Radiation Exposure From Diagnostic Imaging in Severely Injured Trauma Patients

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Background: Trauma patients often require multiple imaging tests, including computed tomography (CT) scans. CT scanning, however, is associated with high-radiation doses. The purpose of this study was to measure the radiation doses trauma patients receive from diagnostic imaging.

Methods: A prospective cohort study was conducted from June 1, 2004 to March 31, 2005 at a Level I trauma center in Toronto, Canada. All trauma patients who arrived directly from the scene of injury and who survived to discharge were included. Three dosimeters were placed on each patient (neck, chest, and groin) before radiologic examination. Dosimeters were removed before discharge. Surface doses in millisieverts (mSv) at the neck, chest, and groin were measured. Total effective dose, thyroid, breast, and red bone marrow organ doses were then calculated.

Results: Trauma patients received a mean effective dose of 22.7 mSv. The standard “linear no threshold” (LNT) model used to extrapolate from effects observed at higher dose levels suggests that this would result in approximately 190 additional cancer deaths in a population of 100,000 individuals so exposed. In addition, the thyroid received a mean dose of 58.5 mSv. Therefore, 4.4 additional fatal thyroid cancers would be expected per 100,000 persons. In all, 22% of all patients had a thyroid dose of over 100 mSv (mean, 156.3 mSv), meaning 11.7 additional fatal thyroid cancers per 100,000 persons would result in this subgroup.

Conclusion: Trauma patients are exposed to significant radiation doses from diagnostic imaging, resulting in a small but measurable excess cancer risk. This small individual risk may become a greater public health issue as more CT examinations are performed. Unnecessary CT scans should be avoided.

Key Words: Radiation dosimetry, trauma, cancer risk.

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The use of computed tomography (CT) has increased dramatically during the past two decades. From 1981 to 1998, the number of CT scans performed annually in the United States has increased nearly 10-fold.1 Of all the X-ray based tests, CT contributes one of the highest radiation doses to patients.2

Trauma patients in particular are at risk for high-dose radiation exposure. Injured patients often receive multiple CT scans and radiographs during their hospitalization.3 Injured patients are also more susceptible to the effects of radiation because they tend to be young in age.4 Radiation exposure has been clearly linked to the development of cancer5 and the young are much more prone to these effects than the elderly.6

We prospectively measured radiation doses to trauma patients during their stay in hospital to quantify the biological risks associated with multiple imaging tests.

PATIENTS AND METHODS

A prospective study was undertaken of all trauma patients assessed at Sunnybrook Health Sciences Centre (a Level I adult trauma center in Toronto, Canada) from June 1, 2004 to March 31, 2005. All patients arriving directly from the scene of injury were included. Patients who died during hospitalization were excluded.

Patients were treated as per Advanced Trauma Life protocol.7 After primary survey, three optically stimulated luminescence (OSL) dosimeters (Landauer type K) were taped to the neck, chest, and groin of each patient. Dosimeters were removed at discharge or upon request. Control dosimeters were maintained in the trauma room. After removal, dosimeters were sent to the vendor (Landauer, Glenwood, IL) for dose determination.

Definitions

Deterministic effect: Any biological effect observable shortly after receiving a radiation dose. Examples are skin erythema or hematologic suppression. Deterministic effects require a dose that exceeds a threshold.

Stochastic effects: These include long-term cancer induction and genetic effects. A stochastic model assumes a linear relationship between dose and biological effect. As such, there is no definitive threshold that is clearly safe.
Absorbed dose: The quantity (milligray [mGy]) of energy absorbed from an X-ray beam by any given tissue. Surface dose is the absorbed skin dose. Organ doses reflect the absorbed radiation dose of a specified organ.

Dose equivalent: The product of the absorbed dose and a corresponding quality factor for the radiation (millisieverts [mSv]). The quality factor standardizes the effects of different sources of radiation. For medical X-ray studies, the quality factor is 1. Therefore, absorbed dose and dose equivalent are identical (mGy = mSv) for medical X-ray studies.

Effective dose: The sum of the dose equivalents (mSv) for each organ in the body, weighted by a factor to reflect radiosensitivity. Effective dose estimates the whole-body dose required to produce the same stochastic risk as the partial-body dose that was actually delivered by a radiologic examination. As such, it is the preferred method for quantifying overall risk from diagnostic imaging.

OSL-Based Estimates of Radiation Dose

The OSL dosimeters measured dose equivalent at the skin surface (surface dose). Organ doses (thyroid, red bone marrow, and breast) and total effective dose were then calculated from surface doses using the computer package CT-Dosimetry.xls (ImPACT CT Patient Dosimetry Calculator version 0.99w; Imaging Performance Assessment of CT Scanners; St. George’s Hospital, Tooting, London, UK). Total effective dose was only calculated for patients who had dosimetry results from all three dosimeters. Also, the assumption was made that all radiation measured by the OSLs was from CT scanning. This assumption was made based on a calculation of the relative impact of planar and CT procedures on total patient effective dose. For the trauma population, we estimated that 90% of the effective dose was a result of CT scans.

Demographics, injury data, length of stay, intensive care unit (ICU) stay, operative procedures, imaging examinations, and outcomes were collected. During the study period, CT scanning was done using a GE LightSpeed Plus four-slice scanner (GE Healthcare, Piscataway, NJ). One major change in our institutional CT protocol involved the installation of the GE lightspeed dose optimization feature, approximately 6 weeks into the study. This feature was designed to reduce the radiation dose from CT scans.

Counting Radiologic Procedures: An Independent Estimate of Radiation Dose

Organ and total effective doses were also estimated by counting radiologic examinations and then multiplying by standard effective doses, as reported in the literature. These dose estimates were then compared with our OSL-based results.

Cancer Risk

Using the OSL-derived effective doses, excess mortality from leukemia, thyroid, and breast cancer (women) was calculated using the National Council on Radiation Protection and Measurement (NCRP) Report 115 risk model, appropriate for patients ages 20 to 65. Also, excess mortality from all cancers was calculated using the same model.

This study was performed in compliance with institutional regulations for clinical research. Approval for delayed consent was obtained. Data are presented as means ± 95% confidence intervals. All p values are two-tailed and p was set at 0.05. All analysis was done using SAS software (version 8.02, SAS Institute Inc., Cary, NC).

RESULTS

During the study period, 291 (65.7%) patients were enrolled out of 443 eligible patients. Thirty-two patients died (11%), leaving 259 study patients who survived to discharge. In all, 87 patients lost all dosimeters or withdrew, leaving 172 patients who had dosimetry results.

Baseline characteristics are presented in Table 1. Study patients appeared to have a higher injury severity score and longer length of stay than nonstudy patients. Likewise, study patients received more CT scans and planar radiographs than nonstudy patients (Table 2). Study patients received a mean of 4.9 (4.5–5.4) CT scans and 13.7 (11.4–15.9) plain film examinations during their admission. In all, 86% of the esti-
mated effective radiation dose was from CT scanning in this study, which was close to our initial estimate of 90%.

In terms of surface doses, most patients received between 0 and 99 mSv of radiation exposure to their torso (chest and groin). Very few had chest or groin surface doses that exceeded 100 mSv (Fig. 1). Total effective dose for patients with three dosimeters was 22.7 (17.1 to 28.3) mSv (Table 3).

Study patients, however, had significant neck surface doses. As a result, thyroid doses were also high. Mean thyroid dose was 58.5 (48.7–68.4) mSv (Table 3). In all, 22% (n = 42) had high thyroid doses (over 100 mSv), with a mean of 156.3 mSv (139.8–172.8).

OSL-based estimates of radiation doses were higher than estimates obtained from counting radiologic procedures. This difference was statistically significant with regards to total effective dose and thyroid dose, and showed a strong trend for marrow dose. There were no differences between the estimates for breast doses (Table 3).

Using our OSL-based results, we estimate that 190 excess cancer deaths would arise in 100,000 similarly irradiated trauma patients. Excess cancer fatality rates for specific organs are reported in Table 4. Of note, 4.4 per 100,000 excess thyroid cancer deaths would be expected and 11.7 per 100,000 expected in the high exposure subgroup.

Because of nonuniform recruitment of study patients, we were not able to compare radiation exposures of patients before and after our institution received the dose optimization package for its CT scanners. Because of a slow startup to the study, we only recruited six study patients before the upgrade was received, and their radiation exposures varied widely.

**DISCUSSION**

Rapid diagnosis and prioritized treatment of injuries are the cornerstone of trauma management. CT scanning has become the screening test of choice for most injuries. Unfortunately, CT examinations result in significantly higher radiation doses than plain radiography.

In general, the risk of missing life-threatening injuries outweighs the small long-term risk for cancer from imaging tests. However, there is a growing recognition that this small individual risk for cancer becomes a greater public health issue when considered in the context of the large number of examinations performed. Furthermore, this risk is accentuated in trauma patients who often receive multiple tests, and who tend to be more radiosensitive because of their relatively younger age.

Two groups have quantified radiation doses to trauma patients. Kim et al. retrospectively calculated radiation doses to critically injured patients requiring prolonged ICU stay and to pediatric trauma patients. They estimated effective

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### Table 2 Number and Types of Imaging Tests Obtained During Admission

<table>
<thead>
<tr>
<th>Test</th>
<th>Study Patients With Dosimetry Results</th>
<th>Study Patients With Lost Dosimeters</th>
<th>Not Enrolled in Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>172</td>
<td>87</td>
<td>133</td>
</tr>
<tr>
<td>CT scans</td>
<td>4.9 (4.5–5.4)</td>
<td>2.6 (2.3–3.2)</td>
<td>4.1 (3.6–4.6)</td>
</tr>
<tr>
<td>Plain film radiography</td>
<td>13.7 (11.4–15.9)</td>
<td>7.3 (5.7–8.8)</td>
<td>10.9 (9.2–12.6)</td>
</tr>
<tr>
<td>Interventional radiography</td>
<td>0.1 (0.04–0.2)</td>
<td>0.06 (0.005–0.1)</td>
<td>0.05 (0.008–0.1)</td>
</tr>
<tr>
<td>Fluoroscopy</td>
<td>0.3 (0.2–0.4)</td>
<td>0.1 (0.05–0.2)</td>
<td>0.3 (0.2–0.35)</td>
</tr>
<tr>
<td>Nuclear medicine scans</td>
<td>0.01 (0–0.02)</td>
<td>0</td>
<td>0.03 (0–0.07)</td>
</tr>
</tbody>
</table>

Data are means (95% confidence interval) unless noted.

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### Table 3 Predicted Exposure Versus Measured Dosimetry

<table>
<thead>
<tr>
<th></th>
<th>n</th>
<th>Predicted Exposure (mSv)</th>
<th>Dosimetry Results (mSv)</th>
<th>Paired t Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total effective dose</td>
<td>108</td>
<td>17.8 (14.5–20.9)</td>
<td>22.7 (17.1–28.3)</td>
<td>0.02</td>
</tr>
<tr>
<td>Thyroid (all)</td>
<td>172</td>
<td>48.0 (44.6–51.5)</td>
<td>58.5 (48.7–68.4)</td>
<td>0.03</td>
</tr>
<tr>
<td>Red marrow (all)</td>
<td>108</td>
<td>17.6 (15.8–19.4)</td>
<td>18.5 (14.5–22.5)</td>
<td>0.097</td>
</tr>
<tr>
<td>Breast (women)</td>
<td>40</td>
<td>15.3 (11.6–19.0)</td>
<td>20.9 (7.1–34.7)</td>
<td>0.33</td>
</tr>
</tbody>
</table>

Data are means (95% confidence interval) unless noted.

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### Table 4 Excess Lifetime Cancer Mortality

<table>
<thead>
<tr>
<th>Excess Cancer Deaths per 100,000 People</th>
</tr>
</thead>
<tbody>
<tr>
<td>All cancers (age 20–64)</td>
</tr>
<tr>
<td>Thyroid cancer</td>
</tr>
<tr>
<td>Breast cancer (women only)</td>
</tr>
<tr>
<td>Leukemia</td>
</tr>
</tbody>
</table>
dose by counting the specific studies obtained for each patient and then multiplying by the typical effective dose reported for each study. Fitzgerald et al. prospectively measured the exposures of 31 trauma patients by placing dosimeters on them before X-ray examination. However, the dosimeters were removed after just 24 hours. Also, this study was conducted between 1980 and 1982, before CT scanning was widely available, thus limiting its applicability to modern trauma practice.

We prospectively measured the radiation doses from diagnostic imaging to trauma patients seen at our institution using dosimeters. We found that patients were exposed to significant radiation doses from radiologic examinations. However, we found that previous studies may have underestimated radiation exposures. These studies estimated effective dose by counting radiologic procedures; in our study, this method underestimated effective doses when compared with dosimeter-based results.

Using our dosimeter results, trauma patients received a mean effective dose of 22.7 mSv. To put this dose in perspective, the average annual background radiation dose to human beings is approximately 2.4 mSv, and the International Commission on Radiation Protection restricts the annual occupational dose limit to the public to 1 mSv. The expected excess cancer mortality expected from this exposure of 22.7 mSv was 190 per 100,000. Approximately 2.6 million injured patients are admitted to hospital annually in the United States. Even though the trauma patients in this study likely represented a more severely injured cohort than the average injury patient requiring hospital admission, this data underscores the potential magnitude of this public health issue.

The radiation exposure was not evenly distributed, but was higher in the neck compared with the chest or groin. The mean thyroid dose was 58.5 mSv. However, 22% of these patients had thyroid doses of 100 mSv or more, with a mean of 156.3 mSv. The risk for thyroid cancer is significantly increased after the 100 mSv dose threshold, and above this dose, there is a linear relationship between the dose and the risk of carcinoma. In our study patients, the excess mortality from thyroid cancer was 4.4 per 100,000 patients. Among patients with thyroid doses greater than 100 mSv, the excess thyroid cancer mortality was 11.7 per 100,000 persons. Thyroid cancer is rarely fatal, however. The number of excess thyroid cancers expected would be 10-fold higher (i.e., 44 and 117 per 100,000 persons, respectively) for our study patients.

As discussed previously, counting radiologic examinations significantly underestimated total effective dose by approximately 25%, when compared with dosimeter-based results. One explanation is that technique factors for plain-film radiographs and CT scans were left to the discretion of the technician. Variations in technique can result in substantial variations in radiation exposure. Also, completing one satisfactory CT examination sometimes required multiple scans and radiation exposures, which was not always documented in the radiologic record. For example, agitated trauma patients often move during scanning, compromising the image quality. As a result, repeat scanning often was required to complete one satisfactory examination. Also, scanning was sometimes required through different phases of contrast circulation. The total dose delivered by CT for a multiple-phase study is the total effective radiation dose per study multiplied by the number of phases.

Diagnostic imaging remains a critical part of the evaluation and management of trauma patients. Indeed, any excess cancer risk from diagnostic imaging should be placed in perspective; the background lifetime probability of a U.S. man dying from any cancer during his lifetime is 23%; for a woman, this probability is 20%. Therefore, the excess cancer mortality reported in this study is small compared with a person’s lifetime risk of developing cancer. As discussed previously, this small risk is probably outweighed by the risk of missing injuries. Missed injuries are a major source of preventable morbidity and mortality in trauma patients and CT scanning has been shown to reduce the incidence of missed injuries.

Even so, clinicians should attempt to minimize radiation dose. One approach would be judicious use of CT scanning. There is some evidence that CT use could be reduced without affecting patient outcomes. Rizzo and coworkers reviewed the use of CT in 1,609 trauma patients. These patients received 2,047 scans. Overall, they concluded that the CT results only helped in the management of 29% of these patients.

Another approach is to work in collaboration with radiologists to optimize CT scanning parameters to reduce dosage without affecting image quality and to improve shielding practices. Reducing tube current, for example, is the most practical way of decreasing CT radiation dose. Other methods include increasing acceptable image noise and increasing image slice profile. Kaira et al. reported that abdominal CT scan quality was acceptable, even with a 50% reduction in radiation dosage. Kalra et al. present a detailed review of strategies for CT radiation dose optimization and shielding practices, which is beyond the purview of this study. As discussed previously in our study, the implementation of the dose-optimization feature occurred early in the study period, such that we were unable to determine whether it had any significant effect on overall radiation exposure.

The disproportionate exposure to the neck region of trauma patients also has implications on medical practice in nontrauma-related specialties. For example, the standard first step after history and physical examination for managing asymptomatic thyroid nodules is a fine-needle aspirate. The exception to this protocol occurs when there is a history of previous head and neck irradiation; in these cases, thyroidectomy is the immediate next step. Although no exposure thresholds are given to assist in this decision-making process, standard surgical texts suggest that a childhood history of
irradiation for tinea capitis would warrant immediate surgery for a thyroid nodule. Modan reported that the average thyroid dose for tinea capitis treatment was less than 90 mSv. In 22% of our study patients, the average measured thyroid exposure was over 150 mSv. One implication, therefore, is that patients with thyroid nodules should also be screened for previous trauma, particularly if injury occurred during childhood, to determine the next appropriate step in management.

Study Limitations

The major limitation of this study was that it was conducted at an adult trauma center. Radiation exposure is a greater health issue for children, who are more radiosensitive and have more years to express stochastic effects. However, there is some evidence to suggest that our findings are applicable to children. When we counted radiologic procedures to estimate effective doses, we found that our adult trauma patients received similar doses as compared with Kim’s pediatric trauma patients (17.8 mSv versus 14.9 mSv). As our dosimeter-based results were significantly higher than these estimates, we think prospective dosimeter studies are warranted in the pediatric trauma population.

Our cancer risk model also has significant limitations. Most cancer risk models assume instantaneous exposure. Fractionated doses of radiation attenuate the stochastic risk, by allowing time for irradiated tissue to repair radiation-induced damage. As a result, the cancer risk is likely overestimated for our study patients because radiation exposure occurred during their entire stay in hospital.

Another limitation is that we based our cancer-risk estimation on a linear, no-threshold model that was primarily designed to determine occupational radiation risk. The basic philosophy of occupational radiation protection is that any radiation exposure is potentially bad, because there is no benefit to the irradiated worker. Thus, this model tends to overestimate the radiation risk. In considering radiation risk to patients, however, overestimating risk may be detrimental because there may be some diagnostic benefit from increasing radiation exposure. For example, the diagnostic quality of the radiologic examination may be improved by increasing radiation exposure, thereby reducing the frequency of missed injuries.

However, our study may also have underestimated the actual radiation exposure. We excluded referred trauma patients to have the OSL dosimeters in place for all imaging examinations. A significant proportion of our trauma population is referred from other centers, where they received multiple CT examinations. Also, many patients required significant numbers of radiologic tests as outpatients after discharge. This radiation exposure also was not captured by our study.

One last limitation was the enrollment of study patients. Study patients were significantly sicker (higher Injury Severity Scale score [ISS]) than nonstudy patients and received more diagnostic imaging. However, our study patients were still much more representative of the typical trauma patient, compared with Kim’s study in ICU patients (mean ISS = 32.0). Furthermore, our study is unique in that it compared effective radiation dose estimated by counting procedures with that obtained using dosimetry results.

CONCLUSION

Trauma patients are exposed to significant amounts of radiation from diagnostic imaging. This exposure is associated with a small but measurable future excess cancer risk. Because of the pattern of exposure, thyroid cancer is likely to be the most important public health issue from this exposure. Unnecessary CT examinations should be avoided if the results will not affect treatment. Consideration should be given to implementing dose-reduction protocols and routine shielding practice.

ACKNOWLEDGMENTS

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REFERENCES


