtained

Indication	Value (%)
evaluation of skull lesion	17 (3)
follow-up for ICH	6 (1)
postop craniotomy	26 (4)
postop craniofacial	44 (7)
postop craniostomy	75 (12)
preop craniotomy	3 (0)
preop craniofacial	10 (2)
preop craniostomy	9 (1)
ventricle/catheter check	434 (70)

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TABLE 4: Survey analysis administered to selected personnel at Seattle Children's Hospital to discern the degree of utility and quality of the low-dose head CT scan protocol*

Survey: Low-Dose Head CTs at Seattle Children's Hospital				
Please answer the following questions to the best of your ability. If you don't feel qualified to answer mark "N/A"				
1. The current quality of images obtained for low dose head CTs provides the information I need to evaluate hydrocephalus and shunt failure (i.e. ventricular size, shunt tip placement, transependymal flow, etc)				
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
2. The current quality of images obtained for low dose head CTs provides the information I need to evaluate the skull and face bones after craniostomy or craniofacial surgery.				
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
3. The current quality of images obtained for low dose head CTs provides the information I need to evaluate for ICH (EDH, SDH, IPH) after shunt surgery or after craniostomy surgery				
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
4. The current quality of images obtained for low dose head CTs provides the information I need to evaluate for ICH (EDH, SDH, IPH) after a tumor resection in the supratentorial space				
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
5. The current quality of images obtained for low dose head CTs provides the information I need to evaluate for ICH (EDH, SDH, IPH) after a tumor resection in the infratentorial space				
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
6. My overall satisfaction with the image quality with the neuro-filter for low dose head CT is high				
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
7. Taking only the image quality into account, support the continued use of low dose head CT at Seattle Children's Hospital				
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

* All personnel who took the survey answered "strongly agree" to all of the questions. EDH = epidural hematoma; IPH = intraparenchymal hematoma; SDH = subdural hematoma.

(including ours) do not have immediate 24-hour access to MRI, necessitating the use of CT for critical, time-sensitive, and often life-saving information. And while a full-dose head CT scan may also be required in situations of diagnostic uncertainty or in patients with non-MRI compatible devices (such as deep brain stimulators, baclofen pumps, cochlear implants, vagal nerve stimulators, and others), most perioperative, follow-up, and surveillance films rarely require the resolution and image quality that necessitate such high radiation dosing. Thus, the low-dose head CT scan further embodies the "as low as reasonably achievable" strategy. We have demonstrated that the low-dose head CT scanning protocol can provide cranial imaging sufficient for follow-up diagnostic purposes while reducing radiation exposure in a large volume, select pediatric neurosurgical population. In 1 year we were able to perform low-dose, rather than full-dose, head CT scans 22% of the time.

A major concern in implementing the low-dose head CT protocol was the potential for unrecognized pathology (such as hemorrhage) in the setting of reduced image quality. However, the image quality of our low-dose head CT has proven to be acceptable for excluding hemorrhage and to our knowledge has not underperformed subsequent full-dose CT scans. This may be in part due to the filter (Neuro 3D Filter N2) that has been adopted to postprocess the images (Fig. 1). Our survey analysis of all of the pediatric neurosurgeons and craniofacial plastic surgeons at Seattle Children's Hospital, as well as 3 pediatric neuroradiologists, demonstrated multidisciplinary

support of the quality and utility of the low-dose CT scans in our selected population. These findings are in agreement with previously published smaller series that objectively demonstrated acceptable image quality, albeit with increased noise, with approximately 50% reduction in tube current.¹⁰

Lastly, it is important to remember that low-dose CT scans still expose each child to ionizing radiation and thus one should not expand the criteria for ordering a head CT scan even though a lower dose is available. Current imaging indications must also be constantly reviewed and re-reviewed to ensure the low-dose scans are even necessary. We do acknowledge that our institution relies heavily on CT to provide data that we feel are valuable and meaningful (such as proper shunt tip placement, exclusion of hematoma, and others). The risk/benefit analysis of this information versus the risk of radiation exposure, even from a low-dose CT scan, is difficult to objectively quantify. Admittedly, the best way to reduce diagnostic radiation is to critically reassess the clinical utility of all radiation studies and potentially exclude imaging in children with certain indications. As such, we have recently stopped obtaining routine postoperative head CT scans in postoperative Chiari decompressions, as we found little utility in the results.

This study has several limitations. First, while low-dose head CT images were subjectively interpreted as satisfactory for the purposes of preselected indications (ventricular size, follow-up hematoma volume, and others), they could not be directly compared with full-dose

CT scans in the same patient at the same time, except in rare situations (Fig. 1). Thus, quantification of the degree of image quality lost with the reduced dose is not usually possible. Also, the vast majority of low-dose head CT scans were performed in the setting of shunted hydrocephalus. While we considered low-dose head CT adequate for the evaluation of other indications (Table 3), a larger sample size of each of these patient populations is needed to fully evaluate the utility of low-dose head CT.

Conclusions

The implementation of a low-dose head CT protocol substantially reduced the amount of ionizing radiation exposure in a preselected population of pediatric neurosurgical patients. Image quality and diagnostic utility were not significantly compromised.

Disclosure

Dr. Levitt has received support of non-study related clinical or research effort from the Volcano Corporation.

Author contributions to the study and manuscript preparation include the following. Conception and design: Morton, Reynolds, Ramakrishna, Browd. Acquisition of data: Morton, Reynolds. Analysis and interpretation of data: Morton, Levitt, Lee. Drafting the article: Morton, Ramakrishna, Levitt, Browd. 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: Morton. Statistical analysis: Morton, Browd. Administrative/technical/material support: Morton, Hopper, Lee, Browd. Study supervision: Hopper, Lee, Browd.

Acknowledgments

The authors would like to thank Victor Ghioni, lead pediatric CT technologist at Seattle Children's Hospital, who was instrumental in data collection for this paper. The authors also thank Jonathan O. Swanson, M.D., who was extremely instrumental in the initial development of the low-dose head CT protocol at Seattle Children's Hospital.

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Manuscript submitted January 2, 2013.

Accepted July 23, 2013.

Please include this information when citing this paper: published online August 23, 2013; DOI: 10.3171/2013.7.PEDS12631.

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