Improving patient CT scanning protocols in the setting of polytrauma

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ABSTRACT

Background: Traumatic injuries are the fourth most common cause of death in all age/race/sex groups. Computed tomography (CT) is considered to be the current gold standard when providing a quick and accurate diagnosis of multiple injuries. However, a consensus regarding the study of chest - abdomen - pelvis (C-A-P) in polytrauma patients (PP) has not been reached.

Aim: To present an attempt at reducing the dose of ionizing radiation from CT in an emergency setting.

Materials and methods: We reviewed the hospital's medical records for PP who had undergone CT scans between 2011 and 2016. We evaluated CT phase sensitivity and contribution to the radiation dose and the associated oncogenic risk, as well as the workload of a radiologist.

Results: The most common traumatic findings were blood and/or hematoma within the abdominal cavity, lung contusion, pneumothorax, parenchymal organ injury, and rib fractures. The non-enhanced phase did not supply any additional information and was inferior to contrast-enhanced phases when diagnosing parenchymal organ injury and active hemorrhaging, meanwhile, it contributed to 19.7% of the workload and 29.5% of the radiation. The mean effective doses (ED) of C-A-P CT and whole body CT (WBCT) were 61.2 (± 27.7) mSv and 109.4 (± 30.5) mSv accordingly. PP' received WBCT related mean ED was associated with cancer morbidity risk of 0.5% or 1/167.

Conclusion: Non-enhanced CT scans in PP contribute to wasted resources, increased radiation doses and higher future cancer risk, and supply no additional data when diagnosing traumatic findings.

Keywords: multiple trauma, radiation dosage, diagnostic imaging

1. INTRODUCTION

Traumatic injuries are the fourth most common cause of death in all age/race/sex groups, and the leading cause of death in children and young adults below 45 years of age (1). Although there are many defining parameters of polytrauma, the medical community generally describes it as injuries to multiple organs or regions of the body (2). The trauma to various systems compromises organs and systems that were not damaged during the initial trauma. Thus polytrauma patients (PP) are expected to be at a higher risk of mortality than the summation of expected mortality owing to each injury (3). A fast and accurate diagnosis is essential, but the diagnostic value of clinical evaluation is limited. Computed tomography (CT) imaging is widely utilized to establish medical diagnoses and perform image-guided interventions (4). Due to the advancements during the past decade, CT has become a sensitive and precise tool when diagnosing injuries following polytrauma (5). CT has also proven to be fast and thus is considered to be the current gold standard when providing a diagnosis of multiple injuries (6). However, there is still room for improvement.

An adequate sensitivity for injury detection and cost-effectiveness without any unjustified radiation has been the primary focus of numerous attempts to develop optimized trauma imaging guidelines, such as the referral guidelines for imaging of the European Commission or the American College of Radiology appropriateness criteria (7,8). In the Lithuanian University of Health Sciences Hospital of Kaunas Clinics, Emergency Clinic patient's examination is based on standardized and widely accepted Advanced Trauma Life Support (ATLS). Exams of conventional radiology, for example, chest or pelvis X-ray, Focused Assessment with Sonography in Trauma (FAST) are have indication defined rather clearly by the aforementioned guidelines, while when it comes to CT, the decision of execution and the region of body to examine is left to the leader of the trauma team (9). While multiple CT scanning protocols for PP have been suggested by the medical community, a consensus regarding the study of the thorax, abdomen, and pelvis has not been reached (10–13). Specific authors consider the non-enhanced CT scans to be necessary when detecting the hyperdensity that suggests the presence of blood (14). The aforementioned scans help to identify small mesenteric, hepatic, splenic, renal hematomas, and the presence of the hemoperitoneum (14). More recently, concern has been raised regarding the risk of carcinogenesis from medical radiation, with a focus on CT (15,16).

With CT scan implementation in emergency medicine as a necessary diagnostic tool, decreased exposure to radiation has become the primary focus of protocol optimization. The literature describes that the average effective dose (ED) of a single-phase CT study is 22-32 mSv, and one single-body CT scan with a risk of death from ionizing radiation-induced cancer is approximately 0.08% (15,17).

Multiple studies have assessed the evaluation, frequency of injuries, and effectiveness of PP treatment in Lithuanian hospitals, however, to our knowledge, none had evaluated the imaging protocols or the radiation doses and correlating risks to the relatively young PP population. (18–23)

With these concerns in mind, this paper presents an attempt at reducing the dose of ionizing radiation from CT in an emergency setting.

2. METHODS AND MATERIALS

2.1. Study design and setting

In this retrospective study, medical health records and CT scan images of patients admitted to The Hospital of Lithuanian University of Health Sciences Kaunas clinic between 2011 and 2016 were analyzed. Kaunas Regional Biomedical Research Ethics Committee (KRBREC) approved the study protocol and waived informed consent.

2.2. PATIENT SELECTION CRITERIA AND DATA ACQUISITION

We reviewed the hospital's medical records for patients who had undergone chest - abdomen - pelvis (C-A-P) CT scans for suspected polytrauma between 2011 and 2016. The initial study population (n = 103) data were acquired by analyzing medical health records for demographic information, trauma mechanism and severity details, and CT scan images stored in Cedara-I-Reach (TM).

For the evaluation of CT scan phase significance, we selected patients (n = 62) who had undergone C-A-P three sequential CT scans. Pathologic CT scan findings were separated into dichotomous groups (present/not present) and evaluated in each phase. For this study, we documented the following chest CT scan findings: pneumothorax, haemothorax, pneumomediastinum, haemopericardium, mediastinal hematoma, lung contusion and laceration, active hemorrhaging into the parenchyma, pleural cavity or mediastinum, injury of the major vessels, traumatic diaphragm or oesophageal injury and bone fractures. Assessed abdominal organ CT scan findings were: fluid, hematoma, the air in the abdominal cavity, parenchymal organ injury with/without active hemorrhaging, and bone fractures. Results in non-enhanced/arterial/venous phases were compared.

To assess the radiation doses (n = 94) of C-A-P CT scans and separate phases, we used fixed technical parameters. ED was calculated using standardized dose-length product (DLP) parameters and conversion coefficient k (k = 0.015 mSv/mGy × cm): ED (mSv)=DLP (mGy x cm) x k (mSv/mGy x cm) Additionally, we estimated the future risk for cancer among patients that had undergone whole-body CT scans (n = 49).

To measure the workload of a radiologist, the CT scan image count for all phases was documented and compared between different phases.

Patients with insufficient medical record data, poor quality or incomplete CT scans were excluded from the study.

2.3. SCANNING PARAMETERS

In each case, CT scans were performed using one of the scanners: either GE VCT 64 or GE VCT

16 slice CT. Images were acquired by using PP scanning protocols: at a slice thickness of 5 mm; pitch 0.969:1; 120 kV, 100 - 665 mA, rotation speed 0.5 s, using an intravenous contrast agent, which was injected at the speed of 2.5 ml/s. All CT scan images were reviewed using the Picture Archiving and Communication System (PACS).

2.4. STATISTICAL ANALYSIS

We analyzed all data using IBM SPSS Statistics v. 23.0 and Microsoft Office Excel 2016. Normally distributed data were expressed as the mean value (± standard deviation) and non-normally distributed data as the median (minimum-maximum values). We used related-samples non-parametric Qochran's Q and McNemar tests to evaluate the significance of differences between different phase findings and group homogeneity using 2, one-way ANOVA and Kruskal-Wallis tests. Values of P less than 0.05 were considered significant.

3. RESULTS

The study population consisted of 82 (79%) male and 21 (21%) female participants with the mean age of 39.8 (± 15.8). (Table 1) 92.6% of traumas were blunt, and merely 7.4% were penetrating. The most common reasons for polytrauma in the study population were vehicle accidents (31.2%), and falling from a height of more than 3 meters (24.7%). Falling from a height of more or less than 3 meters and motorcycle accidents were responsible for accordingly 8.6% and 10.8% of traumas within the study sample. 63,5% (n = 54) patients were haemodynamically stable; however, 36,5% (n = 31) emergency CT scans were performed on patients with unstable haemodynamics.

The most prevalent traumatic findings in the CT scans were blood and/or hematoma within the abdominal cavity (11.8%), lung contusion (11.2%), pneumothorax (9.5%), parenchymal organ injury (hepatic - 5.9%; splenic - 4%, renal and adrenal - 3% each) and rib fractures (9.5%). (Table 2)

Within the sample of PP that had undergone C-A-P three sequential CT scans (n = 62) statistically, significant inferiority was noted when diagnosing parenchymal organ injury with and without active hemorrhaging in non-enhanced CT scans compared to arterial or venous phases (P < 0.05). Otherwise, no statistically significant differences were noted. (Table 3) The non-enhanced phase did not supply any additional information, however, it was useful when diagnosing blood or air in the pleural cavity, pneumomediastinum, lung lacerations and/or contusions, gastrointestinal trauma. Active hemorrhaging was detected only in contrast-enhanced CT scans. The venous phase was superior, but not statistically significant when diagnosing blood in the peritoneum and parenchymal organ injury.

We calculated the number of images analyzed and concluded that by eliminating the arterial phase from PP scanning protocols we would decrease the amount of images by 32.6%, non-enhanced - by 19.7%, both - by 52.3%. Also, several patients' scanning protocols included the late venous phase, which attributed to an additional 197.0 (± 58) images. (Table 4)

The mean of the determined ED of radiation for patients that had undergone C-A-P CT scan was 61.2 (± 27.7) mSv, and 28.2% of the reported dose could be attributed to the radiation exposure during the arterial phase, 29.5% - to the non-enhanced scan and 32.9% to the venous phase. By forgoing the non-enhanced phase, the mean ED value of C-A-P CT scan becomes statistically significantly lower (P < 0.001). Patients, exposed to 109.4 (± 30.5) mSv (mean ED value of the whole body CT scan) had the cancer morbidity risk of 0.5% or 1/167.

Table 1. Demographic and injury severity data of the study population.

Count (n = 103)		Injury severity score (ISS)	Glasgow coma scale (GCS)	Hospitalisation length (days)
Male	Female			
82 (79%)	21 (21%)	30.17 (± 15.05)	12.72 (± 3.8)	19.10 (± 21.92)

Table 2. Trauma related CT scan finding frequency.

Traumatic findings	Number of cases	Percentage
Blood the abdominal cavity	56	11.8
Lung contusion	53	11.2
Pneumothorax	45	9.5
Rib fractures	45	9.5
Spinal column fractures	37	7.8
Haemothorax	35	7.4
Liver injury	28	5.9
Pelvic bone fractures	27	5.7
Spleen injury	19	4.0
Renal injury	14	3.0
Suprarenal gland injury	14	3.0
Lung laceration	14	3.0
Active haemorrhaging in the abdominal cavity	12	2.5
Pneumomediastinum	8	1.7
Haematoma of the mediastinum	5	1.1
Gastrointestinal organ injury	4	0.8
Pancreatic injury	2	0.4
Heart/pericardium injury	2	0.4
Injury of the major vessels in the thorax	2	0.4
Air in the abdominal cavity	1	0.2

Table 3. Non-parametric test results representing the statistical significance of non-enhanced/arterial/venous phase sensitivity differences when detecting trauma related CT scan findings.

Statistically significant differences	Statistically insignificant differences
<u>Parenchymal organ injury without active haemorrhaging:</u> Arterial and venous phases are superior to non-enhanced (McNemar test P = 0.001 and P < 0.001 accordingly) <u>Parenchymal organ injury with active haemorrhaging:</u> Arterial and venous phases are superior to non-enhanced (McNemar test P = 0.004 in each case)	Pleural effusion, (P = 1.000) Pneumothorax and/or pneumomediastinum (P = 1.000), Lung laceration and/ or contusion (P = 1.000), Gastrointestinal injury (P = 1.000); Active haemorrhaging into pleural cavity or mediastinum (P = 0.368); Fluid in the abdominal cavity (P = 0.135); Injury of the major abdominal vessels (P = 0.368)

Table 4. The contribution of each CT phase to the image count.

Chest - abdomen - pelvis CT scan image count	Minimum	Maximum	Mean (CI 95%)
In total	323	1151	631.88 ± 160.4
Non-enhanced	54	247	120.5 ± 27.5
Arterial phase	86	417	202.09 ± 51.7
Venous phase	107	498	239.37 ± 63.9
Late venous phase	82	417	197.0 ± 58

4. DISCUSSION

In this study we observed that non-contrast-enhanced CT scan images are unnecessary when evaluating PP, seeing as they do not supply any additional information. Therefore, preceding the native phase improves the PP CT scanning protocols.

The most common CT scan findings observed in this study were blood and/or hematoma within the abdominal cavity (11.8%), lung contusion (11.2%), pneumothorax (9.5%), parenchymal organ injury (hepatic - 5.9%; splenic - 4%, renal and adrenal - 3% each) and rib fractures (9.5%). These findings are in correlation with the other studies. Parenchymal organ (especially spleen and liver) injury is observed most frequently (6). Lung parenchymal lesions, pleural effusions or pneumothorax, and rib fractures are the most common findings following chest trauma (24–26). Meanwhile, blunt injury to the blood vessels is not common (27). Quick detection of the aforementioned pathological findings ensures prompt diagnosis and treatment, which in turn decreases mortality and the waste of the resources.

However, with the widespread use of CT, ionizing radiation is becoming a significant concern, prompting research into dose reduction methods. The findings of this study indicate that one of the improvement possibilities is the elimination of non-enhanced CT scan images. We have observed that precontrast images provide no additional information in the setting of common polytrauma related findings, and are inferior to contrast-enhanced images. This is in accord with other studies that support the claim that precontrast CT scan image acquisition is superfluous and injury diagnosis in PP is not improved by the use of precontrast scans. Furthermore, both studies agree that unjustified CT scans contribute to an increased radiation dose (28,29). This consecutively suggests that the elimination of non-enhanced images from emergency trauma CT scanning protocols is justified by the reduction of radiation exposure without the loss of diagnostic accuracy.

Undoubtedly, multiple other optimization possibilities have been researched. A single acquisition WBCT scan in the setting of polytrauma could cut down both time and resource consumption in addition to reducing ED without the impairment of diagnostic quality (13,30–32). Meanwhile, a revised triphasic injection single-pass WBCT scan protocol was superior to conventional PP scanning protocols using 64-multidetector CT (MDCT) (33). A split bolus technique suggested by Leung et al. offered a comparable quality with reduced radiation dose (34). Certain studies noted the necessity of dual-phase CT scans when detecting vascular lesions following trauma (35,36).

Meanwhile, Błaż et al. argued that the arterial phase is necessary only for the thorax scans, seeing as clinically significant hemorrhaging of the abdominal arteries would be visible in the venous phase (37). In our study, we found a non-significant superiority of the venous phase when diagnosing blood in the peritoneum and parenchymal organ injury. All in all, numerous CT scanning protocol improvement possibilities today make the unjustifiable radiation dose and thus carcinogenic risk to be even more illogical, entailing an obligation to reach a consensus.

Although the radiation dose received by PP varies greatly, we found the CT related dose to range from 55.81 to 183.96 mSv with the mean value being 109.4 (± 30.5) mSv. These numbers are alarming, seeing as current data support, albeit inconclusively, the notion that doses from 5 mSv significantly increase the oncogenic risk (38–41), while radiation doses above 100 mSv are acknowledged by the medical community to attribute to additional cancer instances (42). CT scans deliver concerning amounts of radiation and may contribute to 29 000 new cancers each year, along with 14 500 deaths (43). To avoid unnecessary risks, exposure to radiation must be As Low As Reasonably Achievable (ALARA) (44). Bearing in mind that patients undergo additional follow-up CT scans, many PP exceeds the 100 mSv and consequently are at a higher risk of developing cancer.

Another important observation of this study was that women and children make up 21% of our study population and the mean age was 39.8 (± 15.8). Multiple factors determine the cancer development risk following radiation exposure:

genetics, age during exposure, sex of the subject, radiation exposure rates, etc. (38). This is important to take into consideration when preparing diagnostic protocols for PP, seeing as the majority of traumatic injuries occur to people younger than 45 years of age, including females and children, who are at a higher risk of developing oncologic diseases (1,38). According to our findings, the majority of the relatively young PP population is at a higher risk of developing oncologic diseases.

Furthermore, we found that the mean amount of CT scan images that a radiologist had to evaluate was 631.88 (± 160.4), with the highest count reaching 1151 images per case. A high count of images requiring evaluation increases the probability of missed injuries and prolongs the time to treatment (45,46). The required time for trauma-related imaging differs depending on scanning protocols. However, WBCT requires approximately 12 min, while non-WBCT requires 75 min on average to scan (47). Taking this time into consideration and factoring in the time to evaluate all the images, time to diagnosis is prolonged. In turn, transfers and/or injury management may be delayed, which negatively affects survival (48–50). Moreover, the additional workload wastes resources increases mortality and morbidity not only due to delayed treatment but also due to misdiagnosis originating from overworked radiologists (46). Therefore, optimization is beneficial both to the patient and the medical community.

It is important to note that this study had some limitations. First of all, the study population was rather small, due to the fact only PP who had undergone three phase C-A-P CT scans were included. This could attribute to decreased reliability of our findings, seeing as other PP may have been excluded. Nonetheless, our results were in agreement with the other studies (28,29). Secondly, the ED calculation was based on a standardized formula that does not take into account the weight, height and other variable parameters of the subject. This method of ED estimation, however, is utilized by other studies (28,29,51). Finally, the evaluation of CT scan findings as either present or not could have had an impact on our conclusions, seeing as the severity of an injury is also an essential factor when visualization sensitivity and specificity are being evaluated.

In conclusion, non-enhanced C-A-P CT scans in PP contribute to wasted resources, increased radiation doses and oncogenic risks, and supply no additional information when diagnosing traumatic findings. Therefore, optimization of PP scanning protocols by non-enhanced phase exclusion is justified and beneficial.

REFERENCES

1. Heron M. Leading Causes for 2014. *Natl Vital Stat Reports* 2016: **65**:1–95.

2. Rau CS, Wu SC, Kuo PJ et al. Polytrauma defined by the new berlin definition: A validation test based on propensity-score matching approach. *Int J Environ Res Public Health* 2017: **14**:1045.

3. Butcher N, Balogh ZJ. The definition of polytrauma: the need for international consensus. *Injury* 2009: **40**:12–22.

4. Linsenmaier U, Rock C, Krötz M et al. Whole-body computed tomography in polytrauma : techniques and management. *Eur Radiol* 2002: **12**:1728–1740.

5. Eurin M, Haddad N, Zappa M et al. Incidence and predictors of missed injuries in trauma patients in the initial hot report of whole-body CT scan. *Injury* 2012: **43**:73–77.

6. Soto JA, Anderson SW. Multidetector CT of Blunt Abdominal Trauma. *Radiology* 2012: **265**:678–693.

7. EUR 16262EN. European Comission: European guidelines on quality criteria for computed tomography - EU Law and Publications. Luxembourg: EUR 2000https://publications.europa.eu/en/publication-detail/-/publication/d229c9e1-a967-49de-b169-59ee68605f1a (accessed 1 Dec2018).

8. Nagel HD, Huda W. Radiation Exposure in Computed Tomography. *Med Phys* 2002: **29**:1922–1922.

9. Brasel KJ. Advanced trauma life support (ATLS??): The ninth edition. *J Trauma Acute Care Surg* 2013: **74**:1363–1366.

10. Salim A, Sangthong B, Martin M et al. Whole Body Imaging in Blunt Multisystem Trauma Patients Without Obvious Signs of Injury. *Arch Surg* 2006: **141**:468.

11. Holmes JF, McGahan JP, Wisner DH. Rate of intra-abdominal injury after a normal abdominal computed tomographic scan in adults with blunt trauma. *Am J Emerg Med* 2012: **30**:574–579.

12. Holly BP, Steenburg SD. Multidetector CT of blunt traumatic venous injuries in the chest, abdomen, and pelvis. *Radiographics* 2011: **31**:1415–1424.

13. Nguyen D, Platon A, Shanmuganathan K et al. Evaluation of a single-pass continuous whole-body 16-MDCT protocol for patients with polytrauma. *Am J Roentgenol* 2009: **192**:3–10.

14. Kelly J, Raptopoulos V, Davidoff A et al. The value of non-contrast-enhanced CT in blunt abdominal trauma. *AJR Am J Roentgenol* 1989: **152**:41–48.

15. Hendee WR, O'Connor MK. Radiation Risks of Medical Imaging: Separating Fact from Fantasy. *Radiology* 2012: **264**:312–321.

16. Costello JE, Cecava ND, Tucker JE et al. CT radiation dose: Current controversies and dose reduction strategies. *AJR Am J Roentgenol* 2013: **201**:1283–1290.

17. Sierink JC, Saltzherr TP, Wirtz MR et al. Radiation exposure before and after the introduction of a dedicated total-body CT protocol in multitrauma patients. *Emerg Radiol* 2013: **20**:507–512.

18. Pamerneckas A, Adukauskiene D, Macas A. [Multiple trauma: evaluation of patient's condition and local injuries by trauma classification systems]. *Med* 2002: **38**:685–694.

19. Pamerneckas A, Macas A, Vaitkaitis D et al. Golden hour - early postinjury period. *Med* 2003: **39**:845–851.

20. Pamerneckas A, Pijadin A, Pilipavicius G et al. The assessment of clinical evaluation and treatment results of high-energy blunt polytrauma patients. *Med* 2007: **43**:137–144.

21. Pamerneckas A, Petrulis A, Pilipavičius G et al. Influences on Mortality of Polytrauma Patients. *Osteosynthesis Trauma Care* 2006: **14**:98–100.

22. Pamerneckas A, Macas A, Blazgys A et al. The treatment of multiple injuries: prehospital emergency aid. *Med* 2006: **42**:395–400.

23. Gaidamonis E, Stanaitis J. Blužnies sužalojimai dėl uždaros pilvo traumos. *Lith Surg* 2007: **9942**:152–160.

24. Rodriguez RM, Friedman B, Langdorf MI et al. Pulmonary contusion in the pan-scan era. *Injury* 2016: **47**:1031–1034.

25. Di Bartolomeo S, Sanson G, Nardi G et al. A population-based study on pneumothorax in severely traumatized patients. *J Trauma* 2001: **51**:677–682.

26. Mirvis SE. Imaging of Acute Thoracic Injury: The Advent of MDCT Screening. *Semin Ultrasound, CT MRI* 2005: **26**:305–331.

27. Muckart DJJ, Pillay B, Hardcastle TC et al. Vascular injuries following blunt polytrauma. *Eur J Trauma Emerg Surg* 2014: **40**:315–322.

28. Naulet P, Wassel J, Gervaise A et al. Evaluation of the value of abdominopelvic acquisition without contrast injection when performing a whole body CT scan in a patient who may have multiple trauma. *Diagn Interv Imaging* 2013: **94**:410–417.

29. Esposito AA, Zilocchi M, Fasani P et al. The value of precontrast thoraco-abdominopelvic CT in polytrauma patients. *Eur J Radiol* 2015: **84**:1212–1218.

30. Sedlic A, Chingkoe CM, Tso DK et al. Rapid imaging protocol in trauma : a whole-body dual-source CT scan. *Emerg Radiol* 2013: **20**:401–408.

31. Eichler K, Marzi I, Wyen H et al. Multidetector computed tomography (MDCT): Simple CT protocol for trauma patient. *Clin Imaging* 2015: **39**:110–115.

32. Hakim W, Kamanahalli R, Dick E et al. Trauma whole-body MDCT: An assessment of image quality in conventional dual-phase and modified biphasic injection. *Br J Radiol* 2016: **89**.

33. Yaniv G, Portnoy O, Simon D et al. Revised protocol for whole-body CT for multi-trauma patients applying triphasic injection followed by a single-pass scan on a 64-MDCT. *Clin Radiol* 2013: **68**:668–675.

34. Leung V, Sastry A, Woo TD et al. Implementation of a split-bolus single-pass CT protocol at a UK major trauma centre to reduce excess radiation dose in trauma pan-CT. *Clin Radiol* 2015: **70**:1110–1115.

35. Hamilton JD, Kumaravel M, Censullo ML et al. Multidetector CT Evaluation of Active Extravasation in Blunt Abdominal and Pelvic Trauma Patients. *RadioGraphics* 2008: **28**:1603–1616.

36. Iacobellis F, Ierardi AM, Mazzei MA et al. Dual-phase CT for the assessment of acute vascular injuries in high-energy blunt trauma: the imaging findings and management implications. *Br J Radiol* 2016: **89**:20150952.

37. Błaż M, Palczewski P, Gołębiowski M et al. Optimization of CT protocol for imaging of polytraumatized patients. 2010: **16**:48–51.

38. Hricak H, Brenner DJ, Adelstein SJ et al. Managing Radiation Use in Medical Imaging: A Multifaceted Challenge. *Radiology* 2010: **258**:889–905.

39. Mayo-Smith WW, Hara AK, Mahesh M et al. How I Do It: Managing Radiation Dose in CT. *Radiology* 2014: **273**:657–672.

40. Huda W. Radiation Risks: What Is to Be Done? 2015: **204**:124–127.

41. Duncan JR, Lieber MR, Adachi N et al. Radiation Dose Does Matter: Mechanistic Insights into DNA Damage and Repair Support the Linear No-Threshold Model of Low-Dose Radiation Health Risks. *J Nucl Med* 2018: **59**:1014–1016.

42. Picano E, Vano E, Rehani MM et al. The appropriate and justified use of medical radiation in cardiovascular imaging: A position document of the ESC Associations of Cardiovascular Imaging, Percutaneous Cardiovascular Interventions and Electrophysiology. *Eur Heart J* 2014: **35**:665–672.

43. Berrington de González A, Mahesh M, Kim K-P et al. Projected Cancer Risks From Computed Tomographic Scans Performed in the United States in 2007. *Arch Intern Med* 2009: **169**:2071.

44. IRCP. ICRP Publication 105. Radiation protection in medicine. *Ann ICRP* 2007: **37**:3–5.

45. Rieger M, Czermak B, El Attal R et al. Initial Clinical Experience With a 64-MDCT Whole-Body Scanner in an Emergency Department: Better Time Management and Diagnostic Quality? *J Trauma Inj Infect Crit Care* 2009: **66**:648–657.

46. Dreizin D, Munera F. Blunt Polytrauma: Evaluation with 64-Section Whole-Body CT Angiography. *RadioGraphics* 2012: **32**:609–631.

47. Gordic S, Alkadhi H, Hodel S et al. Whole-body CT-based imaging algorithm for multiple trauma patients: radiation dose and time to diagnosis. *Br J Radiol* 2015: **88**:20140616.

48. Barbosa RR, Rowell SE, Fox EE et al. Increasing time to operation is associated with decreased survival in patients with a positive FAST examination requiring emergent laparotomy. *J Trauma Acute Care Surg* 2013: **75**:S48–S52.

49. Johns TJ. Characteristics and risk factors of trauma patients readmitted to the ICU within the same hospitalization. *J Trauma Nurs* 2014: **21**:14–21.

50. Gonzalez-Robledo J., Martin-Gonzalez F., Moreno-Garcia M., Sanchez-Barba M. S-HF. Prognostic factors associated with mortality in patients with severe trauma: From prehospital care to the Intensive Care Unit. *Med Intensiva* 2015: **39**:412–421.

51. Huda W, Ogden KM, Khorasani MR. Converting Dose-Length Product to Effective Dose at CT. *Radiology* 2008: **248**:995–1003.