# Pediatric Radiation Exposure During the Initial Evaluation for Blunt Trauma

*Deborah L. Mueller, MD, Mustapha Hatab, PhD, Rani Al-Senan, MS, Stephen M. Cohn, MD, Michael G. Corneille, MD, Daniel L. Dent, MD, Joel E. Michalek, PhD, John G. Myers, MD, Steven E. Wolf, MD, and Ronald M. Stewart, MD*

**Background:** Increased utilization of computed tomography (CT) scans for evaluation of blunt trauma patients has resulted in increased doses of radiation to patients. Radiation dose is relatively amplified in children secondary to body size, and children are more susceptible to long-term carcinogenic effects of radiation. Our aim was to measure radiation dose received in pediatric blunt trauma patients during initial CT evaluation and to determine whether doses exceed doses historically correlated with an increased risk of thyroid cancer.

**Methods:** A prospective cohort study of patients aged 0 years to 17 years was conducted over 6 months. Dosimeters were placed on the neck, chest, and groin before CT scanning to measure surface radiation. Patient measurements and scanning parameters were collected prospectively along with diagnostic findings on CT imaging. Cumulative effective whole body dose and organ doses were calculated.

**Results:** The mean number of scans per patient was 3.1 ± 1.3. Mean whole body effective dose was 17.43 mSv. Mean organ doses were thyroid 32.18 mGy, breast 10.89 mGy, and gonads 13.15 mGy. Patients with selective CT scanning defined as ≤2 scans had a statistically significant decrease in radiation dose compared with patients with >2 scans.

**Conclusions:** Thyroid doses in 71% of study patients fell within the dose range historically correlated with an increased risk of thyroid cancer and whole body effective doses fell within the range of historical doses correlated with an increased risk of all solid cancers and leukemia. Selective scanning of body areas as compared with whole body scanning results in a statistically significant decrease in all doses.

**Key Words:** Radiation, CT, Computed tomography, Pediatric, Trauma.

(*J Trauma.* 2011;70: 724–731)

Computed tomography (CT) fundamentally changed the practice of medicine, and specifically the evaluation of injured patients. As CT technology evolved, scans could be obtained expeditiously with superb anatomic detail. However, the ionizing radiation dose a patient receives from CT imaging varies from 100 to 1,000 times the dose delivered by standard conventional radiographs.[1] In quantitative animal tumorigenesis and human epidemiologic studies, low-level ionizing radiation acts as a tumor initiator through damage to DNA.[2] The most recent comprehensive assessment of the health risks from exposure to low levels of ionizing radiation is known as the Biological Effects of Ionizing Radiation (BEIR) VII Phase 2 report, which was published in 2006 by the National Research Council of the National Academy of Sciences. The committee defined low dose as a range of near zero to 100 milliSievert (mSv). For perspective, recent studies showed that ionizing radiation effective doses range from 0.3 mSv to 90 mSv for typical CT scans obtained in trauma patients.[3] The BEIR VII Phase 2 report committee concluded that current scientific evidence supports a linear, no-threshold dose-response relationship between exposure to ionizing radiation and the development of cancer in humans.

Utilization of CT in blunt trauma evaluation has increased over time and the liberal use of whole body imaging with CT scanning has been promoted in adult trauma patients.[4] The carcinogenic risk of the radiation dose delivered with imaging tests for blunt trauma evaluation has rarely been considered to outweigh the benefit of the clinical information garnered. In one study of adult trauma patients, radiation dose and excess lifetime cancer mortality was estimated but clinical information gained from scanning was not reported.[5] Children are particularly susceptible to long-term carcinogenic effects of ionizing radiation secondary to body size and years of life remaining in which to develop cancer. Lifetime risk of all solid tumors and leukemia and associated death increases with lower age and exposure to low-level ionizing radiation.[2] Retrospectively, in pediatric trauma patients, Kim et al.[6] estimated total effective dose by reviewing radiology records of children admitted to a pediatric Level I trauma center. However, direct measurements of exposure were not performed. This knowledge is critical in assessing risk of radiation exposure. Therefore, we undertook this study to prospectively measure and calculate radiation dose in pediatric patients undergoing initial evaluation for blunt trauma. We sought to evaluate ionizing radiation exposure and diagnostic benefit of our current imaging practices in children. We hypothesized that radiation doses exceed doses historically shown to correlate with an increased risk of thyroid cancer.

Submitted for publication July 31, 2010.
Accepted for publication November 29, 2010.

From the Departments of Surgery (D.L.M., S.M.C., M.G.C., D.L.D., J.G.M., S.E.W., R.M.S.), Radiology (M.H., R.A.S.), and Epidemiology and Biostatistics (J.E.M.), University of Texas Health Science Center, San Antonio, Texas.
Presented at the 40th Annual Meeting of the Western Trauma Association, February 28–March 6, 2010, Telluride, Colorado.
Address for reprints: Deborah L. Mueller, MD, 7703 Floyd Curl Drive, Mail Code 7740, San Antonio, TX; email: muellerd@uthscsa.edu.

DOI: 10.1097/TA.0b013e3182092ff8

## PATIENTS AND METHODS

We performed a prospective study of pediatric blunt trauma patients defined as younger than 18 years during a 6-month period from February to August 2009 at University Hospital, San Antonio, TX, the Level I trauma center affiliated with the University of Texas Health Science Center at San Antonio. Only pediatric blunt trauma patients arriving Priority 1, resulting in full activation of the trauma team, were included. Hemodynamically unstable patients, defined as patients with cardiopulmonary resuscitation in progress or the need for immediate operative intervention, were excluded. The study was approved by the UTHSCSA Institutional Review Board as an expedited minimal risk protocol with waiver of documentation of informed consent.

After completion of the primary and secondary survey including plain film radiographs, three optically stimulated luminescence (OSL) dosimeters (Landauer NanoDot Glenwood, IL) were placed in standardized locations on the neck, chest, and groin with tape by study personnel. Further diagnostic imaging with CT was completed based on the clinical scenario and judgment of the trauma team as no pediatric imaging protocols were in place. Demographic information, mechanism of injury, physical examination findings, Glasgow Coma Score, radiographic studies ordered, and CT scanning parameters such as voltage (kVp) and tube current second (mAs) were gathered prospectively. Torso length and chest circumference were measured in all patients. The majority of CT scans were performed on a 16-slice CT scanner (Philips Healthcare, Andover, MA) located in the emergency department. Two patients had eight CT scans performed in the radiology department on a 64-slice CT scanner (Philips Healthcare, Andover, MA). Dosimeters were removed on completion of CT imaging in the resuscitation room. Dosimeters were read using a computer based on-site reader (Landauer MicroStar InLight System, Glenwood, IL).

The OSL dosimeters measured surface skin doses at specific locations. Organ doses which are affected by depth from the skin surface, the ratio of energy imparted to the mass of the organ, and radiosensitivity factors were calculated using the prospectively collected scanning parameters by the ImPACT CT dosimetry spreadsheet (ImPACT CT Patient Dosimetry Calculator, St. George's Healthcare NHS Trust, London, UK) method in the Department of Radiology Clinical Medical Physics Section. Effective dose, defined by the International Commission on Radiologic Protection (ICRP) as the tissue-weighted sum of the equivalent doses in all specified tissues and organs of the body was also calculated utilizing ICRP 60 values.[7] Effective dose reflects the risk of nonuniform exposure in terms of a whole body exposure and allows comparison across various diagnostic imaging procedures and to historical cohorts of ionizing radiation exposure.[8] ImPACT software provides dose values for an average adult which then can be age-normalized to provide pediatric effective doses reflecting the higher radiation dose received because of the smaller body habitus of our cohort.

Radiologic reports were reviewed and findings were classified as traumatic or atraumatic. Traumatic injuries included intracavitary injuries or bony fractures while soft tissue swelling and lacerations obvious on physical examination were not considered positive findings on CT scans. Data are presented as mean ± 95% confidence intervals. Statistical significance was considered at $p < 0.05$ for all comparisons. Statistical analysis was performed with SAS version 9.2 for Windows (SAS Institute, Cary, NC).

## RESULTS

During the study period, 510 pediatric blunt trauma patients arrived Priority 1 (Fig. 1). CT imaging was not performed in 123 patients. The majority of patients who did not require CT were transferred to our trauma center from outside facilities with imaging already completed or for isolated injuries requiring pediatric subspecialty surgical care. CT imaging was obtained in 387 patients; 55% (n = 213) were enrolled. Analysis included 197 subjects with complete data and dosimetry results available.

Characteristics of the study population are presented in Table 1. The mean age of study subjects was 9 years ± 6 years; 82 (42%) were aged 0 years to 5 years, the most vulnerable group for ionizing radiation exposure. The most common mechanisms of injury were motor vehicle crashes in 37% and falls in 32%. Mechanisms classified as other included all terrain vehicle crashes and recreational-related injuries. The Glasgow Coma Score was 15 in 83% of the study population and the mean Injury Severity Score was 6.3 ± 7.2 while 16% had an Injury Severity Score >15. Twenty-one percent of patients were discharged from the emergency room after evaluation.

A total of 619 CT scans were obtained in the study population for a mean number of scans per patient of 3.1 ± 1.3. The most common type of CT scan obtained was of the head in 97%, followed by abdomen/pelvis 69%, chest 63%, neck 61%, and face 17%. Twelve patients (6%) had duplicate

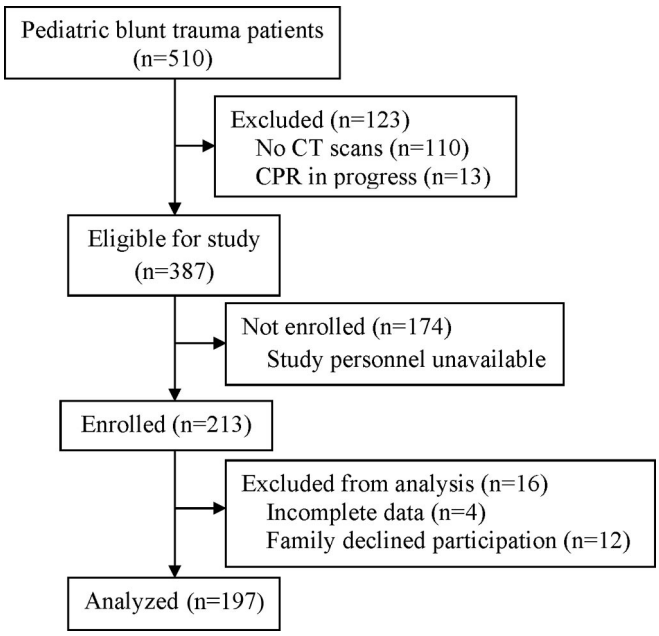


**Figure 1.** Patient flow chart.

**TABLE 1.** Demographic Table

| Demographic | N (%) |
|---|---|
| Age, mean ± SD (yr) | 9 ± 6 |
| 0–5 | 82 (41.6) |
| 6–10 | 27 (13.7) |
| 11–15 | 48 (24.4) |
| >15 | 40 (20.3) |
| Male | 119 (60.4) |
| Female | 78 (39.6) |
| Mechanism | |
| MVC | 73 (37.1) |
| Fall | 63 (32) |
| MV pedestrian | 21 (10.7) |
| Assault | 10 (5.1) |
| Other | 30 (15.2) |
| Glasgow Coma Scale score | |
| 13–15 | 180 (91.4) |
| 9–12 | 8 (4.1) |
| 3–8 | 9 (4.6) |
| Disposition | |
| Admitted | |
| Floor | 103 (52.3) |
| PICU | 45 (22.8) |
| OR | 7 (3.6) |
| Home | 42 (21.3) |
| Injury Severity Score, mean ± SD | 6.3 ± 7.2 |

MVC, motor vehicle collision; PICU, pediatric intensive care unit; OR, operating room.

**TABLE 2.** Injuries Identified by CT Scan

| Injuries Identified by CT Scan | N (%) |
|---|---|
| Head CT | |
| Subarachnoid hemorrhage | 11 (5.6) |
| Cerebral contusion | 13 (6.6) |
| Subdural hematoma | 8 (4.1) |
| Epidural hematoma | 6 (3) |
| Skull fracture | 41 (20.8) |
| Neck CT | |
| Fracture | 3 (1.5) |
| Spinal cord compression | 1 (0.5) |
| Vascular injury | 0 (0) |
| Chest CT | |
| Rib fracture | 5 (2.5) |
| Hemothorax/pneumothorax | 12 (6.1) |
| Lung contusion | 20 (10.2) |
| Thoracic spine injury | 3 (1.5) |
| Aortic injury | 0 (0) |
| Abdominal/Pelvis CT | |
| Liver injury | 2 (1) |
| Splenic injury | 2 (1) |
| Kidney injury | 1 (0.5) |
| Pancreatic injury | 1 (0.5) |
| Possible small bowel injury | |
| Isolated free fluid | 3 (1.5) |
| Small bowel thickening | 1 (0.5) |
| Free air | 1 (0.5) |
| Mesenteric stranding | 1 (0.5) |
| Lumbar spine injury | 6 (3) |
| Pelvic fracture | 5 (2.5) |

imaging of a body area secondary to noninterpretable studies from movement during the initial examination. Whole body CT scans defined as head, neck, chest, abdomen, and pelvis scans were obtained in 96 (49%) children. Traumatic injuries were identified in 120 of 619 scans (19%) with positive scans for 50% (18 of 36) of face, 24% (49 of 201) of head, 23% (28 of 123) of chest, 15% (21 of 136) of abdomen/pelvis, and 3% (4 of 123) of neck scans. Injuries identified by CT scans are shown in Table 2.

Skin surface dosimetry results as measured by the OSL dosimeters in specific locations with patients classified according to the total number of scans obtained are provided in Table 3. Neck skin surface dose continues to rise with the increasing number of CT scans performed due to overlapping imaging with resultant increasing radiation exposure to the neck when scanning the head, face, neck, and chest simultaneously. Chest and groin skin surface measurements increase more modestly with an increasing number of scans but seem to plateau once a decision has been made to scan the chest and/or the abdomen/pelvis (Fig. 2).

Total effective dose and organ dose for the thyroid, breast and gonads calculated from the ImPACT CT Patient Dosimetry Calculator with patients classified according to number of scans is presented in Table 4. The mean effective dose for the entire study cohort was 17.43 mSv (range, 0.05–59.72 mSv). Similar to neck skin surface dose measurements, the calculated thyroid dose continued to rise with the increasing number of CT scans performed. The mean organ dose for the thyroid was 32.18 mGy (range, 0.07–174.3 mGy), breast 10.89 mGy (range, 0.01–38.55 mGy), and gonads 13.15 mGy (range, 0–42.99 mGy) in all patients (Table 5 and Fig. 3). Correlation between dosimeter measurements and calculated organ doses were performed and $r$ values were 0.82, 0.9, and 0.91 at the neck/thyroid, chest/breast, and groin/gonad sites, respectively. Substratification into groups comparing patients with less than or equal to two body areas scanned and more than two body areas scanned demonstrate a statistically significant increase in total effective dose and all organ doses (Table 6).

**TABLE 3.** Dosimeter Results

| No. of CTs | Patients | Neck* (mGy) | Chest* (mGy) | Groin* (mGy) |
|---|---|---|---|---|
| 1 | 34 | 2.97 ± 6.59 | 1.55 ± 4.03 | 0.58 ± 1.83 |
| 2 | 27 | 14.89 ± 11.9 | 5.2 ± 10.21 | 3.56 ± 7.15 |
| 3 | 37 | 15.76 ± 8.3 | 14.69 ± 10.94 | 10.14 ± 7.09 |
| 4 | 77 | 27.87 ± 12.64 | 21 ± 9.54 | 12.64 ± 5.44 |
| 5 | 20 | 35.43 ± 17.31 | 26.25 ± 14.05 | 13.55 ± 6.31 |
| 6 | 2 | 51.5 ± 7.4 | 23.83 ± 8.98 | 11.36 ± 6.04 |
| | $p$ value† | <0.001 | 0.004 | 0.024 |

* Mean ± 1 SD.
† Unadjusted Wald test for linear trend (SAS version 9.2 for Windows).

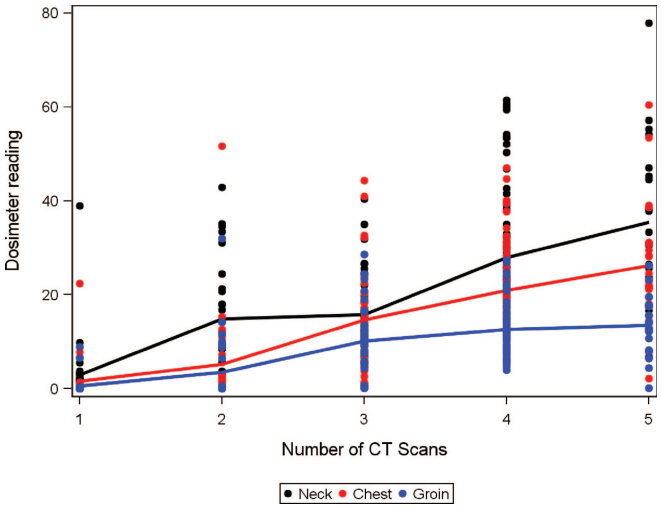


**Figure 2.** Dosimeter reading is plotted versus the number of CT scans for all subjects (n = 197), color coded by anatomical site. Overlaid line segments indicate mean dosimeter readings by site.

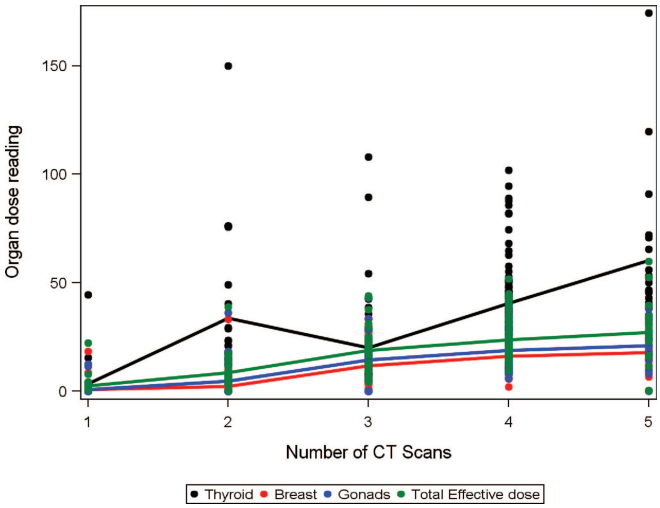


**Figure 3.** Organ dose reading is plotted versus the number of CT scans for all subjects (n = 197), color coded by anatomical site. Overlaid line segments indicate mean organ dose readings by site.

## DISCUSSION

CT scanning has an established role in the evaluation of blunt trauma patients. Refinements in CT technology have led to excellent imaging for the diagnosis of many traumatic injuries such as solid organ injury, spine fracture, and blunt aortic injury (BAI). However, this comes with a risk of significantly increased ionizing radiation exposure; children in particular are more susceptible to the carcinogenic risk of radiation.

Multiple authors have documented significant growth in the utilization of CT scanning for pediatric patients.[9–11] Broder et al.[9] showed a marked increase in the use of CT for all patients presenting to a pediatric emergency room over a 6-year period. Most notable were the increases in neck and chest CT scans of 366% and 435%, respectively, despite only a 2% increase in patient volume over the same time frame and no change in patient triage acuity. Markel et al.[10] documented a more modest but statistically significant increase of 5% in

**TABLE 4.** Organ Dose and Total Effective Dose

| No. of CTs | Patients | Thyroid* (mGy) | Breast* (mGy) | Gonad* (mGy) | Effective Dose* (mSv) |
|---|---|---|---|---|---|
| 1 | 34 | 3.47 ± 7.69 | 0.86 ± 3.43 | 0.71 ± 2.88 | 2.49 ± 3.77 |
| 2 | 27 | 33.63 ± 34.61 | 2.36 ± 6.52 | 4.59 ± 8.92 | 8.48 ± 7.54 |
| 3 | 37 | 19.95 ± 22.42 | 11.66 ± 9.77 | 14.38 ± 10.39 | 18.91 ± 9.49 |
| 4 | 77 | 40.54 ± 20.44 | 16.1 ± 6.85 | 18.79 ± 8.55 | 23.61 ± 8.52 |
| 5 | 20 | 60.22 ± 34.29 | 17.85 ± 8.7 | 21.11 ± 9.19 | 27.15 ± 14.52 |
| 6 | 2 | 124.45 ± 18.17 | 11.9 ± 1 | 20.27 ± 12.99 | 29.38 ± 7.91 |
| | *p* value† | 0.018 | 0.052 | 0.006 | 0.001 |

* Mean ± 1 SD.
† Unadjusted Wald test for linear trend (SAS version 9.2 for Windows).

**TABLE 5.** Dosimeter (mGy), Organ Dose (mGy), and Effective Dose (mSv) for Entire Cohort

| Entire Group | N | Mean | Median | Minimum | Maximum |
|---|---|---|---|---|---|
| Neck dosimeter entire cohort | 197 | 20.52 | 17.99 | 0.39 | 77.91 |
| Chest dosimeter entire cohort | 196 | 14.85 | 14.17 | 0.1 | 60.48 |
| Groin dosimeter entire cohort | 197 | 8.93 | 9.09 | 0.05 | 32 |
| Thyroid dose entire cohort | 197 | 32.18 | 25.63 | 0.07 | 174.3 |
| Breast dose entire cohort | 197 | 10.89 | 11.46 | 0.01 | 38.55 |
| Gonad dose entire cohort | 197 | 13.15 | 13.69 | 0 | 42.99 |
| Total effective dose entire cohort | 197 | 17.43 | 17.94 | 0.05 | 59.72 |

**TABLE 6.** Organ Dose (mGy) and Effective Dose (mSv) by Number of Scans

| | Number of Scans | | |
|---|---|---|---|
| **Location** | **≤2** | **>2** | ***p* Value*** |
| Thyroid | | | <0.001* |
| N | 61 | 136 | |
| Mean (SD) | 16.82 (27.92) | 39.07 (28.51) | |
| Median | 2.7 | 35.02 | |
| Min, Max | 0.07, 149.8 | 4.3, 174.3 | |
| Breast | | | <0.001* |
| N | 61 | 136 | |
| Mean (SD) | 1.52 (5.05) | 15.09 (8.22) | |
| Median | 0.11 | 14.37 | |
| Min, Max | 0.01, 33.23 | 0.07, 38.55 | |
| Gonads | | | <0.001* |
| N | 61 | 136 | |
| Mean (SD) | 2.43 (6.54) | 17.95 (9.41) | |
| Median | 0 | 16.84 | |
| Min, Max | 0, 36.18 | 0, 42.99 | |
| Total effective dose | | | <0.001† |
| N | 61 | 136 | |
| Mean (SD) | 5.14 (6.44) | 22.94 (10.15) | |
| Median | 2.95 | 20.91 | |
| Min, Max | 0.05, 38.85 | 0.18, 59.72 | |

* Based on a repeated measures linear model with a compound symmetric autocorrelation matrix (SAS version 9.2 for Windows).
† Two-sample Wilcoxon test (SAS version 9.2 for Windows).

the use of chest CT for the evaluation of pediatric blunt trauma patients over a 5-year period. Interestingly, they concurrently showed a 28% decrease in the utilization of an initial chest X-ray, a study with a fraction of the ionizing radiation exposure. Using a national database, Blackwell et al.[11] demonstrated an increase in the use of head CT for closed head trauma in children of 9.6%. It appears that as CT scans have become quicker to obtain, clinicians have become quicker to use them.

In 2004, Fenton et al.[12] suggested that we may be "overdoing it" with CT scan and the pediatric blunt trauma patient. In that retrospective review, 1,422 children received 2,361 scans or 1.7 scans per patient and 54% of scans were interpreted as normal. Our much smaller, yet prospective study, showed even more extensive CT scanning tendencies with 3.1 scans per patient with 81% of scans considered normal. The consequential mean total effective dose of ionizing radiation due to CT scanning in our study was 17.43 mSv (range, 0.05–59.7 mSv). This dose was 17% greater than the 14.9 mSv total effective dose previously estimated by Kim et al.[6] retrospectively in a study of pediatric trauma patients.

Multiple authors estimated the risks of radiation-induced cancer from pediatric CT using risk projection models found in the BEIR VII Phase 2 report.[13–15] In a comprehensive analysis based on type of CT scan stratified for age and gender during the examination, Berrington de Gonzalez et al.[13] published the most detailed risk estimates in children to date. According to their model, 3-year-old girls and boys have a 1 in 166 and a 1 in 333 mean lifetime cancer risk, respectively, after whole body CT scan. At 15 years of age, the risks were estimated at 1 in 250 for girls and 1 in 500 for boys. The mean lifetime cancer risk continues to decline with age and averages ~1 in 1,500 for all adults undergoing whole body scan. Multiple authors touted the benefit of whole body scanning in adult blunt trauma patients and the benefit potentially outweighs the risk of radiation-induced cancer given their lower radiation risk profile and the difficulty obtaining adequate plain film imaging of areas like the cervical spine.[4,16] However, as ionizing radiation induced lifetime cancer risk estimates demonstrate, children are not simply little adults.

In regards to specific organ dose and cancer risk, our study demonstrated that mean thyroid dose was 32.18 mGy. In a pooled analysis of five cohort studies of thyroid cancer developing after childhood exposure to external radiation, Ron et al.[17] showed an increased risk of thyroid cancer (RR = 2.5; 95% CI = 2–4) at a mean dose to the thyroid of 50 mGy (range, 10–90 mGy). In our study cohort, 141 patients or 71% had a thyroid dose in the range of 10 mGy to 90 mGy and 38 patients (19%) exceeded a dose of 50 mGy. In a recent review of the National Cancer Institute Surveillance, Epidemiology, and End Results database, Hogan et al.[18] note concern about an annual increase of 1.1% in the incidence of pediatric thyroid cancer between the years of 1973 and 2004. Although no etiology can be linked to this increasing incidence, the authors note that childhood exposure to ionizing radiation is a well-established risk factor for the development of well-differentiated thyroid cancer.

Three methods to reduce radiation dose from CT were suggested by Brenner and Hall[15] in their article highlighting the radiation risks of CT. Individual patient dose can be significantly lowered by changing scanning parameters such as tube current in pediatric patients. Likewise, alternative imaging techniques such as ultrasound and magnetic resonance imaging may be used if appropriate. Finally, and most effectively, they suggest would be to decrease the number of CT studies obtained. The remainder of this discussion will focus on achieving this last recommendation in the pediatric blunt trauma patient as our results demonstrated a statistically significant decrease in radiation dose by limiting body areas scanned.

Head CT was the most commonly ordered scan in our study population. Kuppermann et al.[19] recently derived and analyzed clinical prediction rules for clinically important traumatic brain injury stratified by age (<2 years and ≥2 years) in more than 42,000 children in 25 emergency departments as part of the work of the Pediatric Emergency Care Applied Research Network. The derived clinical prediction rule in the preverbal group (<2 years) when validated had a negative predictive value of 100% (95% CI, 99.7–100.0) and a sensitivity of 100% (95% CI, 86.3–100.0). In the age group ≥2 years, negative predictive value was 99.95% (95% CI, 99.81–99.99) and sensitivity was 96.8% (95% CI, 89.0–99.6). No clinical prediction rule will be perfect, nor completely supplant astute clinical decision making, but it might help decrease overzealous utilization of head CT scans.

In adult trauma patients, increased utilization of cervical spine CT and chest CT have evolved secondary to their superiority in screening for spine fractures and BAI. Importantly, children, especially the very young, rarely sustain these injuries. In a retrospective review of evaluation for cervical spine injury in children younger than 5 years, Hernandez et al.[20] demonstrated that all children with an injury had an abnormal lateral plain film of their cervical spine. The authors suggest limiting CT scans of the cervical spine to those patients younger than 5 years who warrant screening and also have an initial abnormal lateral plain film, inadequate visualization of the lower cervical spine on plain film, or are unconscious. In a review of the National Trauma Databank, Heckman et al.[21] recorded an incidence of BAI of only 0.02% in 16,703 children younger than 14 years. Independent predictors of pediatric BAI were severe injury to the head, thorax, abdomen/pelvis, or lower extremities. If CT scans of the neck and chest have increased in pediatric blunt trauma patients to screen for these injuries, knowledge of their rarity, age predilection, and typical clinical scenario should allow for more judicious use of these studies.

In regards to face and abdomen/pelvis CT, reasonable alternatives exist to imaging with CT scan in some patients. Marinaro et al.[22] found head CT alone was both sensitive (90%) and specific (95.1%) for identifying nonnasal bone midfacial fractures in patients who received both a head CT and facial CT. Although five head CTs were falsely negative, none of the subsequently identified fractures on facial CT required any intervention. Multiple authors have examined the use of ultrasound for pediatric abdominal trauma.[23–25] Although children seem to have an ideal body habitus for sonography, a meta-analysis of 25 studies of ultrasound to detect intra-abdominal fluid in pediatric blunt trauma revealed a sensitivity of 80% and a specificity of 96%.[26] The authors attribute this lower sensitivity as compared with adult ultrasound to the need to detect a smaller amount of fluid in children and to the fact that a fair amount of intra-abdominal injuries exist without hemoperitoneum. When limiting the analysis to the strictest methodologic studies which they defined as having a definitive criterion standard test (CT scan, laparotomy, or diagnostic peritoneal lavage) sensitivity dropped to 66% for detection of hemoperitoneum, whereas specificity was 95%. The real question though is whether any of the missed injuries were clinically significant. Perhaps, there is a subset of the pediatric blunt trauma patient population in which ultrasound combined with physical examination and screening laboratory values could avoid abdominal CT that has yet to be clearly identified.

The primary objective of our study was to prospectively measure and calculate the ionizing radiation exposure of pediatric blunt trauma patients during their initial evaluation. While radiation exposure has been measured in adults, the current pediatric trauma literature only gives estimates based on average doses seen with particular types of scans. The true ionizing radiation exposure can vary substantially based on scanning parameters and in a recent study of adult doses a 13-fold variation was seen in dose within each type of CT study and across four institutions using the same type of CT scanner.[3] For this reason, we think our study most accurately reflects the current ionizing radiation dose in children undergoing CT scanning after blunt trauma.

Our study had several limitations. First, our institution routinely used automatic exposure control techniques while scanning to preserve image quality while lowering radiation dose. At the beginning of our study, the radiology department adopted a more aggressive protocol for lowering dose based on the Image Gently campaign promoted by The Alliance for Radiation Safety in Pediatric Imaging.[27] Therefore, our doses may be some of the lowest doses achievable and not reflective of institutions without strict radiation dose reduction protocols for CT scanning in children. The majority of study scans were completed with a 16-slice CT scanner, so radiation doses in the study may not represent doses received with other CT scan models. Additionally, we included subjects who were transferred to our facility sometimes with accompanying outside CT images. We did not repeat CT scans in this subset unless absolutely necessary and did not assess radiation dose from outside scans. This subset of 56 patients had fewer scans performed with a mean number of scans per patient of $2.3 \pm 1.3$. Because these patients were scanned less, their inclusion would lead to an underestimation of total effective dose as compared with including only patients presenting directly from the scene of injury. Despite our use of dose reduction CT scanning protocols and inclusion of the transferred patients who underwent more limited CT imaging, we still found a higher total effective dose in the entire cohort than estimated previously. We did not capture 100% of the eligible population secondary to study personnel availability which could introduce bias; however, in our opinion the sample is representative of our practice. Although we measured and calculated radiation exposure, we did not estimate lifetime-attributable risk of cancer as extensive work has been published on these risks already. In general, for children undergoing whole body CT scanning, the lifetime-attributable risk of cancer has been estimated between 0.2% and 0.6%.[13] The risk increases with decreasing age and with increasing dose.

## CONCLUSION

The total effective dose of ionizing radiation due to CT scanning during the initial evaluation of pediatric blunt trauma falls within the range of historical doses shown to correlate with an increased risk of all solid cancers and leukemia. Specifically, thyroid doses in 71% of our cohort fell within the dose range historically correlated with an increased risk of thyroid cancer. Selective scanning of body areas as compared with whole body scanning results in a statistically significant decrease in all organ doses and total effective dose. Future investigation should focus on continued development and refinement of clinical decision rules for obtaining different types of CT scans in the very young to reduce unnecessary CT scans and radiation exposure while preserving diagnostic accuracy of serious injuries.

 

## ACKNOWLEDGMENTS

*We thank the research staff of the Division of Trauma and Emergency Surgery and Biostatistician Prakash Nair for their assistance with this project.*

## REFERENCES

1. Mettler FA Jr, Huda W, Yoshizumi TT, Mahesh M. Effective doses in radiology and diagnostic nuclear medicine: a catalog. *Radiology.* 2008; 248:254–263.
2. Board of Radiation Effects Research Division on Earth and Life Sciences National Research Council of the National Academies. *Health Risks From Exposure to Low Levels of Ionizing Radiation: BEIR VII Phase 2.* Washington, DC: National Academies Press; 2006.
3. Smith-Bindman R, Lipson J, Marcus R, et al. Radiation dose associated with common computed tomography examinations and the associated lifetime attributable risk of cancer. *Arch Intern Med.* 2009;169:2078–2086.
4. Salim A, Sangthong B, Martin M, Plurad D, Demetriades D. Whole body imaging in blunt multisystem trauma patients without obvious signs of injury. *Arch Surg.* 2006;141:468–475.
5. Tien HC, Tremblay LN, Rizoli SB, et al. Radiation exposure from diagnostic imaging in severely injured trauma patients. *J Trauma.* 2007;62:151–156.
6. Kim PK, Zhu X, Houseknecht E, Nickolaus D, Mahboubi S, Nance ML. Effective radiation dose from radiologic studies in pediatric trauma patients. *World J Surg.* 2005;29:1557–1562.
7. International Commission on Radiological Protection. 1990 Recommendations of the international commision on radiologic protection. *Ann ICRP* 1991;21:publication no. 60.
8. McCollough CH, Schueler BA. Calculation of effective dose. *Med Phys.* 2000;27:828–837.
9. Broder J, Fordham LA, Warshauer DM. Increasing utilization of computed tomography in the pediatric emergency department, 2000–2006. *Emerg Radiol.* 2007;14:227–232.
10. Markel TA, Kumar R, Koontz NA, Scherer LR, Applegate KE. The utility of computed tomography as a screening tool for the evaluation of pediatric blunt chest trauma. *J Trauma.* 2009;67:23–28.
11. Blackwell CD, Gorelick M, Holmes JF, Bandyopadhyay S, Kuppermann N. Pediatric head trauma: changes in use of computed tomography in emergency departments in the United States over time. *Ann Emerg Med.* 2007;49:320–324.
12. Fenton SJ, Hansen KW, Meyers RL, et al. CT scan and the pediatric trauma patient—Are we overdoing it? *J Pediatr Surg.* 2004;39:1877–1881.
13. Berrington de Gonzalez A, Mahesh M, Kim KP, et al. Projected cancer risks from computed tomographic scans performed in the United States in 2007. *Arch Intern Med.* 2009;169:2071–2077.
14. Brenner DJ, Elliston CD, Hall EJ, Berdon W. Estimated risks of radiation-induced fatal cancer from pediatric CT. *AJR Am J Roentgenol.* 2001;176:289–296.
15. Brenner DJ, Hall EJ. Computed tomography—An increasing source of radiation exposure. *N Engl J Med.* 2007;357:2277–2284.
16. Huber-Wagner S, Lefering R, Qvick LM, et al. Effect of whole-body CT during trauma resuscitation on survival: a retrospective, multicentre study. *Lancet.* 2009;373:1455–1461.
17. Ron E, Lubin JH, Shore RE, et al. Thyroid cancer after exposure to external radiation: a pooled analysis of seven studies. *Radiat Res.* 1995;141:259–277.
18. Hogan AR, Zhuge Y, Perez EA, Koniaris LG, Lew JI, Sola JE. Pediatric thyroid carcinoma: incidence and outcomes in 1753 patients. *J Surg Res.* 2009;156:167–172.
19. Kuppermann N, Holmes JF, Dayan PS, et al. Identification of children at very low risk of clinically-important brain injuries after head trauma: a prospective cohort study. *Lancet.* 2009;374:1160–1170.
20. Hernandez JA, Chupik C, Swischuk L. Cervical spine trauma in children under 5 years: productivity of CT. *Emerg Radiol.* 2004;10:176–178.
21. Heckman SR, Trooskin SZ, Burd RS. Risk factors for blunt thoracic aortic injury in children. *J Pediatr Surg.* 2005;40:98–102.
22. Marinaro J, Crandall CS, Doezema D. Computed tomography of the head as a screening examination for facial fractures. *Am J Emerg Med.* 2007;25:616–619.
23. Katz S, Lazar L, Rathaus V, Erez I. Can ultrasonography replace computed tomography in the initial assessment of children with blunt abdominal trauma? *J Pediatr Surg.* 1996;31:649–651.
24. Thourani VH, Pettitt BJ, Schmidt JA, Cooper WA, Rozycki GS. Validation of surgeon-performed emergency abdominal ultrasonography in pediatric trauma patients. *J Pediatr Surg.* 1998;33:322–328.
25. Holmes JF, Brant WE, Bond WF, Sokolove PE, Kuppermann N. Emergency department ultrasonography in the evaluation of hypotensive and normotensive children with blunt abdominal trauma. *J Pediatr Surg.* 2001;36:968–973.
26. Holmes JF, Gladman A, Chang C. Performance of abdominal ultrasonography in pediatric blunt trauma patients: a meta-analysis. *J Pediatr Surg.* 2007;42:1588–1594.
27. How to develop ct protocols for children [Image Gently Web site]. December 11, 2007. Available at: http://spr.affiniscape.com/associations/5364/files/Protocols.pdf.

## EDITORIAL COMMENT

Computed tomographic (CT) imaging has revolutionized medicine and trauma. Readily available in most centers, CT scanning can quickly and noninvasively provide vital information about potentially fatal or serious injuries and has greatly facilitated the increased use of nonoperative management.

Unfortunately, CT is not without harm. Although the precise risks of diagnostic radiation remain a matter of debate, it is universally acknowledged that radiation can injure tissues, is a risk factor for cancer, and that children are more susceptible to radiation harms and more likely to live long enough to suffer the consequences.[1] As such, public and medical authorities have recently raised the alarm that unless we start incorporating the risk of radiation into our decision making and start paying greater attention to minimize diagnostic radiation exposures, our patients may pay a significant price with cancers in the years to come.[2]

However, in the trauma bay, balancing small future risks versus the potentially large and immediate benefits of quickly identifying morbid or lethal injuries is not easily done. There are few studies to guide us as to the risk of CT versus not for different trauma populations, and invariably, even the radiation dose of the CTs we order in our institutions—key for determining risk—is unbeknownst to us.

In this issue, Mueller et al.[3] add to our understanding with a prospective study in which the radiation dose from initial trauma CTs in children was measured. Despite limitations such as the scanner used (predominantly a 16 slice) and other factors (e.g., software and protocols) that preclude direct extrapolation of their findings to other settings, this study does provide a more contemporary and accurate assessment of radiation dose with pediatric trauma assessments than previous retrospective reviews. Moreover, findings of Mueller et al. that children with a low mean ISS of 6 were exposed to a mean whole body effective dose of 17 milliSieverts (with 71% of patients exceeding thresholds associated with thyroid cancer) should give us pause. This dose is higher than previous retrospective studies despite including only admission CTs (thereby underestimating total radiation exposure) and was associated with fewer positive findings (only 19% of scans) and very few high-risk findings. As such, this study supports the notion that scanning has become more indiscrim-

 

inate, and that radiation exposure could be reduced, if fewer CTs were targeted to those more likely to benefit.[4–6]

In summary, although CT provides timely and useful information to reduce trauma morbidity and mortality, studies such as that by Mueller et al. suggest significant opportunities remain to reduce and better track radiation exposure. Although technological advancements and standardization will certainly help, better protocols are also needed to improve clinical decision making and reduce the cost and harms of excessive testing, as is better education of both patients and their doctors as to the risks and benefits of CT.

**Lorraine N. Tremblay, MD, PhD, FACS, FRCSC**
Department of Surgery & Critical Care Medicine
Sunnybrook Health Sciences Centre
University of Toronto
Ontario, Canada

## REFERENCES

1. Board of Radiation Effects Research Division on Earth and Life Sciences National Research Council of the National Academies. *Health Risks From Exposure to Low Levels of Ionizing Radiation: BEIR VII Phase 2.* Washington, DC: National Academies Press; 2006.
2. Berrington de Gonzalez A, Mahesh M, Kim KP, et al. Projected cancer risks from computed tomographic scans performed in the United States in 2007. *Arch Intern Med.* 2009;169:2071–2077.
3. Mueller DL, Hatab M, Al-Senan R, et al. Pediatric radiation exposure during the initial evaluation for blunt trauma. *J Trauma*. 2011;70:724–731.
4. Kim PK, Zhu X, Houseknecht, Mahboubi S, Nance ML. Effective radiation dose from radiologic studies in pediatric trauma patients. *World J Surg.* 2005;29:1557–1562.
5. Salottolo K, Bar-Or R, Fleishman M, et al. Current utilization and radiation dose from computer tomography in patients with trauma. *Crit Care Med.* 2009;37:1336–1340.
6. Fenton SJ, Hansern KW, Meyers RL, et al. CT scan and the pediatric trauma patient—are we overdoing it? *J Pediatr Surg.* 2004;39:1877–1881.

 