Inpatient radiation exposure in patients with spinal trauma

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Context/objective: Radiation exposure from medical imaging is an important patient safety consideration; however, patient exposure guidelines and information on cumulative inpatient exposure are lacking.

Design/setting: Trauma patients undergo numerous imaging studies, and spinal imaging confers a high effective dose; therefore, we examined cumulative effective radiation dose in patients hospitalized with spinal trauma. We hypothesized that people with spinal cord injury (SCI) would have higher exposures than those with spine fractures due to injury severity.

Participants/interventions: Retrospective data were compiled for all patients with spine injuries admitted to a level I trauma center over a 2-year period.

Outcome measures: Injury severity score (ISS) and cumulative radiation exposure were then determined for these patients, including 406 patients with spinal fractures and 59 patients with SCI.

Results: Cumulative effective dose was 45 millisieverts (mSv) in SCI patients, compared to 38 mSv in spinal fracture patients ($P=0.01$). Exposure was higher in patients with an ISS over 16 ($P=0.001$). Mean exposure in both groups far exceeded the European annual occupational exposure maximum of 20 mSv. More than one-third of patients with SCI exceeded the US occupational maximum of 50 mSv.

Conclusion: Patients with SCI had significantly higher radiation exposure and ISS than those with spine fracture, but the effective dose was globally high. Dose did not correlate with injury severity for patients with SCI. While the benefits of imaging are clear, radiation exposure does involve risk and we urge practitioners to consider cumulative exposure when ordering diagnostic tests.

Keywords: Imaging studies, Radiation, Ionizing, Radiation risks, Spinal cord injuries, Spinal trauma, Fractures, Computed tomography, Injury severity score

Introduction

Radiation exposure from medical imaging is an important patient safety consideration and a topic of great concern and debate. It has been postulated that ionizing radiation exposure due to imaging results in an increased risk of germline abnormalities and certain types of cancer, including lymphoma, thyroid, and breast.¹⁻⁷ This hypothesis is extrapolated from long-term effects of previous exposure events, such as Hiroshima, Nagasaki, and Chernobyl, medical exposures, and occupational exposures.^{1,5,8-10} Ionizing radiation exposure secondary to medical imaging has

escalated to over 700% the levels seen in the mid-80s, comprising almost half of all ionizing radiation exposure to the US population.¹¹ This increase is due, in part, to increased accessibility and speed of computed tomography (CT) as well as to the development of multiphase scanners. Spinal imaging confers a relatively high effective radiation dose, particularly compared to the appendicular skeleton, due to its proximity to radiosensitive tissues and to imaging through the trunk.¹² Recently, the risk ratio of developing cancer was shown to be significantly increased following lumbar spine CT, and even more so after thoracic spine CT.¹³

Diagnostic imaging is vital to current management of acute trauma. Clinicians use CT extensively in diagnosis and characterization of spinal trauma, either with primary imaging or reformatting of trunk CT

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images.^{14–18} As our ability to diagnose and manage trauma patients improves, our reliance on imaging to monitor, diagnose, and treat has become indispensable. Unfortunately, this comes at a cost to the patient, who repetitively incurs high doses of ionizing radiation when undergoing radiographic imaging.

In this study, we have looked at the effective dose, which is a weighted average used to impart risk of cancer or heritable conditions from ionizing radiation.¹⁹ It is both age- and sex-averaged and is based on the premise that an imaging study confers a non-uniform exposure to different tissues and organs, and these exposed tissues have differing radio sensitivities. Effective dose is higher as tissues that are more sensitive to radiation are exposed to higher levels of radiation.

Occupational exposure limits are regulated; however, there are no specific guidelines on reasonable amounts of patient exposure. A recent article by Fazel *et al.*²⁰ used US yearly occupational limits as guidelines for patient exposure, quantifying medical exposures as low ≤ 3 mSv; mod 3–20; high 20–50, and very high > 50 . As specific patient exposure limits do not exist, we have also elected to use occupational maximums for our analysis. Of note, the European annual occupational maximum is lower still, at 20 mSv.

Because spinal imaging imparts a relatively high effective dose, and trauma patients tend to undergo numerous imaging studies, we chose to study radiation dose in spinal trauma patients. We hypothesized that patients with spinal cord injury (SCI) would receive considerable effective radiation doses through their hospitalization, and that these patients would incur a substantially higher dose and have sustained more severe injuries than patients with other spinal trauma. The aim of this retrospective study was to evaluate the total radiation dose that patients with traumatic SCI receive during an inpatient stay, and to compare this to patients with a spinal fracture with no cord injury. We also looked at injury severity on presentation using the injury severity score (ISS). By tracking the cumulative exposure for spinal trauma patients during the course of their hospitalization, we feel that we can draw greater attention to the implications associated with frequent use of radiographic imaging.

Table 1 Patient demographics for non-SCI and SCI groups

	Age	Patients	% Female
No SCI demographics	<18	32	41
	18 < 50	253	26
	50 < 70	114	26
	70 +	69	49
SCI demographics	<18	4	25
	18 < 50	34	21
	50 < 70	12	25
	70 +	10	30

Methods

Institutional Review Board approval was obtained prior to study initiation. Data were obtained retrospectively from a Level-I trauma center database including all trauma patients hospitalized from January 11, 2007 through October 16, 2008. Patients of all ages with spine fractures (ICD-9 805) and SCI (ICD-9 806) were extracted from this data set. Data were de-identified prior to analysis. We excluded patients with sacral fracture and no concomitant cervical, thoracic, or lumbar pathology. Each patient's ISS was noted on admission. Any patient who had SCI was analyzed in the SCI group even if they had a coexisting spine fracture. Polytrauma was defined as a patient having an ISS greater than 16. After implementing exclusion criteria, a sample of 465 patients was extracted and analyzed. All demographic data are represented in Table 1. These data represent a typical trauma population.

For each patient admitted during the study period, a list was generated containing all studies he or she had received during their hospitalization. After considering the number of studies in the data set and the numerous variables involved in calculating the radiation dose for each study, such as time, patient size, individual instrument variability, and dose values, the decision was made to estimate effective radiation dose for each study using previously published values.²¹ Fluoroscopy time was not included in our analysis, as this information was not readily available. (See Table 2)

Statistical method

Statistical analyses were performed with SPSS Statistical Package version 18.0 (SPSS Inc., Chicago, IL, USA). Minima, maxima, means, and standard deviations (SDs) were calculated for sum effective dose, patient

Table 2 Descriptive statistics

	Age (years)	Effective dose (mSv)	Injury severity (ISS)
Fracture ($n = 406$)	45.66 $\pm$ 22.05 (1.50–90)	37.73 $\pm$ 21.64 (0.02–159.35)	15.19 $\pm$ 9.57 (4–50)
SCI ($n = 59$)	43.80 $\pm$ 21.38 (3.9–88.6)	45.11 $\pm$ 17.75 (0.03–108.61)	30.17 $\pm$ 17.58 (4–75)
Total ($n = 465$)	45.43 $\pm$ 21.95 (1.5–90)	38.67 $\pm$ 21.31 (0.02–159.35)	17.09 $\pm$ 11.98 (4–75)

age, number of injury codes, and ISS. A P value of 0.05 was considered significant, and estimates for the population are 95% confidence intervals. ISS and sum effective dose were converted into categorical variables (over/under) to support two-sample independent t -tests between patients identified with ISS above 16 and patients receiving more than 50 mSv of radiation.

A two-sample t -test for independent variables was used to determine whether statistically significant differences in age, radiation exposure, or ISS were found in patients with spine fractures or SCI. Whether or not statistically significant radiation exposure occurred in patients with spinal injury and ISS of 16 or less compared to those with an ISS of greater than 16 was calculated.

SPSS was also used to perform a correlation and linear regression, and to graph the relationship between ISS and radiation exposure.

Data verification

From the data set provided only those patients having an ICD-9 code of 805 or 806 were extracted. Subcategories denoting sacral injury (805.6, 805.7, etc.) were excluded unless those patients also had another 805 or 806 code. Although patients in the data set may have had multiple injury codes, no other codes were included in the analysis.

Results

Total inpatient exposure

There were 10 504 radiographic studies performed on our population of 465 spine-injured patients, which included 6720 X-ray studies and 3606 CT scans. A total of 178 fluoroscopic studies were performed. The mean cumulative effective dose within the entire sample was 38.7 mSv, 92% of which was from CT

imaging. Total exposure in both groups was quite high; 45.11 mSv in SCI, compared to 37.73 mSv in fracture. (See Fig. 1) Cumulative effective dose for patients with SCI was significantly higher than for those with spinal fractures without cord injury ($P = 0.01$; 95% confidence interval (CI) = 1.6–13.2).

A large number of patients received considerably higher doses. Within the total sample, 97 patients (21%) were subjected to more than the maximum US allowable occupational yearly exposure of 50 mSv. Looking at each group individually, 22 patients of 59 total with SCI (37%) and 75 patients of 406 total (18%) with spine fracture experienced effective doses of 50 mSv or more. Extending our sample findings to estimates for the general patient population, all patients with SCI have at least a 25% likelihood of receiving more than 50 mSv of radiation (95% CI = 25–50%) and those with spine fractures have more than a 17% likelihood of exceeding a cumulative effective dose of 50 mSv (95% CI = 17–25%).

ISS in fracture versus SCI

Mean ISS was found to be 15.1 in spinal fracture patients and 30.1 in SCI patients ($P < 0.001$; 95% CI = 10.3–19.7). Mean radiation dose was higher in patients with an ISS greater than 16 versus an ISS of 16 or below ($P < 0.001$; 95% CI = 14.7–22) (See Fig. 2). The correlation between ISS and radiation exposure showed a weakly positive relationship between the variables when looking at the complete population ($R^2 = 0.153$) and when looking at spinal fracture ($R^2 = 0.224$).

In patients with SCI, there is no statistically significant correlation between ISS and radiation exposure ($R^2 = 0.003$); therefore, SCI and ISS were found to be independently predictive of higher radiation dose (see

Figure 1 Cumulative effective dose for patients with SCI was significantly higher than for those with spinal fractures without cord injury.

Figure 2 Mean radiation dose was higher in patients with an ISS greater than 16 versus an ISS of 16 or below.

Figure 3 Patient radiation exposure levels and corresponding ISS. Spinal fracture and SCI groups are indicated.

Fig. 3). Patients with SCI received approximately 45 mSv of radiation regardless of ISS or age.

Mean ages of the fracture and SCI groups were 45.7 and 43.8 years, respectively, with no significant difference in the ages between the two groups. There was no correlation between age and radiation exposure, or between age and ISS.

Discussion

Patients with traumatic spine injuries are exposed to considerable amounts of radiation through their hospitalization. Radiation effects can be deterministic, such as burns or radiation sickness from predictable amounts of toxic doses. More relevant to diagnostic imaging, however, are the stochastic effects, which are multifactorial responses to lower doses possibly resulting in cancer-inducing damage to somatic cells or to heritable effects in germline cells.

The most commonly used model for radiation effects involves a linear, no threshold model, which is based on the premise that any radiation dose can cause a stochastic effect, and the effect increases linearly with cumulative exposure.¹ Doses thought to confer increased cancer risk are below those reflected by the average patient exposures in our study.^{8–10,13,16,22} While this increased cancer risk is small, it is not negligible.

While much of our understanding of cancer risk is extrapolated from prior population exposures and has been estimated to be a linear relationship with no threshold,^{8–10} the true effect of low-dose radiation is uncertain. The competing linear threshold model contends that radiation exposure at low doses beneath a specific threshold is not cumulative. This theory proposes a threshold below which the defenses against ionizing radiation are able to adequately prevent any lasting effects. While there certainly is data to support this model,^{23,24} there is also evidence based on prior

exposures to support the no-threshold model. Since neither model has been fully proven, the safest approach is to keep medical radiation exposure as low as is necessary for diagnosis and treatment.

In this study, patients with SCI were found to have higher radiation exposure than those with spine fractures. Although the average ISS was significantly higher in the SCI group, higher levels of exposure were independent of ISS. In the combined group, ISS only had a weak correlation with total radiation exposure. This is somewhat surprising, as we suspected that injury severity would correlate strongly with the cumulative amount of radiation exposure sustained by any patient with spine injury during their hospitalization.

Particularly striking was the number of patients whose total inpatient exposures exceeded occupational yearly limits. Employees in occupations that involve medical ionizing radiation are likely to be aware of the exposure as well as the risks involved; many are subject to required training on the topic. Patients, however, are not necessarily briefed on the amount of radiation they are receiving, nor the possible effects.

SCIs confer multiple reasons for high cumulative radiation exposure, including concomitant injuries, long hospital stays, complications and the high effective dose associated with spinal imaging. Almost 40% of patients with SCI received greater than the US yearly occupational limit. That patients with SCIs received high levels of radiation was not surprising, given the severity of this type of injury. However, our spinal fracture data included all spine fractures, regardless of severity, meaning that transverse process and isolated spinous process fractures were included along with unstable spinal fractures. Almost one-fifth of patients with spine fractures received exposure over the US occupational yearly limit. The average was 37.7 mSv, which is in the “high” range for occupational exposure and well over the European maximum of 20 mSv. It is possible that many of these patients with spinal fracture are getting high levels of radiation despite having a relatively minor spine injury. While the benefits of advanced imaging for diagnosis, delineation of injuries, and treatment planning are clear, our concern is that patients with relatively minor injuries are exposed to high levels of radiation.

One limitation of this study was this lack of ability to examine severity of fracture or cord injury in individual patients. Including the ISS in our analysis did provide a global idea of injury severity; however, we are unable to comment on the exact degree of spinal injury. Nine patients in the group had a spinal fracture in addition to a SCI, and these patients were included in the SCI

group; however, it is not known how many of these fractures were directly associated with the SCI.

We did not include fluoroscopy time from our analysis as this information was not readily available. This exclusion effectively decreases our estimates for those patients who underwent one of the 178 procedures involving fluoroscopic imaging including IVC (Inferior Vena Cava) filters and operative instrumentation placement. Total fluoroscopy time is one part of this exposure; however, there are many other variables that contribute to patient dose, such as position of the c-arm, technique, and type of fluoroscopy unit. While including fluoroscopy time would have resulted in higher cumulative radiation dose, this further highlights that patients with spinal trauma receive considerable radiation through their hospital stay, and surgeons should be prudent about their use of fluoroscopy, imaging technique and total fluoroscopy time.

As this study was performed at a level I trauma center, patients are often transferred from another institution following an initial workup. Any studies performed outside our institution were not included in this analysis, further underestimating total radiation exposure. Also not included were examinations performed after our study end date.

We also did not account for length of stay in these trauma patients; however, duration of hospitalization could have an effect on radiation exposure. Patients with SCI or severe spine fracture may be hospitalized longer or have more complications and that may lead to higher exposure.

We included pediatric patients in our patient population, but used adult effective dose estimates values in our analysis. Effective dose for pediatric patients is generally greater than for adults; therefore, we are underestimating the exposures to children.²⁵ Use of these estimated doses also underestimates dose for overweight and obese patients, as effective dose increases with higher body mass.

A significant limitation is our use of estimated dose for each study performed. Doses can vary greatly between machines, differ between protocols on the same machine, and depend on patient factors such as size and positioning.^{22,26} These global values, however, did not account for patient variables such as age and size. A recent study estimated the dose for spinal imaging to be higher than in the study we used as our reference doses.¹² While we did not measure exact radiation exposures for our patient population, using the estimated doses may be more generalizable as it takes into account these variations between machines and protocols.

It has been recommended that exposure be kept as low as reasonably allowable while not sacrificing quality of care. But this recommendation relies in part on the ordering physician's appreciation of radiation doses associated with CT scans, which has been shown to be limited in several studies.^{27,28}

Conclusion

Patients with traumatic SCI had significantly higher radiation exposure than those with spine fracture and no cord injury. Effective dose in both populations was high, and a significant number of these patients had exposures over the occupational limit. Exposure was notably higher than we anticipated in the spinal fracture population, as we included minor, stable spine fractures.

Clinical implications

We feel that radiation exposure during diagnostic imaging should not be considered as an isolated entity that raises concern only for that specific imaging test. As a significant proportion of our patients with spinal trauma were subjected to greater than US and European recommended occupational yearly limits during their inpatient stay, many unknowingly, we believe that cumulative radiation exposure should be a concern for our patients. Regardless of radiation dose limits, the goal is to limit exposure as much as is feasible. While the role of advanced imaging in diagnosis and treatment is indispensable, obtaining this information involves risk to the patient. We urge practitioners to be astutely aware of the implications of different imaging studies and weigh these against the benefits when ordering any study. This is what ALARA (as low as reasonably achievable) means. Studies that are needed to accomplish patient care should be obtained. Those that serve any other purpose should not be done. We have to do all we can to limit the risks to our patients, staff, and ourselves.

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