Theoretical Breast Cancer Induction Risk From Thoracic Spine CT in Female Pediatric Trauma Patients

WHAT’S KNOWN ON THIS SUBJECT: High doses of radiation have been linked to cancer induction in irradiated populations such as atomic bomb survivors. Medical imaging directs significant radiation doses to human tissues. Epidemiological studies have demonstrated that children are more sensitive to radiation than adults.

WHAT THIS STUDY ADDS: The link between cancer induction from moderate radiation doses such as diagnostic imaging is controversial. This study uses Food and Drug Administration–accepted formulas to calculate theoretical risk of breast cancer induction in female pediatric trauma patients receiving diagnostic imaging of the thoracic spine.

abstract

OBJECTIVES: To quantify the radiation dose received during thoracic spine computed tomography (CT) versus plain radiographs as well as the theoretical risk of breast cancer induction in a pediatric trauma population.

METHODS: A retrospective evaluation of 179 female pediatric trauma patients who received CT or plain radiographs for clearance of the thoracic spine was performed. Subjects were secondarily grouped as children (0–12 years) or adolescents (12–17.9 years). Radiation doses were calculated by using the ImPACT Patient Dosimetry Calculator. Excess absolute risk (EAR) of induction of breast cancer was determined by multiplying the radiation dose by breast cancer induction rates taken from the National Academy’s Biological Effects of Ionizing Radiation Committee’s seventh report.

RESULTS: The average radiation dose to the breast from a thoracic spine CT was 41.1 (SD 11.4) mSv and 1.8 (SD 0.9) mSv for plain radiographs. The EAR for plain radiographs was 2.7 (95% confidence interval [CI] 2.48–2.85) excess cases of breast cancer per 10 000 studies for female children and 1.4 (95% CI 1.14–1.55) for female adolescents. The breast cancer EAR for thoracic spine CT was significantly higher —79.6 (95% CI 58.6–100.5) and 45.8 (95% CI 42.0–49.6) excess cases per 10 000 scans for female children and adolescents, respectively. There was a substantially higher risk of breast cancer induction for children receiving thoracic spine CT compared with adolescents.

CONCLUSIONS: CT clearance of the thoracic spine in the pediatric trauma patient results in a high dose of radiation and an age-dependent increase in theoretical breast cancer induction. Pediatrics 2012;130:e1614–e1620

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KEY WORDS: radiology, radiation, radiation dose

ABBREVIATIONS
BEIR VII report—National Academy’s Biological Effects of Ionizing Radiation Committee’s seventh report
CI—confidence interval
CT—computed tomography
EAR—excess absolute risk

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Evaluation of the thoracic spine is important to exclude significant injury in pediatric blunt trauma patients. Thoracic spine injuries are relatively rare in this population, occurring with an incidence of 0.4% to 1.0% of all traumas, but missing an injury can be associated with significant neurologic injury. Historically, plain radiographs have been used to evaluate the thoracic spine when imaging is required. In the past 2 decades, the use of computed tomography (CT) in pediatric patients has increased exponentially because of its efficiency and greater sensitivity. CT exposes the body to significant amounts of radiation, which is especially concerning in pediatric patients because of their high sensitivity to ionizing radiation and longer expected life. The concern for cancer induction from excessive diagnostic imaging has caused many authors to question the justification of CT in children. For the female pediatric trauma patient, a specific concern for diagnostic radiation is raised because of the relative radiosensitivity of breast tissue. Research has linked radiation exposure, at the high levels used for radiation therapy, to induction of breast cancer in several pediatric populations, such as atomic bomb survivors and those treated with radiation for medical conditions. The linkage of radiation exposure to breast cancer has motivated clinicians to avoid plain radiographs or minimize breast radiation exposure. Diagnostic imaging, particularly CT, used to evaluate the thoracic spine in the female pediatric trauma patient results in relatively high doses of radiation absorbed by breast tissue. However, the risk of breast cancer induction from CT evaluation of the thoracic spine in female pediatric trauma patients is currently unknown.

The pediatric trauma patient presents a unique challenge, because the concern for missed injuries must be balanced with the risk of radiation. The primary goal of this study was to quantify the amount of radiation the breast is exposed to in thoracic spine CT in comparison with thoracic spine plain radiographs. We also aimed to calculate the theoretical risk of breast cancer induction from radiation received during clearance of the thoracic spine in female pediatric trauma patients and to compare the radiation received in thoracic spine CT with that from plain radiograph. This study aimed to increase knowledge and understanding of the amount of radiation to which is exposed the female pediatric trauma patient to guide physician decisions when ordering diagnostic imaging.

**METHODS**

**Study Population**

A retrospective evaluation of 283 consecutive female pediatric (age <18 years) trauma patients was performed at an academic, level I trauma center. Institutional review board exemption was obtained to perform a retrospective chart review from June 2004 to January 2009. All level I (emergent activation of the trauma team secondary to cardiopulmonary duress, gunshot wound to the neck chest or abdomen, or Glasgow Coma Scale <8) or level II trauma (emergent trauma evaluation but have no physiologic abnormalities) patients at our institution who had thoracic spine plain radiograph or CT to exclude injury were included.

**Calculation of Absorbed Dose to the Breast for CT**

The following parameters are necessary to calculate the amount of radiation absorbed by the breast from a plain radiograph: field of view (35 × 20 is standard at our institution), the tube current and exposure time (milliampere-second [mAs]), maximum voltage (kVp), distance from source to patient (75 cm), and tissue-specific absorption value (mrad/R). The dose was calculated by using the known output in milliroentgens/milliampere-second (mR/mAs), as a function of kVp, by using reference tables and multiplying by mAs. Calculated radiation doses from each plain radiograph received were multiplied by an organ-specific absorption value in millirads per roentgen (mrad/R) of exposure that was selected based on field of view and radiographic position (anteroposterior, lateral, swimmer’s). The following formula allowed the calculation and conversion of radiation units to final organ dose:

\[
\text{Effective dose to breast (mSv)} = \text{(tissue-specific absorption value, mrad/R)} \times \frac{mR}{mAs} \times \left(\frac{mAs}{mR/mAs}\right) \times 10^{-7}
\]

where 1 mrad = 0.01 mSv.

The exact settings (mA and kVp) for each patient are not recorded at our institution; therefore, we used standard values from institutional protocols. Additionally, to confirm that the assumptions made were accurate, radiation technologists at our institution recorded radiograph settings for all pediatric trauma patients (n = 5) who received diagnostic thoracic spine radiographs over the course of a 30-day period.

**Calculation of Absorbed Dose to the Breast for Plain Radiographs**

The following parameters are necessary to calculate the amount of radiation absorbed by the breast from a plain radiograph: field of view (35 × 20 is standard at our institution), the tube current and exposure time (milliampere-second [mAs]), maximum voltage (kVp), distance from source to patient (75 cm), and tissue-specific absorption value (mrad/R). The dose was calculated by using the known output in milliroentgens/milliampere-second (mR/mAs), as a function of kVp, by using reference tables and multiplying by mAs. Calculated radiation doses from each plain radiograph received were multiplied by an organ-specific absorption value in millirads per roentgen (mrad/R) of exposure that was selected based on field of view and radiographic position (anteroposterior, lateral, swimmer’s). The following formula allowed the calculation and conversion of radiation units to final organ dose:

\[
\text{Effective dose to breast (mSv)} = \text{(tissue-specific absorption value, mrad/R)} \times \frac{mR}{mAs} \times \left(\frac{mAs}{mR/mAs}\right) \times 10^{-7}
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The BEIR VII report compiled Committee rates based on the National Academy of Sciences. The breast cancer risk, specifically breast cancer in females from thoracic spine CT, was determined by multiplying the radiation dose received. The average radiation dose per million (mSv) absorbed in the breast by a female patient is 41.1 mSv for all radiographs. The theoretical excess absolute risk (EAR) for inducing breast cancer in females from thoracic spine CT was 42.75 (11.0) per 10,000 woman years, or 41.1 excess cases of breast cancer per 10,000 plain radiographs. There was a significantly higher radiation dose to the breast from thoracic spine CT than from thoracic spine plain radiographs (P < .001).


table 1 Radiation Dose (mSv) From Diagnostic Imaging During Clearance of the Thoracic Spine in the Female Pediatric Trauma Patient

<table>
<thead>
<tr>
<th></th>
<th>Plain Radiograph</th>
<th>CT</th>
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<tbody>
<tr>
<td></td>
<td>Mean (SD), mSv</td>
<td>n</td>
</tr>
<tr>
<td>Overall</td>
<td>1.81 (0.94)</td>
<td>119</td>
</tr>
<tr>
<td>0–&lt;12 y</td>
<td>0.82 (0.45)</td>
<td>40</td>
</tr>
<tr>
<td>≥12–17.9 y</td>
<td>2.31 (0.69)</td>
<td>79</td>
</tr>
</tbody>
</table>

P-values are based on comparison between age groups.

Equation for EAR of breast cancer:

\[
EAR = 9.4 \times \exp (\frac{0.05 (exposure\ age - 30)}{\text{attained\ age/60}}).
\]

Ear is reported in 10,000 person-years for a female living to age 60, that is, attained age = 60. EAR was then converted to cases of cancer per 10,000 scans by multiplying EAR times attained age of 60 years times 10,000 scans.

Rate of Injury and Missed Injuries

Rate of injury and missed injuries in our patient population were determined through medical record review. Injuries were classified into two categories, clinically significant or not clinically significant, by an orthopedic surgeon who is an expert in the field of spinal stability (PAA). Clinically significant injuries were defined as injury that would require treatment with bracing or surgery. Thoracic transverse process fractures were not considered significant injuries because they do not contribute to stability. Missed injuries were defined as an injury detected by thoracic spine CT that was missed on initial thoracic spine plain radiograph series.

Statistical Methodology

Subjects were grouped according to age as children (0–<12 years) or adolescents (≥12–17.9 years) to look at effects by average age of menarche in US females. Two-tailed t-tests were performed to identify differences between age groups in females receiving thoracic spine CT. Bonferroni corrections for pairwise differences were used, and P < .05 was considered statistically significant.

RESULTS

Demographics

One hundred seventy-nine subjects met the study inclusion criteria. One hundred nineteen subjects received plain radiographs of the thoracic spine; 40 were <12 years of age, and 79 were ≥12 years of age. On average, 2.43 plain radiographs were required to ensure accurate imaging of each subject’s thoracic spine. Sixty subjects received thoracic spine CT; 12 were <12 years of age, and 48 were ≥12 years of age.

Radiation Dose

The average radiation dose to the breast from thoracic spine plain radiographs totaled 1.81 (SD 0.9) mSv for all radiographs received per patient. The average radiation dose to the breast from thoracic spine CT was 41.1 (SD 11.4) mSv (Table 1, Fig 1). There was a significantly higher dose to the breast from thoracic spine CT than from thoracic spine plain radiographs (P < .001).

There was a significant difference in average radiation dose absorbed to the breast from radiographs by age (P < .001), with older children receiving a larger radiation dose. No age-dependent trends were found in average radiation dose absorbed to the breast from thoracic spine CT by age (P = .56). (Table 1)

Theoretical Excess Absolute Risk

The theoretical EAR of breast cancer for subjects receiving thoracic spine plain radiographs was 0.037 (95% confidence interval [CI] 0.034–0.040) excess cases of cancer per 10,000 woman years or 22 excess cases of breast cancer per 10,000 plain radiographic examinations. The EAR for breast cancer for subjects receiving thoracic spine CT was 0.88 (95% CI 0.78–0.97) per 10,000 woman years or 52.6 excess cases of breast cancer per 10,000 CT scans. The theoretical EAR for breast cancer was significantly higher in patients receiving thoracic spine CT than in those receiving thoracic spine plain radiographs (P < .001) (Table 2, Fig 2).
Patient age had a significant effect on excess absolute risk of breast cancer from plain radiographs, \( P < .001 \). Females <12 years had twice the EAR, 0.044 (95\% CI 0.041–0.047) in comparison with adolescent females, who had an EAR of 0.022 (95\% CI 0.019–0.026) per 10,000 woman-years. This means that adolescent patients theoretically had 1.43 excess cases of breast cancer per 10,000 scans, compared with 2.76 excess cases of breast cancer per 10,000 scans for females <12 years. (Table 2) CT was similarly associated with an age-dependent theoretical risk of breast cancer for adolescent females. After 1 thoracic spine CT, females <12 years had an EAR of 1.3 (95\% CI 0.98–1.68) compared with 0.76 (95\% CI 0.70–0.83) per 10\(^4\) years for adolescent females, or 79.6 excess cases of breast cancer per 10,000 scans in females <12 years and 45.8 excess cases of breast cancer per 10,000 scans in females \( \geq 12 \) years. EAR for breast cancer for female children receiving thoracic spine CT was significantly higher in comparison with female adolescents (\( P = .005 \)). (Table 2, Fig 2)

**Rate of Injury and Missed Injuries**

Only 1 significant injury was seen of the 119 patients screened by plain radiographs. One other patient had a spinous process fracture, which was missed by plain radiographs but seen on CT. This was deemed insignificant, because it was not treated by brace or surgery. This was the only incidence of missed injury in our study population. Only 2 significant injuries, burst fractures, were seen on 60 CT examinations. Additionally, 2 cases of spinous process fractures and 3 cases of compression fractures were identified by CT.

**DISCUSSION**

An increased risk of breast cancer has been observed among women exposed to therapeutic levels of radiation.\(^9,10,11,19,20\) However, the risk and average radiation dose of imaging methods such as plain radiograph and CT in pediatric patients is not well characterized. A retrospective review of female pediatric trauma patients who received diagnostic imaging in the form of CT or plain radiograph at a single institution was performed. The radiation dose absorbed by the female breast was 20-fold higher when a patient received CT versus plain radiograph (41.1 mSv vs 1.8 mSv, \( P < .001 \)). There was a corresponding increase in theoretical cancer risk with increased radiation dose.

With the use of the formula from the BEIR VII report, a female pediatric patient receiving thoracic spine CT at our institution had an EAR of 0.87 per 10,000 woman-years, or 52.6 excess cases of breast cancer per 10,000 scans administered when using an attained age of 60 years. This is significantly higher than the excess absolute risk of 0.037 per 10,000 woman-years, or 2.2 excess cases of breast cancer per 10,000 thoracic spine plain radiographs (\( P < .001 \)). Further analysis of these patients by age finds that, although younger patients received less radiation, they had an increased theoretical risk for breast cancer. This affirms the importance of making critical decisions when choosing diagnostic imaging in younger patient populations. Although no studies are available that evaluate the sensitivity of thoracic spine plain radiographs versus CT in pediatric trauma patients, it is assumed that the significantly higher sensitivity of CT would also be present in this population and location. In addition, plain radiographs are more sensitive in the pediatric population due to generally smaller body mass and the absence of osteoporotic fractures or degenerative

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**FIGURE 1**

Skeleton box plot of radiation dose (mSv) by age group for CT and plain radiographic examinations. The horizontal lines of the box from top to bottom are the 75th, 50th, and 25th percentiles, respectively. The error bars are the highest and lowest extreme values.

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**TABLE 2** Theoretical Excess Absolute Breast Cancer Risk From Diagnostic Imaging During Clearance of the Thoracic Spine in Female Pediatric Trauma Patients

<table>
<thead>
<tr>
<th>Age Group</th>
<th>Plain Radiograph, Mean (95% CI) EAR(^a)</th>
<th>Excess Cases of Cancer per 10(^4) Patients (95% CI)</th>
<th>( P )</th>
<th>CT, Mean (95% CI) EAR(^a)</th>
<th>Excess Cases of Cancer per 10(^4) Patients (95% CI)</th>
<th>( P )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall</td>
<td>0.037 (0.034–0.040)</td>
<td>2.2 (2.04–2.40)</td>
<td>—</td>
<td>0.08 (0.78–0.97)</td>
<td>52.6 (46.8–58.5)</td>
<td>—</td>
</tr>
<tr>
<td>&lt;12</td>
<td>0.044 (0.041–0.047)</td>
<td>2.7 (2.48–2.85)</td>
<td>—</td>
<td>1.3 (0.98–1.68)</td>
<td>79.6 (58.6–100.5)</td>
<td>—</td>
</tr>
<tr>
<td>( \geq 12 )</td>
<td>0.022 (0.019–0.026)</td>
<td>1.4 (1.14–1.55)</td>
<td>.005</td>
<td>0.76 (0.70–0.83)</td>
<td>45.8 (42.0–49.6)</td>
<td>&lt;.001</td>
</tr>
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\(^a\) Units are excess cases of breast cancer per 10\(^4\) woman-years.
changes. Of the 60 CT scans performed in our patient population, only 2 clinically significant injuries were detected. Essentially, <5% of CT scans performed changed patient management. In addition, there was only 1 injury found on CT that was missed by plain radiographs, and this injury was not treated and was deemed not clinically significant. However, our purpose was not to examine sensitivity and specificity of plain radiographs, and our sample size did not have sufficient power to make any conclusions.

One of this study's strengths is its clinical applicability. Although pediatric spine trauma is a relatively rare occurrence, the main purpose of this study was to calculate radiation dose of thoracic spine CT and to highlight the potential effects of radiation in a vulnerable pediatric population. In addition, thoracic spine CT and chest CT only differ on field of view, allowing these findings to be generalized to populations other than blunt trauma patients. The marker we used in our study, thoracic spine CT, was intended to be a surrogate for widespread use of CT. When we looked through patient charts, the majority of patients had multiple imaging studies. Five patients even had both thoracic spine CT and chest CT performed separately, which directed additional radiation exposure to the same location. However, cumulative dose assessment is beyond the scope of this study.

A validated calculator, ImPACT CT Patient Dosimetry, was used to determine absorbed dose to the breast from CT. Khursheed et al22 have studied potential limitations of using the ImPACT Calculator in a pediatric population. The dosimetry calculator is based on adult phantoms and may potentially underestimate the absorbed dose to pediatric patients. When using pediatric phantoms, they estimated that actual absorbed doses to the breast from thoracic spine CT could be as much as 1.1 (for a 15-year-old child) to 2.2 (for a 1-year-old child) times higher than our estimates. Even with this knowledge, we chose to not include these pediatric weighting factors in our protocol to ensure that the most conservative parameters in calculating dosage estimates were used.

This study is also limited by not having patient-specific radiation dose information available in the charts of those receiving plain radiographs. A standard distance of 75 cm from source to patient was used, regardless of patient age or size. This introduces a source of error that must be acknowledged. In addition, reference tables used to calculate organ-specific absorption values are for adult reference patients and not specific to a pediatric population.15 However, our estimates using Food and Drug Administration–approved absorption values for radiation dose to the breast corresponded to previously reported values in the literature.23,24 Furthermore, the difference between the radiation dose from a CT versus a plain radiograph is significantly large enough that any potential error in calculation would not affect study outcomes. Finally, we chose to group patients into 2 groups by age to compare differences in the radiation dose absorbed, based on average age of menarche in females in the United States.16 This classification could potentially misrepresent the true effect of age on radiation dose absorbed and risk of cancer induction, because it could mask important intergroup variability based on body weight and size.

There are 2 major theories on biological effects of low-dose ionizing radiation. Our calculations were based on the “linear-no threshold” model of radiation exposure, which falls in line with current Food and Drug Administration recommendations.23 Simply, this theory states that no threshold exists where radiation effect begins and that the effect is dose-dependent in a linear fashion and additive across time. However, there are uncertainties in estimating theoretical cancer risk with the use of the BEIR VII report recommendations. There are no published prospective studies reporting a detrimental effect of radiation at a dose of less than ~100 mSv, so calculations are based on extrapolation of known effects from radiation at higher doses.4 Contrarians to the linear no-threshold model postulate that a small amount of radiation may not be harmful, and they suggest it may even be protective against cancer, a phenomenon referred to as radiation hormesis.26–28 The data available on either theory are inconclusive. In our aim to highlight the significant differences in potential risk
between plain radiography and CT, we used the BEIR estimates because they are based on a review of current research. We are not able to conclude that radiation from CT definitively causes breast cancer. However, we hope to expand the knowledge of the amount of radiation received by the breast in the female trauma patient and its potential implications on cancer induction. Until prospective, longitudinal studies involving low doses of radiation can be completed, it would be most prudent to proceed as if there are potential risks associated with such exposure.

Research has already shown that radiation protocols can be instituted to reduce radiation without compromising image quality. For example, the use of automated exposure settings can control slice thickness and exposure dose. Furthermore, CT protocols can be adjusted to decrease the number of images obtained by ordering CT scans limited to areas of interest only. In addition, institutions have had success in altering behavior by including a diagnostic imaging algorithm in their medical orders system to help guide physicians in choosing the most appropriate imaging method (eg, radiograph, CT, and MRI). Such measures have shown significant reductions in the number of CT scans ordered. Other ideas include adding reports of anticipated radiation dose when ordering or offering a “checklist” to help guide imaging method selection. Our institution has implemented many of these actions. Since data were collected, fewer CTs are being ordered in pediatric trauma patients.

Thoracic spine clearance by using CT in the female pediatric trauma patient results in a high dose of radiation to the breast in comparison with plain radiographs. Selection of the appropriate method of imaging when required should be done with care, to minimize risk from unnecessary radiation. The concern for missed injury is important, but physicians have an obligation to balance this with potential future risk for breast cancer induction in this vulnerable patient population. These findings support the development of protocols to encourage the prudent use of diagnostic imaging in female pediatric trauma patients.

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