Journal of Pediatric Surgery 51 (2016) 1944–1948

Contents lists available at ScienceDirect

Journal of Pediatric Surgery

journal homepage: www.elsevier.com/locate/jpedsurg

Don't forget the dose: Improving computed tomography dosing for pediatric appendicitis☆,☆☆,★

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ARTICLE INFO

Article history:
Received 7 August 2016
Accepted 12 September 2016

Key words:
Ct
Appendicitis
Pediatrics
ALARA

ABSTRACT

Background: A pediatric computed tomography (CT) radiation dose reduction program was implemented throughout our children's associated hospital system in 2010. We hypothesized that the CT dose received for evaluation of appendicitis in children would be significantly higher among the 40 referral, nonmember hospitals (NMH) than the 9 member hospitals (MH).
Methods: Preoperative CTs of pediatric (<18 years) appendectomy patients between April 2012 and April 2015 were reviewed. Size specific dose estimate (SSDE), an approximation of absorbed dose incorporating patient diameter, and Effective Dose (ED) were calculated for each scan.
Results: 1128 (65%) of 1736 appendectomy patients underwent preoperative CT. 936 patients seen at and 102 children evaluated at NMH had dosing and patient diameter data for analysis. SSDE and ED were significantly higher with greater variance at NMH across all ages (all $p < 0.05$, Figure). NMH's SSDE and ED also exceeded reference levels.
Conclusion: Radiation exposure in CT scans for evaluation of pediatric appendicitis is significantly higher and more variable in NMH. A proactive approach to reduce dose, in addition to frequency, of CT scans in pediatric patients is essential.
Level of evidence: Level III.

An estimated 60% of manmade radiation exposure in the United States is attributable to computed tomography (CT) alone [1]. Despite the known potential oncogenic risk of radiation, which is increased in children, CT continues to be a frequent modality employed to evaluate the pediatric population. Children are reported to receive between 4 and 7 million CT scans every year [2]. Other imaging modalities are available; however, more than 50% of pediatric patients with suspected appendicitis undergo CT. [3] Though the true risk is unknown, it is estimated that 1 in 1000 pediatric abdominal CT scans will cause cancer [4].

Organizations such as the Joint Commission and the American College of Radiology (ACR) have promoted CT use reduction in children [5]. There is a national trend of slowly declining CT rates; however, there are scant data on the dosing of the CTs that are conducted. The Image Gently Alliance, a collaboration of healthcare groups campaigning for appropriate medical imaging and dose reduction in pediatric patients, has published recommendations and techniques for CT protocols [6]. The dissemination and implementation of these guidelines have not been established.

Community nonchildren's hospitals, where the majority of pediatric appendicitis patients present, have higher rates of CT use [7,8]. [9] CT may be appropriate in certain pediatric populations, such as trauma patients, but even in cases of appropriate application, the literature reports higher doses in nonchildren's hospitals [10]. Dosing levels for a common pediatric condition such as appendicitis at nonchildren's hospitals are unknown.

In our institution, a network of member hospitals anchored by an academic children's hospital integrated within its adult counterpart, a pediatric CT radiation dose reduction program was implemented in 2010. The program included standardizing pediatric CT protocols, policy implementation, staff education and training, as well as performance measurement and feedback. An institution-wide study of the program the following year found a greater than 50% reduction in CT dosing in pediatric head and abdominal scans [11]. For continued quality improvement, we assessed our current dosing for pediatric appendectomy patients and compared it to other children's hospitals and our referral nonmember hospitals (NMH). We hypothesized that the 9 children's associated, member hospitals (MH) in our system would have dosing

☆ Retrospective Comparative Study.
☆☆ Winner of PAPS prize (Clinical) 2016.
★ Financial Disclosures: None.

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http://dx.doi.org/10.1016/j.jpedsurg.2016.09.015
0022-3468/

comparable to published ranges from other children's hospital data and lower than the NMH.

1. Methods

1.1. Study setting

All patients were operated on within our institution which consists of a tertiary academic children's hospital (Children's Memorial Hermann Hospital) and 9 affiliated member hospitals within metropolitan Houston. Children were operated on at both the children's hospital and affiliated member hospitals. Nonmember hospitals included 40 independent centers (community hospitals and freestanding emergency departments) with ability to transfer pediatric patients to a MH, generally with a transfer time of less than 1 h.

1.2. Dose reduction program

Our institution's dose reduction program is an iterative process that began in 2010 with standardization of pediatric CT protocols across the hospital system. The Image Gently Alliance's recommendations were the starting point [6]. In collaboration with pediatric radiologists, dosing was systematically decreased to minimize exposure while maintaining appropriate image quality. Policies, such as saving dose profiles with each study, and procedures, such as when to abort a study owing to patient motion, were implemented. Education and training were conducted with technologists and physicians. Compliance auditing and feedback are conducted by dedicated imaging quality managers, are reviewed monthly, and continue system-wide.

1.3. Study design

A retrospective cohort study of patients <18 years undergoing appendectomy for acute appendicitis from April 2012 to April 2015 was performed. IRB approval was obtained for this study (HSC-MS-15-0330). Patients were identified as having undergone appendectomy by searching for International Classification of Diseases, 9th Revision, Clinical Modification (ICD 9-CM) procedure codes for appendectomy (470.0, 47.01, 47.09, 47.1, 47.11, 47.19, 47.2). Appendectomy for appendicitis, not as part of another procedure was confirmed by excluding those without the ICD 9-CM admission diagnosis of appendicitis (540, 540.0, 540.1, 540.9, 541). Children undergoing interval appendectomy were also excluded. Those whose CT examinations or dose reports were not available for review in our Picture Archiving and Communication System (PACS) were also excluded.

1.4. Data collection

Electronic medical records were abstracted for patient demographics, imaging location, diagnostic modality employed, and location of surgery. Imaging and operation may not have been at the same facility. Imaging was attributed to the center in which it was performed, not where the patient received surgery. For patients who underwent CT scans, the additional data collected included CT dose index by volume (CTDIvol), Dose Length Product (DLP), reference phantom size (16 cm or 32 cm), and body width (anterior–posterior and lateral diameters). Phantoms are acrylic cylinders of different widths (16 cm or 32 cm) used in the calibration of scanners.

1.5. Calculated parameters

CTDIvol is the CT scanner output in milliGray (mGy). Projected CTDIvol can be seen by the technician before starting the scan, and parameters such as pitch, voltage, rotation time, exposure time and current can be modified to change CTDIvol. DLP is the CTDIvol multiplied by the length of the scan (unit: mGy·cm). These measurements, recorded in the dose report for each CT scan, are used as Diagnostic Reference Levels (DRLs) to estimate the dose *delivered* by a scan. DRLs do not represent the dose *received* by a particular patient or body tissue, only the radiation emitted by the scanner. The American Association of Physicists in Medicine (AAPM) Task Group 204 recommends using size-specific dose estimate (SSDE) which is calculated based on the diameter of the patient [12]. The body width (anterior–posterior plus the lateral dimension) translates to a conversion factor, based on phantom size and fit equations developed by the AAPM, which is then multiplied by CTDIvol to calculate SSDE.

The patient body width (BW) was obtained with digital calipers measuring the axial image in anterior–posterior and lateral dimensions at the level of the splenic vein. This technique, recommended by the Quality Improvement Registry for CT scans in Children (QuIRCC), was used to establish reference ranges [13]. As pediatric patients, even of the same age, will have highly variable BW, this method is intended to improve the estimation of the dose received. SSDE is reported in mGy which is measure of absorbed dose whereas mSv (millisievert) refers to the biologic effect of different types of radiation. 1 mGy equals 1 mSv if the radiation type is a gamma ray. CT scans use x-ray technology, a different wavelength than gamma rays. The Effective Dose (ED), reported in mSv, is a measure of the radiation effect on tissue. ED is calculated using the DLP, the body tissue imaged, and a coefficient based on age of the patient. The benefit of the ED is that it can be compared on the same scale as other types of radiography and radiation [14].

Because the United States has no mandatory criteria for pediatric CT scans, the QuIRCC, in 2013, described Diagnostic Reference Ranges (DRRs) to address the ACR's recommendation for a national database of radiation dose indices [13]. The data the QuIRCC used to calculate DRRs were based on BW and SSDE from 4 academic children's hospitals and two pediatric sections within adult-focused hospitals using the aforementioned methods of obtaining BW [13]. DRRs are reported as the interquartile range, 25th to 75th percentile, of the ED and SSDE.

In our audit process, our institution uses 20 mGy as the dose threshold for pediatric abdominal CTs, based on the ACR's pass/fail criteria for a 5 year old abdomen [11, 15]. Background radiation per year in the United States is 3 mSv. Radiation greater than 100 mSv has a strongly established risk of cancer, with an estimated 1 in 1000 patients developing a cancer from only a 10 mSv exposure [16].

1.6. Statistical analysis

Descriptive statistics were used to characterize the study population. Patients were stratified by age group (1–5, 6–12 and 13–17 years old). Chi-square, Student's t-test, and analyses were performed. A p-value <0.05 was considered statistically significant. All statistical analyses were performed using STATA 13.1 (College Station, TX).

2. Results

During the study period, 1736 pediatric patients underwent appendectomies in our system, 17% (n = 288) of whom were transferred from an NMH. The majority of patients (65%, n = 1128) underwent CT: 992 (69%) of patients at MH were scanned vs 136 (47%) of NMH patients. Images and dose reports were available for 94% (n = 936) of MH patients and 75% (n = 102) of NMH patients (Fig. 1).

Overall, NMH patients were slightly younger and more had commercial insurance (Table 1). Among those who received a CT, there was no difference in gender, race, or insurance status. Controlling for age, MH and NMH patients did not differ in weight or body width (Table 2).

2.1. Local hospital comparison

Even though NMH patients tended to be younger, the average SSDE was still higher (Table 3). Controlling for age, younger children (≤ 5 years of age) did not receive higher doses at NMHs. However, school