The Journal of **TRAUMA**® *Injury, Infection, and Critical Care*

Cumulative Radiation Dose Caused By Radiologic Studies in Critically Ill Trauma Patients

Patrick K. Kim, MD, Vicente H. Gracias, MD, Andrew D. A. Maidment, PhD,
Michael O'Shea, Patrick M. Reilly, MD, and C. William Schwab, MD

Background: Critically ill trauma patients undergo many radiologic studies, but the cumulative radiation dose is unknown. The purpose of this study was to estimate the cumulative effective dose (CED) of radiation resulting from radiologic studies in critically ill trauma patients.

Methods: The study group was composed of trauma patients at an urban Level I trauma center with surgical intensive care unit length of stay (LOS) greater than 30 days. The radiology records were reviewed. A typical effective dose per study for each type of plain film radiograph, computed tomographic scan, fluoroscopic study, and nuclear medicine study was used to calculate CED.

Results: Forty-six patients met criteria. The mean surgical intensive care unit and hospital LOS were 42.7 ± 14.0 and 59.5 ± 28.5 days, respectively. The mean Injury Severity Score was 32.2 ± 15.0. The mean number of studies per patient was 70.1 ± 29.0 plain film radiographs, 7.8 ± 4.1 computed tomographic scans, 2.5 ± 2.6 fluoroscopic studies, and 0.065 ± 0.33 nuclear medicine study. The mean CED was 106 ± 59 mSv per patient (range, 11–289 mSv; median, 104 mSv). Among age, mechanism, Injury Severity Score, and LOS, there was no statistically significant predictor of high CED. The mean CED in the study group was 30 times higher than the average yearly radiation dose from all sources for individuals in the United States. The theoretical additional morbidity attributable to radiologic studies was 0.78%.

Conclusion: From a radiobiologic perspective, risk-to-benefit ratios of radiologic studies are favorable, given the importance of medical information obtained. Current practice patterns regarding use of radiologic studies appear to be acceptable.

Key Words: Radiology, Radiation, Effective dose, Computed tomography, Arteriography, Critical illness.

J Trauma. 2004;57:510–514.

Radiologic studies inform major decisions and sometimes reveal life-threatening injuries and are thus integral to the care of the trauma patient. Plain film radiography, computed tomography, fluoroscopy, and nuclear medicine are modalities that use ionizing radiation. Exposure to low-level ionizing radiation from individual radiologic studies is associated with infinitesimal risks.[1] However, critically ill trauma patients may undergo many radiologic studies during a hospital stay.[2,3] There are few data regarding either the total number of radiologic studies performed or the cumulative dose of radiation these patients receive.[4–7] Estimating cumulative effective dose of radiation would provide clinicians with objective data where none currently exist, would facilitate comparison among individuals and groups of patients, and would provide a foundation for further investigation.

A brief review of relevant medical physics is warranted. The following definitions are adapted from Hendee and Edwards.[1] Exposure refers to the simple act of exposing tissue to ionizing radiation, without reference to energy source, amount, or biologic effects. Absorbed dose, measured by the rad ($1 \text{ rad} = 0.01 \text{ J kg}^{-1}$) and gray ($1 \text{ Gy} = 100 \text{ rad}$), quantifies the energy absorbed by tissue from any radioactive source. Dose equivalent, measured by the rem and sievert ($1 \text{ Sv} = 100 \text{ rem}$), standardizes absorbed doses from different types of radiation by using a radiation quality factor. For x- and gamma radiation, the types of radiation used for medical imaging, the radiation quality factor is 1. Thus, $1 \text{ Sv} = 1 \text{ Gy}$. Radiation effects also vary by tissue type, requiring tissue-specific weighting factors. Effective dose, the sum of tissue dose equivalents, is a single quantity reflecting the overall effect of radiation on the whole organism. It is also measured by the rem and sievert. Effective dose is considered the most useful quantity for comparing radiation exposure from different procedures.[8] In this study, cumulative effective dose (CED) is defined as the sum of the effective doses of all radiologic studies. Finally, total detriment is the probability of adverse effects from radiation. Derived by radiation biologists, total detriment incorporates malignancy, hereditary defects, loss of life, and loss of quality of life. The total detriment allows comparison of radiation effects to other environmental and occupational hazards. Total detriment for medical sources of radiation is $7.3 \times 10^{-2} \text{ Sv}^{-1}$ (i.e., the

---

Submitted for publication March 23, 2004.
Accepted for publication May 18, 2004.

From the Division of Traumatology and Surgical Critical Care, Department of Surgery (P.K.K., V.H.G., P.M.R., C.W.S.), and Department of Radiology (A.D.A.M., M.O.), University of Pennsylvania School of Medicine, Philadelphia, Pennsylvania.

Poster presentation at the 17th Annual Meeting of the Eastern Association for the Surgery of Trauma, January 13–17, 2004, Amelia Island, Florida.

Address for reprints: Patrick K. Kim, MD, Division of Traumatology and Surgical Critical Care, University of Pennsylvania School of Medicine, 3440 Market Street, Philadelphia, PA 19104; email: kimp@uphs.upenn.edu.

DOI: 10.1097/01.TA.0000141028.97753.67

Table 1 Radiologic Studies Included in Calculation of CED

Plain Film Radiography	Computed Tomographic Scan	Fluoroscopy	Nuclear Medicine
Chest	Head	Diagnostic angiography	V/Q study
Abdomen	Chest	Angioembolization	Hepatobiliary scan
Pelvis	Abdomen	Vena caval filter	
Spine	Pelvis	Neuroangiography	
Extremity	Spine	Upper gastrointestinal series	
	CT angiography	Small bowel follow through	
		Contrast enema	
		Tube/drain study	
		Cystography/urethrography	

CED, cumulative effective dose; V/Q, ventilation-perfusion.

probability of clinically evident harm attributable to a 1-Sv dose is 0.073, or 7.4%).[1] The purpose of this study was to estimate the cumulative effective dose of radiation from radiologic studies in critically ill trauma patients.

PATIENTS AND METHODS

The trauma registry of our institution, an urban Level I trauma center, was queried for patients admitted between January 1998 and January 2003 who had surgical intensive care unit (SICU) length of stay (LOS) greater than 30 days, a period representing “chronic” critical illness. The radiology records of the index trauma admission were reviewed. All studies using ionizing radiation were tabulated (Table 1). A typical effective dose for each type of plain film radiograph (XR), computed tomographic (CT) scan, and nuclear medicine study (NM) was obtained from references in the literature[8–12] or estimated by a radiation physicist if no typical dose could be found. Effective dose from each fluoroscopic study (FL) was a product of the total fluoroscopy time and the fluoroscopic dose rate, both obtained from department of radiology records. The CED was defined as the sum of effective doses of all studies during the index admission. Fluoroscopic studies performed by surgeons in the operating room were excluded from analysis, because data regarding fluoroscopic dose time and rate were incomplete. The study group’s CED from radiologic studies was compared with average annual CED for members of the general population from background, medical, and consumer products (3.6 mSv in the United States).[1] The total detriment was calculated as the product of CED and total detriment from x-radiation ($7.3 \times 10^{-2}\ \text{Sv}^{-1}$). Values are given as mean ± 1 SD where appropriate. Correlation between CED, age, Injury Severity Score (ISS), hospital LOS, and SICU LOS, was determined by regression analysis. The Student’s *t* test was used to compare means among subgroups. The protocol was approved by our institutional review board.

RESULTS

During the study period, 46 trauma patients had SICU LOS greater than 30 days. Eighty percent were male patients. Mechanisms of injury were motor vehicle crash (43% of total); gunshot wound (26%); fall (17%); pedestrian struck by motor vehicle (7%); and crush, assault, or smoke inhalation (other) (7%) (Fig. 1). The mean age was 43.4 ± 21.2 years. The mean ISS was 32.2 ± 15.0. The mean SICU LOS was 42.7 ± 14.0 days. The mean hospital LOS was 59.5 ± 28.5 days (Table 2). By mechanism, there was no statistically significant difference in ISS, SICU LOS, or hospital LOS.

In total, the study group underwent 3,223 XRs, 359 CT scans, 117 FLs, and 3 NMs. The mean number of studies per patient was 70.1 ± 29.0 XRs, 7.8 ± 4.1 CT scans, 2.5 ± 2.6 FLs, and 0.065 ± 0.33 NMs (Fig. 2). The mean CED resulting from radiologic studies was 106 ± 59 mSv (range, 11–289 mSv; median, 104 mSv). XR, CT scan, FL, and NM contributed 12.3%, 66.6%, 21.1%, and 0.02%, respectively, to the CED (Fig. 3). The distribution of CED in the study group is shown in Figure 4. By mechanism of injury, patients who sustained gunshot wounds had the highest mean CED, followed by motor vehicle crash, pedestrian struck by motor vehicle, and fall, although there were no statistically significant differences among groups (Fig. 5). Among age, ISS, and hospital or SICU LOS, there was no correlation with CED

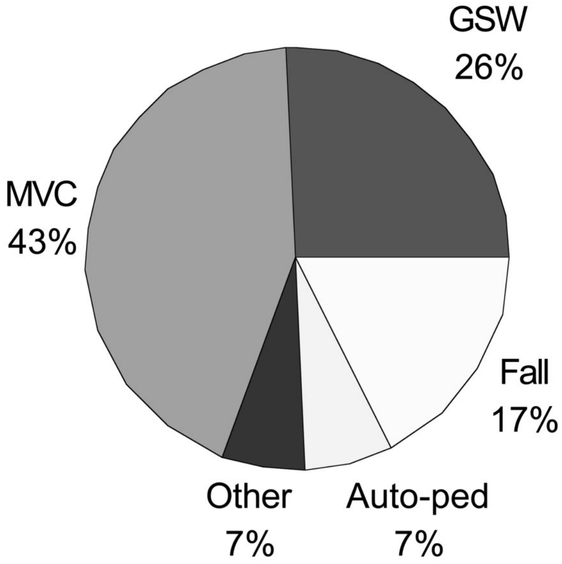

Fig. 1. *Mechanism of injury in the study group. MVC, motor vehicle collision; GSW, gunshot wound; Auto-ped, pedestrian struck by motor vehicle.*

Table 2 Characteristics of the Study Group by Mechanism of Injury

	All	GSW	MVC	Fall	Auto-ped	Other
No. of patients	46	12	20	8	3	3
Males (%)	80	100	75	57	67	100
Age (yr)	43.4 ± 21.2	29.7 ± 9.7	45.4 ± 24.2	63.6 ± 19.6	35.0 ± 13.0	46.3 ± 4.6
ISS	32.2 ± 15.0	30.0 ± 20.9	34.0 ± 13.4	34.1 ± 14.3	34.0 ± 9.0	24.8 ± 5.0
SICU LOS (days)	42.7 ± 14.0	39.3 ± 5.5	46.0 ± 18.6	46.1 ± 13.0	35.7 ± 3.1	36.3 ± 5.7
Total LOS (days)	59.5 ± 28.5	53.9 ± 15.4	66.2 ± 35.4	52.6 ± 12.0	70.3 ± 56.2	47.3 ± 10.5

GSW, gunshot wound; MVC, motor vehicle collision; Auto-ped, pedestrian struck by motor vehicle; ISS, Injury Severity Score; SICU, surgical intensive care unit; LOS, length of stay.

Mean ± SD where appropriate.

(Table 3). The mean CED exceeded the typical yearly dose to persons in the United States by a factor of 29.5. Total detriment from this CED is $(106 \times 10^{-3}\ \text{Sv})\ (7.3 \times 10^{-2}\ \text{Sv}^{-1}) = 7.8 \times 10^{-3}$. In other words, the theoretical probability of morbidity or mortality attributable to effects of the radiologic radiation is 0.78%.

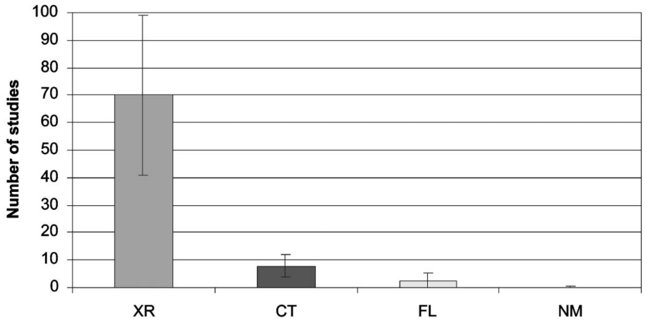

Fig. 2. *Mean number of radiologic studies per patient during index admission by modality. XR, plain film radiograph; CT, computed tomographic scan; FL, fluoroscopic study; NM, nuclear medicine study. Error bars indicate 1 SD.*

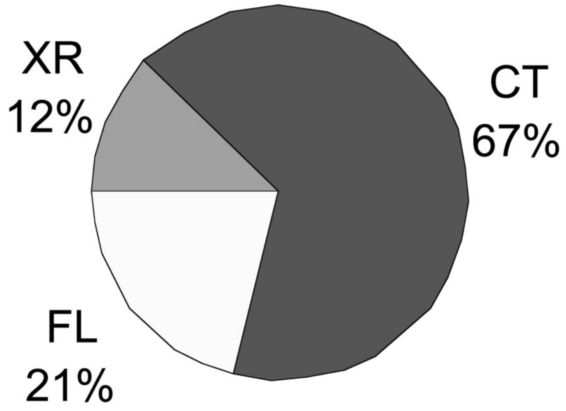

Fig. 3. *Overall effective dose of radiation by radiologic modality. XR, plain film radiograph; CT, computed tomographic scan; FL, fluoroscopic study. Nuclear medicine studies contributed 0.02% to the total.*

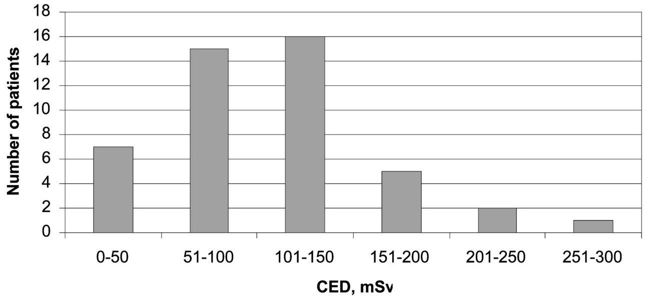

Fig. 4. *Distribution of CED in study group. CED, cumulative effective dose.*

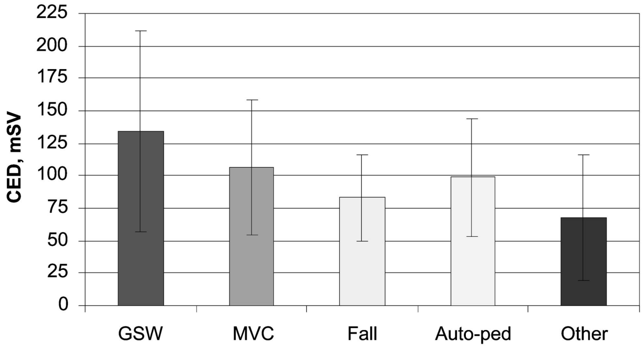

Fig. 5. *Mean cumulative effective dose of radiation from radiologic studies by mechanism of injury. CED, cumulative effective dose; GSW, gunshot wound; MVC, motor vehicle collision; Auto-ped, pedestrian struck by motor vehicle. Error bars indicate 1 SD.*

Table 3 Correlation of Variables with Cumulative Effective Dose

	R^2
Age vs. CED	0.0303
ISS vs. CED	0.0058
Hospital LOS vs. CED	0.0499
SICU LOS vs. CED	0.0695

ISS, Injury Severity Score; LOS, length of stay; SICU, surgical intensive care unit.

DISCUSSION

Radiologic studies are integral to the evaluation of the trauma patient. Radiographs, CT scans, and interventional radiology studies frequently reveal life-threatening injuries that require immediate intervention. Indeed, in select circumstances, there are no reasonable alternatives to specific radiologic studies. Among patients who require single or only sporadic radiologic studies, the benefit from information obtained usually far outweighs the infinitesimal risk from radiation. However, advances in trauma care have resulted in a growing number of patients who survive severe injury or complication and subsequently require long hospital or SICU stay because of critical illness. These "chronically" critically ill trauma patients are a unique cohort because of the frequent exposure to low-level radiation from radiologic studies. There is a conspicuous absence of literature to quantify cumulative radiation dose in either trauma or SICU patients, although some studies have estimated radiation exposure among patients with shorter lengths of stay in the intensive care unit[4] or examining dose from chest radiography only.[7] As both trauma care and radiology evolve, it is incumbent on trauma physicians to understand risks and benefits of diagnostic and therapeutic interventions. This study was undertaken to characterize the pattern of radiologic studies performed in critically ill trauma patients and to estimate the magnitude of radiation exposure in this group.

The patients in this study underwent a surprising number of radiologic studies. As expected, plain film radiographs were by far the most common studies performed. In the initial evaluation of trauma patients at our institution, a chest radiograph is routinely obtained, and extremity radiographs are obtained as clinically indicated. Pelvic radiographs were obtained with decreasing frequency.[13] When spine imaging was indicated, the cervical and thoracic spine was imaged by plain radiography, whereas the lumbosacral spine was increasingly imaged with anteroposterior and lateral CT scouts ("scanograms") in patients who required CT scanning to evaluate the abdomen.[14] During subsequent stay in the SICU, patients in this group underwent chest radiography many times. Because there was no institutional policy regarding daily chest radiographs for intubated patients, practice patterns varied by treating physician. No attempt was made to retrospectively determine the utility of radiographs.

Computed tomographic studies constituted less than 10% of the total number of studies performed but accounted for two thirds of the total radiation dose. During initial trauma evaluation, CT scans were selectively obtained on the basis of history, physical examination, and plain film findings. Like plain films, the majority of CT scans in this study were obtained after initial trauma evaluation during SICU stay. Because the indications for obtaining CT scans were not retrospectively evaluated in this study, it is not possible to determine the diagnostic utility of CT scanning in our study group. Among patients with solid organ injury, follow-up CT scans were not routinely obtained as part of nonoperative management. Although some CT scans were obtained solely for diagnosis, others were performed for guidance of aspiration and drainage procedures. As described above, CT scanning of the spine was performed to image the portions of the cervical spine incompletely imaged by plain film and to selectively image portions of the spine suspected of having injury by plain film. Among patients who required abdominopelvic CT scanning, the anteroposterior and lateral CT scanograms supplanted lumbosacral plain films.[14]

Fluoroscopic studies were also used frequently for both diagnosis and treatment of injuries (e.g., angioembolization)[15] and complications (e.g., drainage of intra-abdominal abscess). Fluoroscopic studies varied widely in effective dose, because of both varying dose rates and varying dose times. Nuclear medicine studies were unusually rare, reflecting the growing use of other modalities for excluding pulmonary embolism and cholecystitis.

The mean CED in the study group was striking, especially considering that the radiation exposure occurred over a mean of approximately 2 months. Despite this, the calculated total detriment (i.e., the sum of adverse effects, including loss of life and loss of quality of life) was less than 1%. No studies have documented adverse short- or long-term effects directly attributable to frequent diagnostic radiologic procedures, which are considered to be "low-dose" exposure by radiation biologists. However, adverse effects of high-dose radiologic procedures have been reported: high-dose fluoroscopy from cardiac catheterization and transjugular intrahepatic portosystemic shunt procedures has been associated with short-term dermatologic complications,[16] and in utero high-dose radiation exposure early in pregnancy has been implicated in fetal complications[17] and risk of childhood leukemias.[18]

Interestingly, CED was not predicted by age, mechanism of injury, ISS, or length of stay. The study group was heterogeneous in clinical course, and this was likely the most important factor in determining an individual's CED. Given that the majority of CED resulted from CT scanning, it is plausible that the strongest predictor of most individuals' CED is simply the number of CT scans obtained. With recent studies demonstrating the superiority of CT scanning over plain film radiography to evaluate the cervical, thoracic, and lumbosacral spine, it seems likely that the use of CT scanning will only increase with time.[14,19,20]

This study has several limitations. It is a retrospective, single-center experience. There was no attempt to directly measure patient exposure at the time that studies were performed. Technique factors for plain film studies and CT scans were at the discretion of the radiologic technologist. In essence, effective doses were estimated post facto. Furthermore, the typical effective dose for specific studies obtained from the literature may differ from typical effective doses at this institution. Of note, the radiation dose required for radiologic studies is determined by patient weight. Thus, weight differences between the study population and the reference population affect CED. Because the scope of the current study was simply to quantify the number and effective dose of radiologic studies performed, no attempt was made to evaluate the indications for or utility of radiologic studies obtained. Finally, it is emphasized that effective dose is subject to variability[21] and that total detriment is at best merely an estimate of effects of radiation, because it is derived by radiation advisory committees based on observational studies.[1]

In summary, critically ill trauma patients at our institution underwent many radiologic studies during their index admission. Despite a large cumulative effective dose of radiation, the estimated risks of radiation attributable to these studies are minute. From a radiobiologic perspective, cumulative radiation doses from radiologic studies appear to be acceptable, given that radiologic studies and procedures are potentially life saving in the acute setting and may guide major clinical decisions. Current practice patterns regarding radiologic studies are probably justified. The long-term effects of cumulative radiation exposure deserve further study.

ACKNOWLEDGMENT

We thank Keith Maston for computational assistance.

REFERENCES

1. Hendee WR, Edwards FM. *Health Effects of Exposure to Low-Level Ionizing Radiation*. Philadelphia: Institute of Physics Publishing; 1996.
2. Chahine-Malus N, Stewart T, Lapinsky SE, et al. Utility of routine chest radiographs in a medical-surgical intensive care unit: a quality assurance survey. *Crit Care (London).* 2001;5:271–275.
3. Price MB, Grant MJ, Welkie K. Financial impact of elimination of routine chest radiographs in a pediatric intensive care unit. *Crit Care Med.* 1999;27:1588–1593.
4. Boles JM, Boussert F, Manens JP, Le Cam B, Bellet M, Garre M. Measurement of irradiation doses secondary to bedside radiographs in a medical intensive care unit. *Intensive Care Med.* 1987;12:60–63.
5. Henschke CI, Yankelevitz DF, Wand A, Davis SA, Shiau M. Chest radiography in the ICU. *Clin Imaging.* 1997;21:90–103.
6. Diederich S, Lenzen J. Radiation exposure associated with imaging of the chest: comparison of different radiographic and computed tomography techniques. *Cancer.* 2000;89(11 suppl):2457–2460.
7. Pandit-Bhalla M, Diethelm L, Espenan G. Portable chest radiographs in the intensive care units: referral patterns and estimated cumulative radiation exposures. *J Thorac Imaging.* 2002;17:211–214.
8. Wall BF, Hart D. Revised radiation doses for typical x-ray examinations: report on a recent review of doses to patients from medical x-ray examinations in the UK by NRPB. *Br J Radiol.* 1997;70:437–439.
9. Weatherburn GC, Bryan S, Davies JG. Comparison of doses for bedside examinations of the chest with conventional screen-film and computed radiography: results of a randomized controlled trial. *Radiology.* 2000;217:707–712.
10. U.S. Food and Drug Administration. What are the radiation risks from CT? Available at: http://www.fda.gov/cdrh/ct/risks.html. Accessed June 20, 2003.
11. Parry RA, Glaze SA, Archer BR. The AAPM/RSNA physics tutorial for residents: typical patient radiation doses in diagnostic radiology. *Imaging Ther Technol.* 1999;19:1289–1302.
12. McParland BJ. A study of patient radiation doses in interventional radiological procedures. *Br J Radiol.* 1998;71:175–185.
13. Guillamondegui OD, Pryor JP, Gracias VH, Gupta R, Reilly PM, Schwab CW. Pelvic radiography in blunt trauma resuscitation: a diminishing role. *J Trauma.* 2002;53:1043–1047.
14. Gestring ML, Gracias VH, Feliciano MA, et al. Evaluation of the lower spine after blunt trauma using abdominal computed tomographic scanning supplemented with lateral scanograms. *J Trauma.* 2002;53:9–14.
15. Johnson JW, Gracias VH, Gupta R, et al. Hepatic angiography in patients undergoing damage control laparotomy. *J Trauma.* 2002;52:1102–1106.
16. Geise RA, O'Dea TJ. Radiation dose in interventional fluoroscopic procedures. *Appl Radiat Isot.* 1999;50:173–184.
17. Dekaban AS. Abnormalities in children exposed to x-irradiation in utero. *Surg J Nucl Med.* 1968;9:471–477.
18. Diamond EL, Schmerler H, Lilienfeld AM. The relationship of intrauterine radiation to subsequent mortality and development of leukemia in children: a prospective study. *Am J Epidemiol.* 1973;97:283–313.
19. Berne JD, Velmahos GC, El-Tawil Q, et al. Value of complete cervical helical computed tomographic scanning in identifying cervical spine injury in the unevaluable blunt trauma patient with multiple injuries. *J Trauma.* 1999;47:896–903.
20. Sheridan R, Peralta R, Rhea J, Ptak T, Novelline R. Reformatted visceral protocol helical computed tomographic scanning allows conventional radiographs of the thoracic and lumbar spine to be eliminated in the evaluation of blunt trauma patients. *J Trauma.* 2003;55:665–669.
21. Wall BF. Diagnostic reference levels: the way forward. *Br J Radiol.* 2001;74:785–788.