Emerg Radiol (2014) 21:341–347
DOI 10.1007/s10140-014-1200-x

ORIGINAL ARTICLE

# Utility of additional CT examinations driven by completion of a standard trauma imaging protocol in patients transferred for minor trauma

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Received: 23 August 2013 / Accepted: 28 January 2014 / Published online: 16 February 2014


**Abstract** Many clinicians order focused computed tomography (CT) examinations for trauma patients based on history and physical examinations. Trauma patients transferred to our level I trauma center undergo an extensive, nonfocused standard trauma CT protocol. We hypothesize that the use of the standard trauma CT protocol does not contribute significant clinical information for patient care when compared with CT examinations based on history and physical examination. We aim to quantify the utility of the additional CT examinations required by our institution's trauma protocol compared with emergent CT examinations dictated by the patient's history and physical examination findings. In this IRB-approved study, we retrospectively evaluated 132 trauma patients transferred to our center who underwent additional CT examinations as determined by fulfillment of our institution's standard trauma CT protocol. The emergency radiologist evaluated the CT examinations acquired after the patient's transfer to determine if there were any additional acute findings that were identified on these additional examinations compared with the initial assessment undertaken at the outside institution. A total of 101 patients transferred to our trauma center met inclusion criteria. The majority of these patients sustained minor trauma. The standard trauma protocol generated 474 negative CT examinations in 101 patients. In seven patients, there were unexpected acute findings. However, these unexpected acute findings did not change clinical management in any of the patients. After initial evaluation, the acquisition of additional nonfocused CT examinations based on the standard trauma CT protocol provides little useful clinical information in patients who are transferred for minor trauma. Rather, CT utilization should be based on clinical findings. Replacement of standard trauma CT protocol with focused CT examinations in trauma patients is a way to curtail overutilization, thereby decreasing health care cost and the amount of patient radiation exposure.

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**Keywords** Trauma · Transferred patients · Computed tomography · Utilization

## Introduction

Traumatic injuries continue to rise nationally for all age groups and genders and remain a significant cause of morbidity, mortality, and cost to the health care system [1, 2, 3]. Initial evaluation of the trauma patient may be difficult because of incomplete patient history due to altered levels of consciousness, pain, or amnesia to the traumatic event, particularly in those who have sustained more significant trauma [4, 5]. Likewise, the physical examination may also be suboptimal and equivocal in a variety of patients due to distracting injuries, intoxication, or combativeness [6, 7]. Therefore, imaging utilization has continued to increase for emergency departments nationwide [8]. Specifically, the evolution of multidetector computed tomography (MDCT) has become a reliable, high-resolution tool for rapid assessment of acutely injured patients [9, 10]; the number of emergency department visits associated with a CT examination has increased by 600 % from 1995 through 2007 [11]. Despite its benefits, widespread use of MDCT has led to local and national health policies aimed at curbing its use [12–14]. In the setting of trauma, transferred patients may be more subject to CT overutilization, unnecessary delays, and costs due to lack of communication and improper handling of transfer imaging [15–17]. When patients are injured in locations remote from a trauma center, they are often transported to community hospitals for initial assessment. The decision to transfer a trauma patient is multifactorial but has been associated with increased survival for those sustaining major trauma [18]. Patients sustaining minor or moderate trauma may be transferred from community hospitals due to limited expertise in trauma evaluation, hospital admission policies regarding trauma patients, and/or due to regional referral patterns and insurance guidelines. After transfer, studies have reported that approximately 60 % of patients underwent repeat CT examinations and most did not significantly alter outcomes [19, 20]. At our level I trauma center, we observed that trauma patients transferred from regional community hospitals invariably underwent additional CT examinations of body parts for which there was no documented clinical concern for injury during the initial assessment prior to transfer. In these patients, the initial assessment included CT examinations that were based on the patient's history and physical examination findings. The additional CT examinations following patient transfer were generated to fulfill our institution's standard trauma imaging protocol that is typically applied to all hemodynamically stable trauma patients regardless of injury severity. We hypothesized that acquisition of additional CT examinations driven by fulfillment of a standard trauma imaging protocol in lieu of clinical suspicion did not reveal significant clinical information that altered patient management. Therefore, we sought to evaluate CT utilization in minor trauma patients transferred to our university-based level I trauma center by quantifying the clinical yield of these additional protocol-driven CT examinations. The purpose of this study was to evaluate the diagnostic utility and management implications of CT examinations generated by following a standard trauma imaging protocol in the absence of directed findings on history and physical examination for minor trauma patients transferred to our level I trauma center.

## Materials and methods

Institutional review board (IRB) approval was obtained for this retrospective study, and informed consent was not required. At our institution, the Division of Emergency and Teleradiology provides subspecialty cross-sectional imaging coverage for emergency departments in our system for 14 h/day (5 p.m. until 7 a.m. the following day). The division consists of ten board-certified, subspecialty attending radiologists, half having completed fellowship training in body imaging and the other half in neuroradiology. The experience of the radiologists ranged from 2 to 30 years of clinical service. Of the ten radiologists in the division, seven participated in this study.

For an 11-month period (January 2012 through November 2012), the participating radiologists were asked to identify any trauma patient transferred to our level I trauma center. Trauma patients were transferred from various nontrauma centers/community hospitals to our level I trauma center for the following reasons: lack of resources/expertise, hospital admission policies regarding trauma patients, insurance policies, and regional referral patterns. Inclusion criteria for this study required that the patient had undergone at least one CT examination during initial presentation to the outside facility, the patient's initial CT examinations were available to view on our picture archiving and communication system (PACS), and that the patient subsequently underwent additional CT examinations after they arrived in our level I trauma center for further evaluation and management (Table 1). The participating radiologists were asked to determine if the subsequent CT examinations performed at our level I trauma center were

**Table 1** Distribution of initial CT examinations prior to transfer and characteristics of repeated scans following transfer

| CT type | Total performed prior to transfer (% of total) | Total repeated after transfer | Reason for repeat | Outcome after transfer imaging |
|---|---|---|---|---|
| Chest | 12 (6.5 %) | 1 (1.8 %) | Questionable chest hematoma | Initial finding refuted |
| Abdomen | 12 (6.5 %) | 0 | – | – |
| Pelvis | 13 (7 %) | 0 | – | – |
| Head | 84 (45.7 %) | 50 (90.9 %) | Follow-up of ICH | One initial case refuted; all others stable |
| Cervical spine | 56 (30.4 %) | 4 (7.3 %) | Questionable fracture | Three cases refuted; one substantiated on repeat imaging |
| Thoracic spine | 1 (0.5 %) | 0 | – | – |
| Lumbar spine | 1 (0.5 %) | 0 | – | – |
| Facial bone | 5 (2.7 %) | 0 | – | – |
| Total | 184 (100 %) | 55 (100 %) | – | – |

*ICH* intracranial hemorrhage

completed in order to fulfill the imaging protocol established by the trauma service versus being based on relevant history and physical examination findings. This determination was made by reviewing the history and physical examination in the electronic medical record for each transferred trauma. The traumatic findings from the history/physical examination and the additional CT examinations performed at our level I trauma center were cataloged for each patient. The traumatic CT findings were then categorized as minor or major. Minor findings were defined as those that did not change clinical management while major findings were defined as those that did change clinical management. Changes in clinical management were defined as the need for any of the following: surgery, emergent bedside procedure (chest tube placement), blood transfusion, prolonged immobilization (C-spine precautions), and unanticipated admission to intensive care unit. The elapsed time from the patient's arrival in our emergency department to completion of the subsequent CT examinations was also recorded.

## CT technique

CT examinations performed on the trauma patients at the outside hospitals varied by body region, manufacturer, technique, and use of intravenous contrast material. None of the patients underwent whole-body CT scanning ("pan-scanning") at the outside hospitals. All CT examinations that occurred at our level I trauma center were performed on 16 or 64 slice multidetector machines (General Electric). Per the trauma protocol, a "complete" standard trauma imaging protocol consisted of CT examinations of the head, cervical spine, thoracic spine, lumbar spine, chest, abdomen, and pelvis plus radiographs of the chest and pelvis. CT images were acquired in helical mode in the axial plane and displayed at 5-mm collimation for CT examinations of the head, chest, abdomen, and pelvis and at 1.25-mm collimation for CT examinations of the cervical, thoracic, and lumbar spine. Images were reformatted at 2.5 mm in the sagittal and coronal planes. In patients who received intravenous contrast material, bolus-tracking software (SmartPrep) was used to intravenously inject 125 mL of iopamidol (370 mg/mL) (Isovue-370, Bracco Diagnostics, Princeton, NJ). Administration of IV contrast material was given at the discretion of the trauma service and not all the patients received IV contrast material; reasons for not giving IV contrast material included renal dysfunction, allergy, and low clinical suspicion for significant injury.

## Image review

CT examinations performed on the trauma patients at the outside hospitals were sent to our institution on a compact disk and arrived at the time of patient transfer. The outside CT examinations were immediately loaded into our institution's PACS and reviewed on our PACS (Philips iSite, Amsterdam), by a CT technologist stationed in the CT scanner in the emergency department. A written interpretation report from the transfer institution was not included with the outside CT examinations. The participating radiologists at our institution communicated interpretations of the outside CT examinations by phone or by typing a summary of the findings in the on-screen text box of our PACS. All of the CT examinations performed that were uploaded from the outside hospital or performed at our level I trauma center were of diagnostic quality; these uploaded examinations were displayed and reviewed using our institution's PACS. The radiologist reviewing the CT examination was able to manually scroll and adjust the window and level as needed. All CT examinations were reviewed by a subspecialty radiologist, and a formal written report was generated for examinations performed at our institution.

## Medical record review

The electronic medical record for each transferred trauma patient was searched at the time of transfer by the interpreting subspecialty radiologist. The patient's history and physical examination findings were thoroughly reviewed to assess for evidence of any suspected injury of a body part that was not scanned during the patient's initial CT examination. Each patient's injury severity score (ISS) was determined. If the patient's history or physical examination was noted to be clinically concerning for a potential injury of a body part that had not been already scanned, the patient was no longer flagged for inclusion in the study. If the electronic medical record did not indicate clinical concern for an injury of a body part that was not initially scanned, the patient was included in the study. The electronic medical record of each patient was also reviewed at least 1 month after the patient's trauma transfer to our institution to assess for any missed injuries; we specifically searched discharge summaries and checked for any readmission notes. If additional imaging was performed during the follow-up period, we compared the findings with our CT interpretations to assess for any potential missed or occult injuries.

## Exclusion criteria

Trauma patients who did not undergo CT imaging of at least one of the following body parts prior to being transferred to our main level I trauma center were excluded from the study: the head, neck, spine (cervical, thoracic, or lumbar), chest, abdomen, and pelvis. Trauma patients who had concerning physical examination findings for a body region that was not included during their initial CT examinations at the outside hospital were excluded from the study. Trauma patients for whom the initial CT examinations from the outside hospital were not available for review were excluded from the study.

## Results

A total of 132 transferred trauma patients were identified, and 101 met inclusion criteria. Of the 101 patients, 42 (41.6 %) were women and 58 (58.4 %) were men. Patient ages ranged from 19 to 106 years, with a mean of 59.7 years. The average Glasgow coma scale score was 14.85, and all of the transferred patients were deemed "level 2" traumas, indicating mild severity of injury. The average ISS was 5.93 (range 1–16). Of the 101 patients in our study, 65 presented after ground level fall, 2 presented after falling from a height (8 and 10 ft.), 25 presented after motor vehicle crash, and 9 presented after assault. The total number of additional CT examinations generated by following the CT trauma protocol was 481 (an average of 4.75 per patient) distributed among eight types of CT (Table 2). Of these 481 CT examinations, 474 (98.5 %) were considered to be negative (no traumatic findings), 7 (1.5 %) revealed minor traumatic findings, and none (0 %) revealed major traumatic findings (Table 3). The seven CT examinations with minor traumatic findings revealed four (57.1 %) nondisplaced rib fractures, one (14.3 %) subcutaneous flank hematoma (4 cm), and two (28.6 %) nondisplaced transverse process fractures of the lumbar spine (Table 4). For the seven CT examinations that revealed clinically unsuspected minor trauma, six occurred in patients presenting after ground level fall and one occurred in a patient presenting after a motor vehicle crash. The average time elapsed from the patients' initial CT examination to the CT examination performed in our department after transfer was 216.9 min (3.6 h), and the range was 76–556 min.

## Discussion

To our knowledge, our study is the first to quantify CT overutilization in patients transferred after minor trauma as a consequence of following a standard trauma imaging protocol. At our institution, the standard trauma imaging protocol consists of chest and pelvic radiography plus seven CT examinations covering the head, entire spine (cervical, thoracic, and lumbar), chest, abdomen, and pelvis. This protocol is applied essentially to all hemodynamically stable patients who arrive with a stated history of "trauma," regardless of severity. While this standard imaging protocol has undoubtedly decreased morbidity and mortality for some patients, we believe that its greatest utility lies in the rapid evaluation of severely injured patients in whom medical history and physical examination may be extremely compromised or unavailable [21, 22]. In these cases, CT provides diagnostic information that is vital to triage and the initiation of treatment [23]. Additionally, CT plays a critical role in the evaluation of patients with a benign physical examination but in whom there is significant history or mechanism of injury. An example is the patient presenting after blunt abdominal trauma for whom the physical examination is unrevealing. Studies have indicated that occult abdominal and pelvic injuries are found in approximately 10 % of patients fitting this clinical scenario and that these injuries would change clinical management in approximately 6 % [24].

In the context of these clinical situations, there is rationale for establishing and abiding by a standard trauma imaging protocol. When the American College of Surgeons set forth to formalize trauma care, its main objective was to reduce the morbidity and mortality of trauma patients [25, 26]. A component of this formalization includes diagnostic imaging. With the evolution and success of CT in trauma diagnosis, it is not surprising that many trauma centers nationwide developed a standard approach for acquiring multiple CT examinations in each patient. In fact, many centers employ whole-body CT or pan-scanning. While whole-body CT has not yet been definitively shown to improve survival of blunt force trauma patients, it has been shown to decrease triage time in the emergency department [27, 28]. These successes have solidified the central role of CT in evaluation of the trauma patient. However, it is possible that the comprehensive nature of some standard imaging protocols is due to a desire to offset malpractice liability [29, 30]. Indeed, one may speculate that the avoidance of liability may have partially been a factor for fulfillment of the standard trauma imaging protocol in our study. Particularly, we were surprised by the relatively long average length of time elapsed (3.6 h) between the patients' initial CT examination and the additional CT examinations required to complete the standard trauma imaging protocol. Since the minor trauma patients remained hemodynamically stable during these hours and did not develop any complaints or physical examination findings to suggest additional injuries, it seems that other nontangible factors were also part of the decision analysis to proceed with the additional imaging.

We have found that the CT examinations generated by fulfillment of the standard trauma imaging protocol yielded

**Table 2** Distribution of CT examinations generated from trauma imaging protocol by body part

| CT type | Number (% of total) |
|---|---|
| Chest | 81 (16.8 %) |
| Abdomen | 84 (17.5 %) |
| Pelvis | 83 (17.3 %) |
| Head | 7 (1.5 %) |
| Cervical spine | 36 (7.5 %) |
| Thoracic spine | 94 (19.5 %) |
| Lumbar spine | 95 (19.8 %) |
| Facial bone | 1 (0.2 %) |
| Total | 481 (100 %) |

Table 3 Trauma presentation, CT distribution, and injury categories

| Mechanism of presenting trauma | Number of patients (% of total patients) | Number of CTs generated (% of total CTs) | Number of CTs showing minor injuries (% of total CTs) | Number of CTs showing major injuries |
|---|---|---|---|---|
| Ground level fall | 64 (63.4 %) | 321 (66.7 %) | 6 (1.2 %) | 0 |
| Fall from height | 2 (2 %) | 8 (16.6 %) | 0 | 0 |
| Motor vehicle crash | 25 (24.8 %) | 104 (21.6 %) | 1 (0.2 %) | 0 |
| Assault | 9 (8.9 %) | 48 (47.5 %) | 0 | 0 |
| Total | 101 | 481 (100 %) | 7 (1.5 %) | 0 |

very few unexpected clinical findings. In fact, only 6 of 101 patients were found to have unsuspected acute injuries. Additionally, these injuries were not clinically significant, as the clinical management of the patient was not altered by awareness of these injuries. Since the occult injuries discovered by the additional CT examinations did not contribute to mortality or morbidity, we feel that the additional imaging could have been omitted for the patients in our population. Rather, we propose that the decision to pursue additional CT imaging in transferred minor trauma patients be based on the results of the patient's history and physical examination [31]. In our population, none of the patients declared pain or injury to the body parts that underwent scanning as part of the standard trauma imaging protocol. Additionally, there was no documented abnormality of the subsequently imaged body parts during the physical examination. Based on the results of our study, we feel that the clinical yield gained from the additional CT examinations does not justify the added financial cost and radiation burden.

While we acknowledge the utility of following a standard trauma imaging protocol in many clinical situations, we believe that the decision analysis for consideration of further imaging of the stable, transferred minor trauma patient should also take into account the radiation dose and cost induced by CT. Our results indicate that trauma patients transferred to our institution underwent an additional 4.5 CT examinations due to fulfillment of the standard trauma imaging protocol. From a patient perspective, medical imaging, particularly CT, comprises the largest percentage of radiation exposure by individuals in the USA [32]. In our study, since most patients underwent evaluation for head injury during the initial CT examination, the most common combination of CT examinations incurred after transfer was of the chest, abdomen, and pelvis. With just these three additional CT examinations per patient, the estimated average effective dose is approximately 21 mSv, amounting to roughly seven times the amount of annual background radiation [33]. For most of the patients in this study, these 21 mSv accounted for approximately 75 % of the patients' total CT radiation dose. This calculation is based on the average effective doses of the head and cervical spine CT to be 2 and 8 mSv, respectively; since the thoracic and lumbar spine CT examinations are reconstructed from the existing chest and abdominal CT data, there is no increased radiation dose from reconstructing those images once the chest, abdomen, and pelvis imaging is completed. Additionally, although the reported cost of CT varies widely, the estimated cost associated with the additional CT examinations in transferred patients accounts for a significant portion of the total imaging expenditure.

Our study is limited by the retrospective design and relatively small number of patients. The number of affected transferred trauma patients during our study period is felt to be underrepresented since three of the radiologists in our section did not participate in the study. Additionally, the participating radiologists covered the emergency departments for 14 h/day, leaving a 10 h period when potential transferred patients would not have been enrolled in the study. Another limitation is that a patient's injury may have been missed during our CT interpretation or during our retrospective review of the patient's clinical medical record. To counteract this possibility, we performed an additional review of the patients' medical records at least 30 days after the date of their transfer to our facility. During this additional review, we searched both the subsequent imaging and clinical records for evidence of missed or occult injury that was not identified during the first review. Finally, this study is limited since it represents the experience of a single level I trauma center. Therefore, our results may not be able to be extrapolated to other facilities' practices. Since some institutions may not engage in the practice of standard trauma protocol imaging, CT overutilization may not be an issue for their transferred trauma patients.

Table 4 Clinically unsuspected injuries found on CT examinations generated by trauma protocol imaging

| Injury type | Number (% of total) |
|---|---|
| Nondisplaced rib fractures | 4 (57.1 %) |
| Subcutaneous flank hematoma | 1 (14.3 %) |
| Nondisplaced transverse process fracture | 2 (28.6 %) |
| Total | 7 (100 %) |

## Conclusion

In summary, our study indicates that the additional CT examinations generated by following a standard trauma imaging protocol lead to CT overutilization in patients transferred for minor trauma. The increased number of CT examinations did not increase clinical yield in this population of patients. With this knowledge, it is possible that the current trauma imaging protocol can be revised to curtail the overutilization in transferred trauma patients in whom clinical suspicion for occult injury is low. We propose that the decision to pursue CT beyond the patient's initial assessment is based on obtaining a thorough history, correlating to the mechanism of injury, and performing a meticulous physical examination. We feel that the radiologist should play a more central part of the decision making prior to performing additional CT examinations and establishing institutional scan policies. We believe that open discussion with trauma services regarding current standard protocols and future appropriation of imaging may lead to improved patient care by means of decreasing radiation dose, triage time, and overall cost. Future prospective studies will be needed to corroborate our results and to further determine the clinical parameters that may obviate the need for additional CT imaging in transferred trauma patients.

**Conflict of Interest** The authors declare that they have no conflict of interest.

## References

1. Prevention CfDCa. Initial injury-related visits to hospital emergency departments, by sex, age, and intent and mechanism of injury: United States, average annual, selected years 2005–2006 through 2009–2010. Accessed on May 25, 2013. Available at: http://www.cdc.gov/nchs/data/hus/2012/087.pdf
2. MacKenzie EJ, Weir S, Rivara FP, Jurkovich GJ, Nathens AB, Wang W, Scharfstein DO, Salkever DS (2010) The value of trauma center care. J Trauma 69:1–10
3. Weir S, Salkever DS, Rivara FP, Jurkovich GJ, Nathens AB, Mackenzie EJ (2010) One-year treatment costs of trauma care in the USA. Exp Rev Pharmacoecon Outcomes Res 10:187–197
4. Enderson BL, Chen JP, Robinson R, Maull KI (1991) Fibrinolysis in multisystem trauma patients. J Trauma 31:1240–1246
5. Richards CF, Mayberry JC (2004) Initial management of the trauma patient. Crit Care Clin 20:1–11
6. Ferrera PC, Verdile VP, Bartfield JM, Snyder HS, Salluzzo RF (1998) Injuries distracting from intraabdominal injuries after blunt trauma. Am J Emerg Med 16:145–149
7. Schurink GW, Bode PJ, van Luijt PA, van Vugt AB (1997) The value of physical examination in the diagnosis of patients with blunt abdominal trauma: a retrospective study. Injury 28:261–265
8. Levin DC, Rao VM, Parker L, Frangos AJ (2013) Analysis of radiologists' imaging workload trends by place of service. J Am Coll Radiol 10:760–763
9. Anderson SW, Lucey BC, Rhea JT, Soto JA (2007) 64 MDCT in multiple trauma patients: imaging manifestations and clinical implications of active extravasation. Emerg Radiol 14:151–159
10. Broder J, Warshauer DM (2006) Increasing utilization of computed tomography in the adult emergency department, 2000–2005. Emerg Radiol 13:25–30
11. Larson DB, Johnson LW, Schnell BM, Salisbury SR, Forman HP (2011) National trends in CT use in the emergency department: 1995–2007. Radiology 258:164–173
12. Blackmore CC, Mecklenburg RS, Kaplan GS (2011) Effectiveness of clinical decision support in controlling inappropriate imaging. J Am Coll Radiol 8:19–25
13. Goske MJ, Applegate KE, Boylan J, Butler PF, Callahan MJ, Coley BD, Farley S, Frush DP, Hernanz-Schulman M, Jaramillo D, Johnson ND, Kaste SC, Morrison G, Strauss KJ (2008) Image Gently(SM): a national education and communication campaign in radiology using the science of social marketing. J Am Coll Radiol 5:1200–1205
14. Strauss KJ, Goske MJ, Kaste SC, Bulas D, Frush DP, Butler P, Morrison G, Callahan MJ, Applegate KE (2010) Image Gently: ten steps you can take to optimize image quality and lower CT dose for pediatric patients. AJR Am J Roentgenol 194:868–873
15. Jeffers AB, Saghir A, Camacho M (2012) Formal reporting of second-opinion CT interpretation: experience and reimbursement in the emergency department setting. Emerg Radiol 19:187–193
16. McNeeley MF, Gunn ML, Robinson JD (2013) Transfer patient imaging: current status, review of the literature, and the Harborview experience. J Am Coll Radiol 10:361–367
17. Robinson JD, McNeeley MF (2012) Transfer patient imaging: a survey of members of the American Society of Emergency Radiology. Emerg Radiol 19:447–454
18. Garwe T, Cowan LD, Neas B, Cathey T, Danford BC, Greenawalt P (2010) Survival benefit of transfer to tertiary trauma centers for major trauma patients initially presenting to nontertiary trauma centers. Acad Emerg Med 17:1223–1232
19. Emick DM, Carey TS, Charles AG, Shapiro ML (2012) Repeat imaging in trauma transfers: a retrospective analysis of computed tomography scans repeated upon arrival to a level I trauma center. J Trauma Acute Care Surg 72:1255–1262
20. Gupta R, Greer SE, Martin ED (2010) Inefficiencies in a rural trauma system: the burden of repeat imaging in interfacility transfers. J Trauma 69:253–255
21. Kimura A, Tanaka N (2013) Whole-body computed tomography is associated with decreased mortality in blunt trauma patients with moderate-to-severe consciousness disturbance: a multicenter, retrospective study. J Trauma Acute Care Surg 75:202–206
22. Yeguiayan JM, Yap A, Freysz M, Garrigue D, Jacquot C, Martin C, Binquet C, Riou B, Bonithon-Kopp C (2012) Impact of whole-body computed tomography on mortality and surgical management of severe blunt trauma. Crit Care 16:R101
23. Scaglione M, Pinto F, Lassandro F, Romano L, Pinto A, Grassi R (2002) Value of contrast-enhanced CT for managing mesenteric injuries after blunt trauma: review of five-year experience. Emerg Radiol 9:26–31
24. Michetti CP, Sakran JV, Grabowski JG, Thompson EV, Bennett K, Fakhry SM (2010) Physical examination is a poor screening test for abdominal-pelvic injury in adult blunt trauma patients. J Surg Res 159:456–461
25. Jurkovich GJ, Mock C (1999) Systematic review of trauma system effectiveness based on registry comparisons. J Trauma 47:S46–S55
26. Mann NC, Mullins RJ, MacKenzie EJ, Jurkovich GJ, Mock CN (1999) Systematic review of published evidence regarding trauma system effectiveness. J Trauma 47:S25–S33
27. Sierink JC, Saltzherr TP, Reitsma JB, Van Delden OM, Luitse JS, Goslings JC (2012) Systematic review and meta-analysis of immediate total-body computed tomography compared with

selective radiological imaging of injured patients. Br J Surg 99(Suppl 1):52–58

28. van Vugt R, Kool DR, Deunk J, Edwards MJ (2012) Effects on mortality, treatment, and time management as a result of routine use of total body computed tomography in blunt high-energy trauma patients. J Trauma Acute Care Surg 72:553–559
29. Dunnick NR, Applegate KE, Arenson RL (2005) The inappropriate use of imaging studies: a report of the 2004 Intersociety Conference. J Am Coll Radiol 2:401–406
30. Hendee WR, Becker GJ, Borgstede JP, Bosma J, Casarella WJ, Erickson BA, Maynard CD, Thrall JH, Wallner PE (2010) Addressing overutilization in medical imaging. Radiology 257: 240–245
31. Wu SR, Shakibai S, McGahan JP, Richards JR (2006) Combined head and abdominal computed tomography for blunt trauma: which patients with minor head trauma benefit most? Emerg Radiol 13:61–67
32. Brenner DJ, Hall EJ (2007) Computed tomography—an increasing source of radiation exposure. N Engl J Med 357:2277–2284
33. Huda W, Ogden KM, Khorasani MR (2008) Effect of dose metrics and radiation risk models when optimizing CT x-ray tube voltage. Phys Med Biol 53:4719–4732