Repeated computed tomographic scans in transferred trauma patients: Indications, costs, and radiation exposure

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BACKGROUND: Trauma patients are often transferred to regional Level I trauma centers from other institutions. At times, when the patient presents to the trauma center, radiologic studies performed at the previous institution are repeated. The aim of this study was to assess the proportion of computed tomographic (CT) scans repeated in trauma patients receiving CT scans before transfer and to obtain the indications for these repeats. This study also estimated the additional radiation dose and economic burden associated with repeated CT scans.

METHODS: This prospective, observational cohort study collected data consecutively on transferred trauma patients who had received a CT scan at the transferring institution and investigated whether the CT scan was repeated at the receiving institution. Indications for repeating CT scans were obtained from the general surgery trauma service. The economic impacts were assessed using fee schedules from the hospital and the Center of Medicare and Medicaid Services. Effective dose radiation was estimated using the dose-length product method.

RESULTS: Of the 211 patients who presented with a previous CT scan at the transferring institution, 82 had at least one repeated CT scan. Indications for repeating CT scans varied based on the body region. Additional hospital charges ranged from $728 to $5,892 with an average of $1,762.40 for patients having one or more repeated CT scans. The estimated additional effective dose radiation ranged from 1.2 mSv to 124 mSv with an average of 21.5 mSv.

CONCLUSION: This study reveals the high rates of repeated CT scans in transferred trauma patients and the various indications that lead to them. Additional hospital charges and additional low levels of radiation exposure are a consequence of these repeats. (*J Trauma Acute Care Surg*. 2012;73: 1564–1569. Copyright © 2012 by Lippincott Williams & Wilkins)

LEVEL OF EVIDENCE: Diagnostic study, level IV.

KEY WORDS: Radiation exposure; effective dose; repeated imaging; computed tomography; trauma transfer.

Trauma systems in the United States frequently rely on patient transfers from local institutions to regional Level I trauma centers. At times, patients receive computed tomographic (CT) scans during their initial evaluation before transfer to the trauma center.[1] However, when the patient presents to the trauma center, these scans are often repeated. CT scans are a sensitive, minimally invasive method for diagnosing injury in trauma patients.[2–4] Nevertheless, they have the disadvantage of increasing radiation exposure and incurring greater costs compared with plain radiographs.[5–7] The practice of repeating CT scans on transferred trauma patients may have negative consequences owing to radiation exposure and economic burden.

Effective dose radiation from CT scans is more than 100 times greater than that received by a routine chest x-ray.[7] Previous studies reported that CT scans account for two thirds of the radiation dose that trauma patients receive; in general, trauma patients averaged 22 mSv, which increased to 106 mSv in critically injured patients requiring intensive care unit stays greater than 30 days.[8,9] The effects of high dose radiation, defined as greater than 100 mSv, have been investigated in atomic bomb survivors, and excess cancer rates in this cohort were attributed to radiation exposure.[10–12] The effective dose radiation of CT scans can vary widely but typically falls in the range of 0.3 mSv to 45 mSv, depending on the body location and the use of contrast.[13,14] These levels of effective dose radiation are classified as low dose; the epidemiologic studies performed in atomic bomb survivors found some evidence of elevated cancer risk compared with the general population at levels greater than 50 mSv.[11] Repeated CT scans in transferred trauma patients could result in cumulative radiation dose levels shown to have an increased risk of cancer, especially in younger patients who are more sensitive to radiation effects.

Expense is another important factor to consider when repeating CT scans. With the constant push to decrease health care costs in the United States, the impact of imaging procedures has been investigated. One study reported 31% of high-cost imaging studies were repeated.[15] The Medicare Payment Advisory Commission reported that diagnostic imaging services grew by 62% from 1999 to 2004, the highest of all physician service categories. In dollar terms, this resulted in Medicare spending increases from $5.8 billion in 1999 to $10.9 billion in 2004.[6] Much of this expense was disproportionately caused by high-cost advanced imaging modalities such as magnetic resonance imaging and CT scans.

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The aim of this study was to assess the proportion of CT scans repeated in trauma patients who had received CT scans before transfer from the previous institution and to obtain the indications for these repeats. Moreover, this study estimated the additional effective dose radiation and economic burden associated with the repeated CT scans.

PATIENTS AND METHODS

This study was approved by the institutional review board of our institution; the requirement for informed consent was waived.

Study Population

This is a prospective observational cohort study at an institution that holds a Level I trauma designation for adults and a Level II trauma designation for pediatrics. It received 1,460 patient transfers in 2010 from the regional referral basis. The data collection period was August 1, 2010, to November 30, 2010, and the sample population was obtained consecutively. Subjects included trauma patients transferred to our institution's emergency department who had previously been evaluated and underwent CT scan at an outside institution. Patients were excluded from enrollment if they were not paged as a trauma through the emergency department triage system or if they were directly admitted to the hospital, bypassing the standard trauma evaluation. Moreover, patients were excluded from the analysis if their outside CT scan images were unable to be verified or if, on subsequent chart review, their medical diagnoses were found to be unrelated to trauma.

Data Collection

Once subjects met enrollment criteria, efforts were made to obtain and document the CT scan images performed at the transferring institution. The CT images were scanned from the compact discs (CDs); they were transferred on into an electronic database for storage and assessment. In the event that CDs with CT scan images went missing, efforts were made to obtain a new CD from the transferring hospital. CT studies that were repeated on the initial trauma evaluation were documented, and the indication was sought from either the attending trauma surgeon or chief surgical resident on-call during that trauma evaluation.

Indications for repeated CT scans included technical problems, image problems, reporting problems, clinical reasons, consult request/convenience, and unintentional/error. A technical problem was defined as a problem opening the software, which contained the images, or a problem with manipulating the images in a timely fashion. An image problem included patients who arrived without the digital images, the images inappropriately contained or omitted contrast, or images were deemed as poor quality by the trauma staff on-duty during that patient's evaluation. Reporting problems included patients who arrived without a report stating what was found on the CT scans at the transferring institution or if there was any discrepancy between the report and what the trauma staff reading the images interpreted. At times, the trauma service consulted orthopedics, neurosurgery, otolaryngology, and oral maxillofacial surgery, and if these consulting services requested or ordered a repeated CT scan, this indication was classified under the consult request/convenience category. Moreover, if repeated CT scans were ordered by the trauma service as a courtesy to the consult service, then this indication was also classified under the consult request/convenience category. Rarely, a CT scan was ordered in error by a junior member of the trauma staff; this repeated CT scan was usually caused by a misunderstanding or miscommunication. There were a few repeated images for which we were unable to obtain the indications owing to the fact that we did not immediately approach the trauma staff for the indication, and by the time we did request the indication, they no longer recalled the reason. Finally, clinical reasons included changes in the patient's clinical presentation that warranted reevaluation such as new onset vomiting in a potential head injury. Moreover, if the patient had a previous finding of intracranial bleed at the transferring institution, a repeated head CT scan evaluating for interval changes was considered a clinical indication. If CT scans were obtained for clinical reasons, they were deemed unpreventable and not included in the analysis of preventable CT scans.

Effective Dose Calculation

A record of the dose-length product (DLP) for each CT scan performed was maintained and stored. Owing to a software malfunction, the DLP information for one patient was not recorded. However, this patient had one repeated CT scan that was caused by a clinical reason; therefore, these data were not necessary for our analysis. The DLP values, along with DLP conversion coefficients (k) specific to the respective subject's age and body region scanned, were used to estimate the effective dose received with each respective CT scan. The following equation represents the formula used where E represents effective dose measured in millisieverts:[16]

$$E \approx k(\mathrm{DLP})$$

Economic Calculations

Two sources were used to assess costs. First, the hospital's fee schedule was used to obtain the hospital charges for each CT scan repeated. These values are specific only to one institution. The second source was the Center of Medicare and Medicaid Services (CMS) physician fee schedule 2010B for our state. These values are the same among institutions within our state but differ from other states. The combined value of the technical and physician (26) components were used from each fee schedule.

Statistical Methods

Multivariate logistic regression models were created to determine whether demographic and trauma-related variables influenced the likelihood of having a preventable repeated CT scan. Variables were first analyzed in univariate models. Variables that were found to have significance were then included in multivariate models. Statistical significance was set at $p < 0.05$.

RESULTS

Our sample population included 211 transferred trauma patients, of which 140 were males (Table 1). The age distributions were similar among categories with a slight increase in the age group of 60 years and older. Most of the patients had

TABLE 1. Patient Demographics and Trauma Characteristics

	n	Percentage
Gender		
Male	140	66.4
Female	71	33.6
Age		
Mean	44.7	
0–19	51	24.2
20–39	47	22.3
40–59	44	20.9
≥60	69	32.7
ISS		
Mean	11.7	
≤15	141	66.8
16–23	46	21.8
24–33	20	9.5
≥34	4	1.9
Mechanism		
Assault	24	11.4
Crush	7	3.3
Fall	92	43.6
ATV/MCC	34	16.1
MVC	51	24.2
Penetrating	3	1.4
Insurance		
Auto	3	1.4
Workers compensation	4	1.9
Veteran's administration	2	0.9
Commercial	70	33.2
Medicare	60	28.4
Medicaid	32	15.2
None	40	19.0

ATV, all -terrain vehicle accident; MCC, motorcycle crash; MVC, motor vehicle crash.

TABLE 2. Proportion of Patients With a Repeated CT and Types of Repeated CT scans

	Total/Initial	Repeats		95% CI
Patients	211	82	38.9%	32.5–45.6
CT scans	570	149	26.1%	22.7–29.9
Head	168	26	15.5%	10.8–21.7
C-spine	135	53	39.3%	31.4–47.7
Chest	60	22	36.7%	25.6–49.3
Abdomen	64	19	29.7%	19.9–41.8
Pelvis	60	19	31.7%	21.3–44.2
Maxillofacial	41	8	19.5%	10.2–34.0
T-spine	15	1	6.7%	1.2–29.8
LS-spine	21	1	4.8%	0.8–22.7
Other	6	0	0%	—

CI, confidence interval; C-spine, cervical spine; LS-spine, lumbosacral spine; T-spine, thoracic spine.

an Injury Severity Score (ISS) less than or equal to 15. Falling was the mechanism responsible for most of these traumas. Penetrating trauma was rare in this sample. Commercial insurance and Medicare were the two predominant types of insurance; 40 patients (19%) had no form of insurance.

Of the 211 patients who presented with a previous CT scan at the transferring institution, 82 (38.9%) had at least one repeated CT scan (Table 2). Cervical spine CT scans were repeated most frequently, and maxillofacial, thoracic spine, and lumbosacral spine CT scans were rarely repeated. In our multiple logistic regression model, we found that a unit increase in the ISS increased the odds of obtaining a repeated CT scan by 0.036 ($p = 0.0361$). Although age was not significant, it trended toward an increased odds of 0.009 ($p = 0.0882$) with each additional year.

Indications for repeated CT scans varied based on the body region being scanned (Table 3). For the head, the predominant reason was because of technical problems. Technical problems, reporting problems, and consult request/convenience were the most frequently reported indications for repeating CT scans of the cervical spine. Technical and imaging problems were the predominant indications for chest, abdomen, and pelvis CT scans. Repeated maxillofacial, thoracic spine, and lumbosacral spine CT scans were rare; therefore, determining a predominant indication for these body regions is less informative.

Using the hospital fee schedule, the additional hospital charges ranged from $728 to $5,892 per patient that had one or more repeated CT scans; the majority had fees less than $2,000 (Fig. 1). The combined additional charges totaled $144,517 in this sample, which averages to $1,762.40 per patient for those receiving at least one repeated CT scan. However, when using the CMS physician fee schedule, the additional fees ranged from $182.97 to $1,530.06, and most of the patients had fees less than $600 (Fig. 2). The combined additional CMS fees totaled $37,121.47, which averages to $452.70 per patient for those receiving at least one repeated CT scan.

TABLE 3. Indications for Repeated CT Scans

	Total		Head		C-spine		Chest		Abd		Pelvis		Face		T-spine		LS-spine	
Technical problem	49	32.9%	12	46.2%	16	30.2%	7	31.8%	6	31.6%	6	31.6%	2	25.0%	0	0%	0	0%
Image problem	28	18.8%	2	7.7%	4	7.5%	8	36.4%	5	26.3%	7	36.8%	2	25.0%	0	0%	0	0%
Report problem	37	24.8%	8	30.8%	15	28.3%	3	13.6%	4	21.1%	4	21.1%	2	25.0%	0	0%	1	100%
Consultant/convenience	20	13.4%	2	7.7%	14	26.4%	1	4.5%	1	5.3%	0	0.0%	1	12.5%	1	100%	0	0%
Unintentional error	7	4.7%	2	7.7%	1	1.9%	2	9.1%	1	5.3%	0	0.0%	1	12.5%	0	0%	0	0%
Missing data	8	5.4%	0	0.0%	3	5.7%	1	4.5%	2	10.5%	2	10.5%	0	0.0%	0	0%	0	0%

Abd, abdomen; C-spine, cervical spine; Face, maxillofacial; LS-spine, lumbosacral spine; T-spine, thoracic spine.

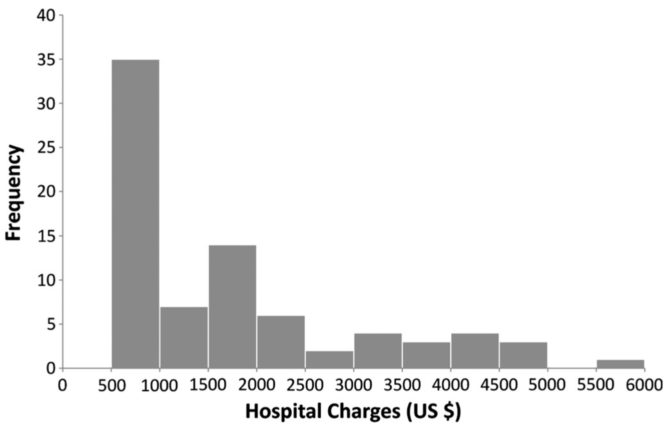

Figure 1. Additional hospital charges (US$) to each patient for repeated CT scans.

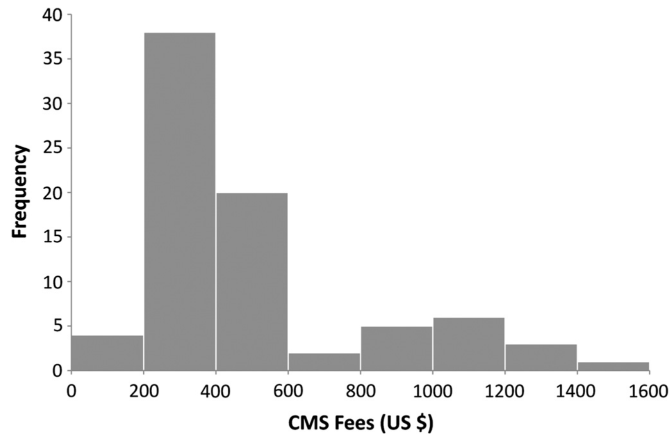

Figure 2. Additional CMS fees (US$) to each patient for repeated CT scans.

The estimated additional effective dose radiation received from the repeated CT scans ranged from 1.2 mSv to 124 mSv with most of the patients having additional effective dose radiation levels less than 20 mSv (Fig. 3). The average estimated effective dose per patient with at least one repeated CT scan equaled 21.5 mSv.

DISCUSSION

Of the 211 transferred trauma patients who received CT scans before arrival at our institution, more than one third received at least one preventable repeated CT scan. The predominant indications for these repeats differed based on the body region being evaluated. This study demonstrates the consequences of these repeats, including the additional imaging charges of $1,762.40 or CMS fees of $452.70 per patient with a repeated CT scan. Patients undergoing a repeated CT scan had an average additional radiation exposure of 21.5 mSv. Studies further assessing the financial consequences should investigate who takes financial responsibility for the additional charges from repeated images. Are they the patient's responsibility, do insurance companies cover them, or do the hospitals ultimately absorb these costs?

There are several limitations to this study including the fact that it was performed in one trauma institution in a rural network. Therefore, these results may not be reflected in other types of institutions or trauma networks. Moreover, this study required observation and inquiry about the decision by the trauma staff at our institution to repeat CT scans. This increases the potential of the Hawthorne effect, in which participants being studied or observed alter or improve their behavior because they are aware they are being studied. If this is true, then the reported results may be an underestimate. Another limitation is the use of a single institution's fee schedule to determine the financial burden. As previously mentioned, these fee schedules vary from one institution to the next and are therefore not generalizable. We included the 2010B CMS physician fee schedule for our state, but again, this schedule differs among states. Moreover, we estimated effective dose radiation exposure using the DLP method, which has been found to underestimate the effective dose by 14% to 37% when compared with more direct measurements.[17,18] Therefore, the actual additional effective dose radiation received is probably slightly higher than the calculations presented in this study. We did not estimate the total effective dose radiation the patients received because we did not include the original CT scans obtained at the transferring institution or the nonrepeated CT scans obtained at the receiving institution. Finally, the radiology department at our institution does not formally consult on outside imaging studies, which would make the proportion of repeated CT scans caused by reporting problems nongeneralizable to other institutions that do consult on outside studies.

Another study performed in an urban trauma setting noted 53% of patients received at least one duplicate image (including plain radiographs and CT scans), and these repeats resulted in $2,985 in additional charges per patient who received duplicate imaging; most of the these charges were caused by CT scans.[19] Our study shows a lower average additional hospital charge per patient with a duplicate, and when looking at CMS fees, the results are more modest. These discrepancies may be explained by differences in the respective institutional fee schedules as well as the fact that the previous study did not include CMS fee schedules.

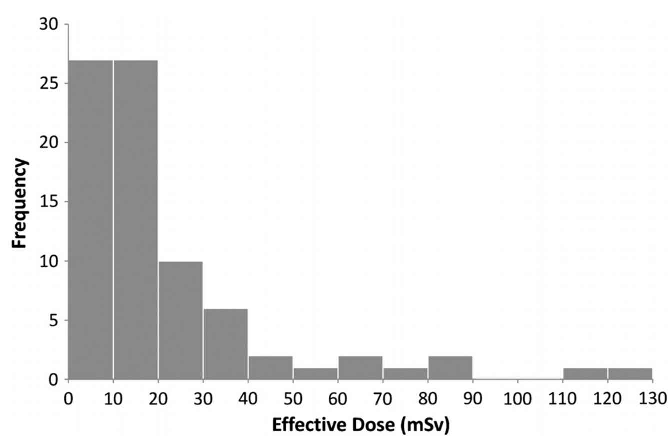

Figure 3. Estimated additional effective dose radiation (mSv) each patient received from repeated CT scans.

To our knowledge, no previous study has investigated the additional effective dose radiation exposure caused by repeated images in transferred trauma patients. Concern about the potential dangers of medical radiation exposure is rising.[20–23] Epidemiologic studies demonstrate the carcinogenic effects of high-dose radiation levels in subjects exposed to gamma radiation.[11,24] However, medical radiation uses x-rays, not gamma rays, and minimal evidence is available to demonstrate carcinogenic risks with the levels of radiation currently used in most medical evaluations. Nevertheless, an important factor to consider when repeating CT scans is the patient's age. Children are more sensitive to radiation exposure because they are growing and their cells are dividing more rapidly. Moreover, children have a longer life expectancy following their radiation exposure and are more likely to survive the interval of time needed for the radiation effects to present.[25] As previously stated, the evidence of cancer risks from high-dose radiation is more clearly defined, and 1 Sv (1,000 mSv) is associated with a risk close to 15% in neonates.[26] One study estimated the risk of low-dose radiation in children exposed to one head CT scan and demonstrated that the lifetime attributable cancer mortality risk was 0.05% (1 in 2,000) in a neonate, less than 0.01% (< in 10,000) in a 15-year-old, and less than 0.005% (<1 in 20,000) in a 35-year-old.[27] In our multivariate logistic regression, models trended toward a higher likelihood of having a repeated CT scan as age increased. This may reflect an understanding by trauma staff of the potential risks that radiation poses to younger patients.

Our results support the findings of similar studies investigating repeated images in transferred trauma patients. One study, also performed in a rural trauma network, found 58% of the patients with CT scans before transfer underwent repeated CT imaging and found similar indications for the repeats that varied based on body region.[28] Our study highlights areas where future efforts can be focused to limit the number of repeated CT scans in trauma patients. Another study demonstrated that importing outside images from the transferred CD into the receiving institution's picture archive and communication system resulted in a 16% to 29% reduction in repeated CT scans.[29] Importing images into the institution's picture archive and communication system would not only aid in viewing the images using familiar software, but it would also potentially decrease the need to repeat CT scans for the consulting services. During this study, we were informed by both the trauma service and the consulting services of their concern for losing the CD with the transferred images. The trauma staff expressed the difficulty of keeping up with the CD owing to multiple consult services needing to see the images. The consult services expressed the difficulty of finding the CD when it was time to take patients to the operating room.

Another potential area to explore is the "imaging problem" indication, which explained 13.5% of the repeated scans. It has been previously demonstrated that patients with extremely high ISSs get transferred to a trauma center quickly without obtaining CT scans.[1] This raises the question as to when and how the outside facility determines the need for transport. Is it necessary to obtain the CT scan before transfer? Evidence supports limiting nontherapeutic tests before transfer because obtaining CT scans significantly delays transfer times.[30,31] Nevertheless, it is impractical to expect the transferring facilities to eliminate all CT scans in suspected trauma patients. A study from Canada suggests that this practice would further overload the resources of many already exhausted trauma centers by increasing the already high overtriage rates to these centers.[32] Therefore, if images are obtained at an outside facility, outreach and education from the regional trauma centers to these transferring institutions sharing trauma imaging protocols and techniques may improve the quality of images obtained before transfer.

In conclusion, this study demonstrated the high rates of repeated CT scans in transferred trauma patients and the various indications that influence the decision to obtain these repeats. Moreover, this study revealed the large economic burden these repeats place on the health care system, and it estimated the potential levels of effective dose radiation patients are exposed to during these repeated scans.

AUTHORSHIP

A.C.J., B.J.P., and G.K.B. designed this study. A.C.J., D.W., and T.F. conducted the literature search and collected data. A.C.J. and G.R.H. analyzed the data, which A.C.J., G.R.H., and G.K.B. interpreted. A.C.J. wrote the manuscript and prepared figures.

DISCLOSURE

Funding was provided by the departments involved in the study. G.K.B. is a consultant for DePuy Orthopaedics. All other authors have no conflicts of interest to disclose.

REFERENCES

1. Mohan D, Barnato AE, Angus DC, Rosengart MR. Determinants of compliance with transfer guidelines for trauma patients: a retrospective analysis of CT scans acquired prior to transfer to a Level I trauma center. *Ann Surg*. 2010;251:946–951.
2. Antevil JL, Sise MJ, Sack DI, Kidder B, Hopper A, Brown CV. Spiral computed tomography for the initial evaluation of spine trauma: a new standard of care? *J Trauma*. 2006;61:382–387.
3. Brown CV, Antevil JL, Sise MJ, Sack DI. Spiral computed tomography for the diagnosis of cervical, thoracic, and lumbar spine fractures: its time has come. *J Trauma*. 2005;5:890–895.
4. Schenarts PJ, Diaz J, Kaiser C, Carrillo Y, Eddy V, Morris JA Jr. Prospective comparison of admission computed tomographic scan and plain films of the upper cervical spine in trauma patients with altered mental status. *J Trauma*. 2001;51:663–668.
5. United States. Congress. House. Committee on Ways and Means. Subcommittee on Health. *MedPAC Recommendations on Imaging Services: Hearing Before the Subcommittee on Health of the Committee on Ways and Means, U.S. House of Representatives, March 17, 2005*. Washington, DC: U.S. G.P.O.; 2005.
6. United States. Congress. House. Committee on Ways and Means. Subcommittee on Health. *MedPAC Recommendations on Imaging Services: Hearing Before the Subcommittee on Health of the Committee on Ways and Means, U.S. House of Representatives, July 18, 2006*. Washington, DC: U.S. G.P.O.; 2006.
7. Wiest PW, Locken JA, Heintz PH, Mettler FA Jr. CT scanning: a major source of radiation exposure. *Semin Ultrasound CT MR*. 2002;23:402–410.
8. Kim PK, Gracias VH, Maidment AD, O'Shea M, Reilly PM, Schwab CW. Cumulative radiation dose caused by radiologic studies in critically ill trauma patients. *J Trauma*. 2004;57:510–514.
9. Tien HC, Tremblay LN, Rizoli SB, Gelberg J, Spencer F, Caldwell C, Brenneman FD. Radiation exposure from diagnostic imaging in severely injured trauma patients. *J Trauma*. 2007;62:151–156.

10. National Research Council (U.S.). Committee to Assess Health Risks from Exposure to Low Level of Ionizing Radiation. *Health Risks From Exposure to Low Levels of Ionizing Radiation : BEIR VII Phase 2*. Washington, DC: National Academies Press; 2006.
11. Pierce DA, Preston DL. Radiation-related cancer risks at low doses among atomic bomb survivors. *Radiat Res*. 2000;154:178–186.
12. United Nations. Scientific Committee on the Effects of Atomic Radiation. *Sources and Effects of Ionizing Radiation: United Nations Scientific Committee on the Effects of Atomic Radiation : UNSCEAR 2000 Report to the General Assembly, with Scientific Annexes*. New York, NY: United Nations; 2000.
13. Cohnen M, Poll LJ, Puettmann C, Ewen K, Saleh A, Modder U. Effective doses in standard protocols for multi-slice CT scanning. *Eur Radiol*. 2003;13:1148–1153.
14. Smith-Bindman R, Lipson J, Marcus R, Kim KP, Mahesh M, Gould R, Berrington de González A, Miglioretti DL. Radiation dose associated with common computed tomography examinations and the associated lifetime attributable risk of cancer. *Arch Intern Med*. 2009;169:2078–2086.
15. Lee SI, Saokar A, Dreyer KJ, Weilburg JB, Thrall JH, Hahn PF. Does radiologist recommendation for follow-up with the same imaging modality contribute substantially to high-cost imaging volume? *Radiology*. 2007;242:857–864.
16. American Association of Physicists in Medicine. *AAPM Report No. 96*. College Park, MD: American Association of Physicists in Medicine; 2008.
17. Hurwitz LM, Yoshizumi TT, Goodman PC, Frush DP, Nguyen G, Toncheva G, Lowry C. Effective dose determination using an anthropomorphic phantom and metal oxide semiconductor field effect transistor technology for clinical adult body multidetector array computed tomography protocols. *J Comput Assist Tomogr*. 2007;31:544–549.
18. Hurwitz LM, Reiman RE, Yoshizumi TT, Goodman PC, Toncheva G, Nguyen G, Lowry C. Radiation dose from contemporary cardiothoracic multidetector CT protocols with an anthropomorphic femal phantom: implications for cancer induction. *Radiology*. 2007;245:742–750.
19. Haley T, Ghaemmaghami V, Loftus T, Gerkin RD, Sterrett R, Ferrara JJ. Trauma: the impact of repeat imaging. *Am J Surg*. 2009;198:858–862.
20. Giordano BD, Grauer JN, Miller CP, Morgan TL, Rechtine GR 2nd. Radiation exposure issues in orthopaedics. *J Bone Joint Surg Am*. 2011;92:e69(1–10).
21. Amis ES Jr, Butler PF, Applegate KE, Birnbaum SB, Brateman LF, Hevezi JM, Mettler FA, Morin RL, Pentecost MJ, Smith GG, et al. American College of Radiology white paper on radiation dose in medicine. *J Am Coll Radiol*. 2007;4:272–284.
22. Brenner DJ. Medical imaging in the 21st century—getting the best bang for the rad. *N Engl J Med*. 2010;362:943–945.
23. Smith-Bindman R. Is computed tomography safe? *N Engl J Med*. 2010;363:1–4.
24. Brenner DJ, Doll R, Goodhead DT, Hall EJ, Land CE, Little JB, Lubin JH, Preston DL, Preston RJ, Puskin JS, et al. Cancer risks attributable to low doses of ionizing radiation: assessing what we really know. *Proc Natl Acad Sci U S A*. 2003;100:13761–13766.
25. Pierce DA, Shimizu Y, Preston DL, Vaeth M, Mabuchi K. Studies of the mortality of atomic bomb survivors. Report 12, Part I. Cancer: 1950–1990. *Radiat Res*. 1996;146:1–27.
26. Hall EJ. Lessons we have learned from our children: cancer risks from diagnostic radiology. *Pediatr Radiol*. 2002;32:700–706.
27. Brenner DJ. Estimating cancer risks from pediatric CT: going from the qualitative to the quantitative. *Pediatr Radiol*. 2002;32:228–233.
28. Gupta R, Greer SE, Martin ED. Inefficiencies in a rural trauma system: the burden of repeat imaging in interfacility transfers. *J Trauma*. 2010;69:253–255.
29. Soickson A, Opraseuth J, Ledbetter S. Outside imaging in emergency department transfer patients: CD import reduces rates of subsequent imaging utilization. *Radiology*. 2011;250:408–413.
30. Onzuka J, Worster A, McCreadie B. Is computerized tomography of trauma patients associated with a transfer delay to a regional trauma centre? *CJEM*. 2008;10:205–208.
31. Svenson J. Trauma systems and timing of patient transfer: are we improving? *Am J Emerg Med*. 2008;26:465–468.
32. Rourke JT, Kennard M. Emergency patient transfers from rural hospitals: a regional study. *CJEM*. 2001;3:296–301.

