ORIGINAL ARTICLE

Single-pass Whole-body vs Organ-selective Computed Tomography for Trauma—Timely Diagnosis vs Radiation Exposure: An Observational Study

Carlos Ordonez[1], Ana M Del Valle[2], Michael Parra[3], Monica Guzman-Rodriguez[4], Juan P Herrera-Escobar[5], Carlos García[6], Alberto F García[7], Hernan E Munevar[8], Constanza Navarro[9], Alejandra de las Salas[10], Laura Ibarra[11], Alfonso Holguin[12]

Abstract

Aim: Whole-body computed tomography (WBCT) has been used as a high-yield diagnostic tool in trauma. However, increased exposure to radiation and delay in treatment have been cited as challenges to its widespread use. We hypothesized that WBCT has at least the same radiation exposure compared to organ-selective CT (OSCT), and it does not inflict further delays in diagnosis.

Materials and methods: We retrospectively review all trauma patients in whom CT scans were performed on arrival at a level I trauma center, from January 2016 to December 2017.

Results: A total of 123 patients were included: 53 in the OSCT group and 70 in the WBCT group. In the OSCT group, 64.1% of the patients had penetrating trauma, and chest injuries were the most common injured body cavity (79.3%). In the WBCT group, 65.7% had blunt trauma, and head injuries were the most common (71.9%). The OSCT group required subsequent follow-up studies to rule out other injuries, which in turn did not occur in the WBCT group (47.2% vs 0%, $p < 0.001$). The total radiation exposure dose was higher in the OSCT group [22 mSv (IQR 6–31) vs 15.1 mSv (IQR 9.9–24.8) $p < 0.001$]. The median CT scan-to-diagnosis time was lower in the WBCT group [22 minutes (14–32) vs 32 minutes (21–65); $p < 0.001$].

Conclusion: The OSCT has the potential of missing potentially life-threatening injuries that require subsequent follow-up scans. This, in turn, would increase the patient's overall radiation exposure and potentially delay definitive surgical treatment. Trauma patients undergoing WBCT had lower total radiation exposure with no delay in diagnosis.

Level of evidence: V, therapeutic.

Keywords: Computed tomography, Delay, Organ-selective CT scan, Radiation exposure, Single pass.

Resumen

Objetivo: La tomografía computarizada de cuerpo entero (TCCE) se ha utilizado como una herramienta de diagnóstico de alto rendimiento en traumatismos. Sin embargo, el aumento de la exposición a la radiación y el retraso en el tratamiento, se han mencionado como desafíos para su uso generalizado. Presumimos que la TCCE tiene al menos la misma exposición a la radiación en comparación con la TC selectiva de órganos (TCSO) y no inflige más demoras en el tratamiento.

Materiales y métodos: Revisamos retrospectivamente a todos los pacientes con trauma en los que se realizaron tomografías computarizadas a su llegada al Centro de Trauma Nivel I de Enero de 2016 a Diciembre de 2017.

Resultados: Se incluyeron 123 pacientes: 53 en el grupo de TCSO y 70 en el grupo de TCCE. En el grupo de RCSO, el 64.1% de los pacientes tenían trauma penetrante y las lesiones torácicas fueron la cavidad corporal lesionada más común (79.3%). En el grupo TCCE, el 65.7% tenía traumatismo cerrado y las lesiones en la cabeza fueron el órgano lesionado más común (71.9%). El grupo TCSO requirió estudios de seguimiento posteriores para descartar otras lesiones que a su vez no ocurrieron en el grupo TCCE (47.2% vs 0%, $p < 0.001$). La dosis total de exposición a la radiación fue mayor en el grupo TCSO [22 mSv (IQR 6–31) frente a 15.1 mSv (IQR 9.9–24.8) $p < 0.001$].

Conclusión: TCSO tiene el potencial de perder lesiones potencialmente mortales que requieren exploraciones de seguimiento posteriores. Esto, a su vez, aumentaría la exposición general a la radiación del paciente y posiblemente retrasaría el tratamiento quirúrgico definitivo. Los pacientes con trauma sometidos a TCCE tuvieron menor exposición a la radiación total sin demora en el tratamiento.

Palabras clave: Tomografía computarizada de un solo pase, exposición a la radiación, TC de órgano selectivo, traumatismo cerrado, trauma penetrante.

Panamerican Journal of Trauma, Critical Care & Emergency Surgery (2020): 10.5005/jp-journals-10030-1262

Introduction

Despite advances in acute trauma care, hemorrhage remains the leading cause of preventable death. Control of the bleeding during the first hour after injury is essential to increase the overall survival in these patients.[1] With this purpose in mind, the American College of Surgeons developed the advanced trauma life support (ATLS) course as a guide in the initial management of trauma patients, which includes ultrasound, X-rays, and CT as adjuncts in the workup

[1,2,7]Department of Surgery, Division of Trauma and Acute Care Surgery, Fundación Valle del Lili, Cali, Colombia

[3]Department of Trauma Critical Care, Broward General Level I Trauma Center, Fort Lauderdale, Florida, USA

[4]Fundación Valle del Lili, Centro de Investigaciones Clínicas (CIC), Cali, Colombia

[5]Center for Surgery and Public Health, Department of Surgery, Brigham

of a trauma patient but limits specifically the use of CT scan in hemodynamic unstable trauma patients.[2]

For many years, the use of CT scan in trauma has been considered part of the secondary evaluation of a stable multitrauma patient,[3] but its use in hemodynamic unstable patients has been limited,[4] because it has been considered that the transfer of critically ill patients from the trauma bay to the CT suite interrupts the ongoing resuscitation of the patient, delays definitive treatment, and increases the risk of death in patients with active bleeding.[5] Currently, multislice computed tomography allows for a fast total body evaluation, an excellent image quality, and a significant reduction in total scan time. For these reasons, the CT scan has been integrated into the initial management of trauma patients and approximately 60% of all European trauma centers include whole-body computed tomography (WBCT) as part of their initial workup algorithm,[6–8] but this is not the case in Latin America because there is restricted availability of the equipment in the region due to costs.

Since there are still gaps in knowledge about the risks or potential benefits of WBCT,[9–11] and its use was recently incorporated at our institution, we hypothesized that WBCT is safe to perform in patients with blunt and penetrating trauma, has the same radiation exposure as compared to organ-selective CT scan (OSCT), and does not necessarily inflict further delays in the definitive treatment of trauma patients. The main objective of our study was to prove that WBCT is a useful diagnostic tool that can be safely and timely used in all trauma patients, independently of their hemodynamic status.

Materials and Methods

Study Design

We conducted an observational, case–control study. We retrospectively included trauma patients admitted at a level I trauma center—Fundacion Valle del Lili (FVL), Cali, Colombia—in whom a CT scan was performed upon arrival, from January 2016 to December 2017. The study included all adult patients (>16 years old) who suffered penetrating and/or blunt trauma and who received a CT scan upon arrival. In all, 74 patients were excluded due to multiple reasons: patients who did not meet the inclusion criteria, patients who underwent CT scans without recorded dose length product (DLP), those who had received CT scans at outside institutions prior to the arrival to our trauma center, and patients with missing data (23 patients).

Dose length product is a measure of CT radiation output/exposure. Dose length product accounts for the length of radiation output along the patient's *z*-axis and its unit of measurement is milliGray (mGy). Dose length product does not take the size of the patient into account and does not represent patient's effective dose. Effective dose depends on others factors including the scanned body zone and is the product of DLP and *K* conversion coefficient. The values for *K* are specific to each part of the body. The unit of measurement for effective radiation dose is miliSievert (mSv).[12,13]

Patients were divided in two groups: those who underwent OSCT scan (OSCT group) and those who had single-pass WBCT (WBCT group). The WBCT is defined as an intravenous (IV) contrast CT scan that included the brain all the way through the pelvis. The OSCT was defined as an IV contrast CT scan limited to a single-body cavity.

Upon arrival, all patients were evaluated by the trauma team and managed according to the ATLS guidelines. Focused assessment with sonography for trauma, chest, and pelvic X-rays were performed in all patients as the initial screening tools. Decision

and Women's Hospital, Harvard Medical School and Harvard TH Chan School of Public Health, Boston, Massachusetts, USA

[6,12]Fundación Valle del Lili, Radiology Department, Cali, Colombia

[8]Trauma and Critical Care Surgery, Universidad del Valle, Cali, Colombia

[9]General and Emergency Medicine, Servicio de Salud del Maule, VII Región, Chile

[10,11]Fundación Valle del Lili, Centro de Investigaciones Clínicas (CIC), Cali, Colombia

Corresponding Author: Carlos Ordonez, Department of Surgery, Division of Trauma and Acute Care Surgery, Fundación Valle del Lili, Cali, Colombia, Phone: +52 3319090, e-mail: ordonezcarlosa@gmail.com

How to cite this article: Ordonez C, Del Valle AM, Parra M, *et al.* Single-pass Whole-body vs Organ-selective Computed Tomography for Trauma—Timely Diagnosis vs Radiation Exposure: An Observational Study. Panam J Trauma Crit Care Emerg Surg 2020;9(1):26–31.

Source of support: Nil

Conflict of interest: None

to perform OSCT or WBCT depended on the trauma surgeon on call and was based on the institutional WBCT guidelines and patients who did not meet the criteria to perform WBCT and underwent OSCT (Table 1). Also, the decision to perform follow-up CT depended on the trauma surgeon and the clinical condition of the patient.

Patients in hemorrhagic shock were initially managed in the trauma bay with endovenous fluid restriction and blood product transfusion. Hemorrhagic shock was defined as a mean systolic blood pressure (SBP) of lower than 90 mm Hg and pulse rate of higher than 100 beats/minute on arrival to the trauma center. If patients responded by means of sustaining their SBP between 80

Table 1: The whole-body computed tomography institutional criteria

1. Mechanism of injury
    - Motor vehicle accidents
    - Prolonged extrication
    - Ejection
    - Pedestrian hit by vehicle
    - Motorcycle accident
    - Falls: >3 meters* or of unknown height
    - Explosion
2. Injuries noticed on primary survey
    - Two or more body zones injured
    - Two or more proximal long-bone fractures
    - Major pelvic injury
    - Proximal amputation
    - Signs of spinal cord injury
3. Vital signs
    - Intubated patient with initial GCS <9
    - Altered mental status: GCS <12
    - Suspected alcohol and/or drugs
    - Systolic blood pressure <100 mm Hg
    - Respiratory rate: <10 or >30 per minute
    - Heart rate: > 120 beats/minute
    - Age over 65
    - Use of anticoagulants

*3 meters = 9.8 ft; GCS: Glasgow Coma Scale and 90 mm Hg during their initial resuscitation, then the patient was taken to the CT suite for a WBCT or OSCT scan. The CT suite is located adjacent to the trauma bay (less than 100 feet), and three CT scanners available at all times in the institution.

WBCT Technique

Data were acquired using a multislice interventional radiology CT system (Aquilion ONE 320 Slice CT scanner, software version 7.0; Toshiba Medical Systems Corp., Tochigi, Japan). Each patient was accompanied by the trauma team (trauma surgeon, general surgeon, fellow, general surgery resident, emergency room (ER) physician, and trauma nurses). A radiologist read each study in real time. Resuscitation which was initiated in the trauma bay was continued in the scanner. The WBCT protocol consists of injection of low osmolar, nonionic contrast medium (Iopromide Ultravist R. Whippany; Bayer HealthCare Pharmaceuticals NJ, USA) with 18-gauge peripheral IV catheters. A simple acquisition phase is performed for head and a phase of acquisition with contrast is performed for neck, thorax, abdomen, and pelvis through high-volume injectors. Overall, we used 130 mL of contrast with biphasic injection technique with an interbolus delay of 45 seconds. First phase involves 60 mL bolus of iopromide IV, at a rate of 2.0 mL/seconds in 30 seconds. An iopromide administration pause for 45 seconds followed by second phase that involves 70 mL bolus of iopromide IV, at a rate of 4.0 mL/seconds in 17 seconds. Finally, 40 mL of normal saline IV solution was administered at a rate of 4.0 mL/seconds in 10 seconds. Sequential contrast bolus results in single acquisition reflecting the combination of arterial and portal venous phases, with excellent image quality and fast reconstruct image acquisition. Slices of CT scanner are 1 mm, and the total number of slices depended on the height of the patient.

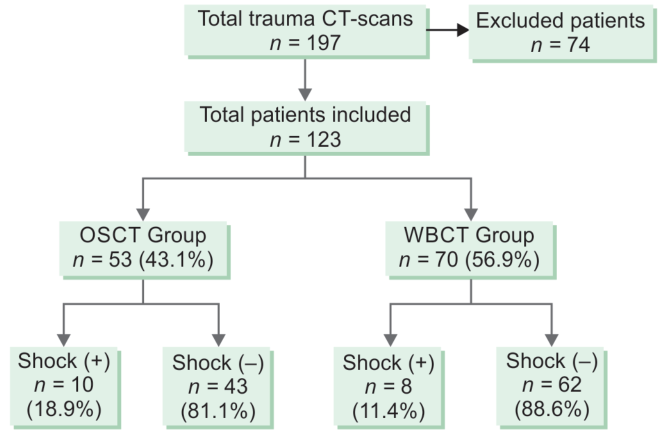
Data Collection and Statistical Methods

Data were extracted from the clinical records. Patients' demographics, clinical variables, and injury-related characteristics were obtained. The DLP values were obtained from each CT scan performed, and the effective radiation dose was estimated using the product of DLP and *K* conversion coefficient specific to each body region. The results were exported to a database from BD Clinic® to be analyzed in Stata 12.1®, College Station, TX. Initially, a descriptive analysis was performed. The continuous variables were summarized as averages ± standard deviation or median and interquartile ranges, depending on their normality analysis, and they were compared with Student *t* or Wilcoxon Mann–Whitney *U* test, according to whether normality assumptions were accomplished or not, respectively. The categorical variables were presented in proportions, and the comparison between them were made with Chi-square or Fisher's exact test accordingly. A value of $p < 0.05$ was considered statistically significant.

Results

A total of 123 patients were included during the study period, 53 were in OSCT group and 70 in WBCT group, and the presence or absence of shock was noted (Flowchart 1). In the OSCT group, 77.4% were male, with a median age of 28 [interquartile range (IQR) 22 to 39]. The median injury severity score (ISS) was 10 (IQR 9–17) and the revised trauma score (RTS) 7.9 (IQR 5.9–7.8). In WBCT group, 92.8% were male, with a median age of 29 years (IQR 23–50). The ISS was 16 (IQR 11–25) and the RTS was 6.9 (IQR 5.9–7.8). Both ISS and RTS were significantly higher in the WBCT group ($p < 0.001$ and $p = 0.01$, respectively).

Flowchart 1: Trauma computed tomography. Scheme summarizing total trauma CT scans and patients included in each group



In the OSCT group, the most common trauma mechanism was penetrating in 64.1% (34 cases); of these, 54.7% had injuries by gunshot wounds. Thoracic cavity was the most commonly injured body zone (79.3%), followed by extremities in 39.6% and head in 17%. Thirty-one cases had two or more body zones injured (58.5%); and of these, 10 patients (18.1%) arrived in shock. The most common trauma mechanism in the WBCT group was blunt (85.7% vs 35.9%; $p < 0.001$), of which 65.7% were secondary to traffic accidents and 21.4% were falls from heights. Head was the most common (71.9%) injured organ, 70% of patients had thoracic trauma, and 57 patients (81%) had two or more body zones injured; of these, 8 (11.4%) patients arrived in shock.

None of the patients of either group presented with cardiac arrest or died in the CT scanner. The median ER-to-CT scan time was lower in the WBCT group compared to the OSCT group [28 minutes (13–50) vs 41 minutes (21–60), $p = 0.01$]. The median CT scan-to-diagnosis time was also lower in the WBCT group [22 minutes (14–32) vs 32 minutes (21–65); $p < 0.001$].

In the OSCT group, 17 patients (47.2%) required a follow-up CT scan for definitive diagnosis. A total of 25 extra CT scans were performed. The most frequent extra CT scans were of the brain and chest. In all patients with extra CT scans, a second transfer to the CT suite was necessary. In one case, three transfers were necessary. This did not occur in the WBCT group, since none of the patients required a follow-up CT scan (47.2% vs 0%, <0.001) (Table 2).

Median total radiation dose in OSCT group was 22 (IQR 6–31) mSv, which was higher than the total radiation dose in the WBCT group [22 mSv (IQR 6–31) vs 15.1 mSv (IQR 9.9–24.8]; $p < 0.001$] (Table 3).

Discussion

In the past decade, the use of CT scan for evaluation of trauma patient has increased significantly. It is much more specific and sensitive for injury detection than conventional imaging strategies.[9] Thanks to its own technological advances, multislice CT has improved speed, image quality, and accuracy, allowing integration of WBCT into the early trauma care algorithm.[14] Currently, WBCT is widely used in trauma centers worldwide as the standard workup of severely injured patients.[15,16]

Table 2: Demographics and clinical characteristics

	Overall (N = 123), n (%)	*WBCT (N = 70), n (%)*	*OSCT (N = 53), n (%)*	*p value*
Age (years)*	29 (22–47)	29 (23–50)	28 (22–39)	
Male	106 (86.1)	65 (92.8)	41 (77.45)	
ISS*	16 (9–24)	16 (11–25)	10 (9–17)	$p < 0.001$
RTS*	7.8 (5.9–7.8)	6.9 (5.9–7.8)	7.9 (5.9–7.8)	0.01
Vital signs				
HR*	91 (75–109)	85 (65–103)	98 (85–113)	NS
RR*	18 (16–20)	17 (15–18)	18 (16–20)	NS
Shock	18 (14.6)	8 (11.4)	10 (18.9)	NS
GCS*	14 (7–15)	12 (7–15)	15 (10–15)	NS
Trauma mechanism				
Penetrating	44 (35.8)	10 (14.3)	34 (64.1)	$p < 0.001$
Blunt	79 (64.8)	60 (85.7)	19 (35.9)	$p < 0.001$
Body zone injured				
Head	60 (48.8)	51 (71.9)	9 (17)	
Cervical	14 (11.4)	12 (17.1)	2 (3.8)	
Thorax	91 (74)	49 (70)	42 (79.3)	
Abdomen	53 (43.1)	35 (50)	18 (34)	
Perineal	13 (10.6)	9 (12.9)	4 (7.6)	
Extremities	49 (39.8)	28 (40)	21 (39.6)	
Multiple trauma	88 (71.5)	57 (81.4)	31 (58.5)	

*Median (interquartile range)
ISS, injury severity score; RTS, revised trauma score; HR, heart rate (beats per minute); RR, respiratory rate; GCS, Glasgow Coma Scale; multiple trauma, 2 or more body zones injured

Table 3: The CT scan parameters

	WBCT (N = 70), n (%)	*OSCT (N = 53), n (%)*	*p value*
ED-to-CT suite time (minute)*	28 (13–50)	41 (21–60)	0.01
CT-to-diagnosis time (minute)*	22 (14–32)	32 (21–65)	<0.001
Extra CT scan	0 (0)	25 (47.2%)	<0.001
TRD (mGy)*	1004 (658–1652)	2040 (1475–3098)	<0.001
TERD (mSv)*	15.1 (9.9–24.8)	22 (6–31)	<0.001

*Median (Interquartile range)
ED-to-CT suite, transfer from emergency department to CT suite (minutes); TRD, total radiation dose; TERD, total effective radiation dose

Specific imaging protocol varies between institutions around the world.[17–20] Usually, WBCT is performed as a multipass CT acquisition technique with different helical CT phases of specific body zones.[21–23] Contrast medium is used for chest, abdomen, and pelvis. Nguyen et al. showed that the use of single-pass WBCT decreased acquisition time in 42.5% compared to the conventional WBCT.[24] In our institution, single-pass continuous WBCT protocol allows biphasic application of contrast medium in 1 minute 27 seconds, with the acquisition of an image in single pass using a high-resolution imaging of both arterial and venous phases.

The benefits of WBCT scan are multiple: it decreases the time to definitive diagnosis and/or treatment, and it shortens the overall emergency department length of stay.[8,17,25] However, it was considered that "WBCT can potentially delay critical interventions".[5] To this point, we found that WBCT decreased by 68% the time between ED arrival and transfer to the CT suite as compared to patients that had selective CT scans. This is partly due to the delay in decision-making on behalf of the treating trauma surgeon in the OSCT cases, who must decide which diagnostic/treatment algorithm he or she must take for each case according to the clinical information obtained on primary survey and initial screening adjuncts in the trauma bay. This phenomenon did not occur in the WBCT group because the patients had higher injury severity scores (ISS and RTS) and were automatically processed via a preestablished institutional diagnostic/treatment algorithm that guarantees the expeditious flow of the definitive workup of the patient. Also, patients in WBCT group were more severely injured, so the evaluation and decision-making had to be faster in order to achieve an early diagnosis and a faster treatment. This time reduction allowed for a faster triage of the most serious injuries and an expeditious onset.

Numerous retrospective studies have shown that the use of WBCT in severe trauma patients increases their survival rates.[26–29] Huber and colleagues showed a decrease in absolute mortality in patients with polytrauma who received WBCT when compared to those who received OSCT scans.[27] However, such results should be evaluated with caution, considering that the inclusion of a substantial number of patients with an ISS higher than 16 (36%) could have affected these results.[30] In our study, differences between groups, especially injury severity upon admission [ISS, New Injury Severity Score (NISS), RTS], made it impossible to fairly compare mortality and clinical outcomes among the groups (the WBCT group had an inherently higher risk of death).

Opponents of WBCT argue that a major potential disadvantage is the increased exposure to radiation and potential long-term risk of developing a malignancy.[31–34] The WBCT was performed using a single-pass and the patient's position with the arms above the head decreased the effective radiation dose by 16–22%.[35] The effective radiation dose in the WBCT group was between 10 mSv and 20 mSv compared to 5 mSv and 16 mSv in the OSCT group, but the net total radiation exposure was higher in the OSCT group because in many cases they required follow-up scans to rule out potential missed injuries.

We believe that time is of essence for a favorable outcome in critically ill trauma patients and this time includes that spent in the prehospital arena and in the trauma bay. To this end, the single-pass WBCT scan allows for an overall reduction in radiation exposure when compared to OSCT and provides timely diagnosis of the multiinjured trauma patient, which would probably decrease time to definitive treatment.

Limitations

Our study was an observational study which inherently carries limitations and selection bias. First, we did not perform a power analysis based on the primary outcome, the sample was a convenience sample, based on the hospital capacity. The decision to perform WBCT or OSCT depended on the treating physician, and even there is a workflow to guide this decision; randomization of the patients was not done to assure the homogeneity of the patient's characteristics. The differences in trauma mechanisms and severity scores between the two groups make the patients noncomparable but is useful to evaluate the characteristics of patients receiving WBCT or OSCT and to establish the potential uses of WBCT at our institution.

Conclusion

Our results suggest that trauma patients undergoing single-pass WBCT seem to have an overall lower total radiation exposure and lower ED-to-CT scan time and lower CT scan-to-diagnosis time, which could also decrease the time to definitive treatment. These findings reiterate our hypothesis that WBCT scan is a safe and efficient tool to diagnose trauma in patients, and we encourage other trauma centers nationally to implement this diagnostic tool for the management of polytrauma patients. However, this is a single-center study, whose results should be interpreted with caution as they cannot be generalized to all trauma centers, and more studies are needed to assess the usefulness, efficacy, and effectiveness of WBCT in severe trauma patients.

Ethics Approval

Ethics approval was granted by the Institutional Review Board from Fundacion Valle del Lili under the number 554 in 2014 and has been updated annually since its approval.

Author Contribution

Carlos Ordonez, Michael Parra, Ana M Del Valle, Monica Guzman-Rodriguez, Hernan E Munevar, Constanza Navarro, Carlos García, Alberto F García, Juan P Herrera-Escobar, Alejandra de las Salas, Laura Ibarra and Alfonso Holguin contributed equally to this work. Ana M Del Valle, Hernan E Munevar, Alejandra de las Salas and Laura Ibarra collected the data. All authors participated in the writing and editing of the manuscript, and the decision to submit for publication.

Acknowledgments

We thank radiologists, radiological technicians, and emergency department personnel for their effort and work at the emergency department in the Fundacion Valle del Lili, Cali, Colombia.

References

1. Gondek S, Schroeder ME, Sarani B. Assessment and resuscitation in trauma management. Surg Clin North Am [Internet] 2017;97(5): 985–998. DOI: 10.1016/j.suc.2017.06.001.
2. ATLS Subcommittee. American college of Surgeons' committee on trauma, international ATLS working group. Advanced trauma life support (ATLS®). J Trauma Acute Care Surg 2013;74(5):1363–1366.
3. Leidner B, Adiels M, Aspelin P, et al. Standardized CT examination of the multitraumatized patient. Eur Radiol 1998;8(9):1630–1638. DOI: 10.1007/s003300050601.
4. Kim Y-J, Kim J-S, Cho S-H, et al. Characteristics of computed tomography in hemodynamically unstable blunt trauma patients. Medicine (Baltimore) 2017;96(49):e9168. DOI: 10.1097/MD.0000000000009168.
5. Çorbacıoğlu ŞK, Aksel G. Whole body computed tomography in multi trauma patients: Review of the current literature. Turkish J Emerg Med 2018;18(4):142–147. DOI: 10.1016/j.tjem.2018.09.003.
6. Weninger P, Mauritz W, Fridrich P, et al. Emergency room management of patients with blunt major trauma: evaluation of the multislice computed tomography protocol exemplified by an urban trauma center. J Trauma - Inj Infect Crit Care 2007;62(3):584–591. DOI: 10.1097/01.ta.0000221797.46249.ee.
7. Wurmb TE, Quaisser C, Balling H, et al. Whole-body multislice computed tomography (MSCT) improves trauma care in patients requiring surgery after multiple trauma. Emerg Med J 2011;28(4): 300–304. DOI: 10.1136/emj.2009.082164.
8. Tsutsumi Y, Fukuma S, Tsuchiya A, et al. Whole-body computed tomography during initial management and mortality among adult severe blunt trauma patients: a nationwide cohort study. World J Surg 2018;42(12):3936–3946. DOI: 10.1007/s00268-018-4732-5.
9. Chidambaram S, Goh EL, Khan MA. A meta-analysis of the efficacy of whole-body computed tomography imaging in the management of trauma and injury. Injury 2017;48(8):1784–1793. DOI: 10.1016/j.injury.2017.06.003.
10. Alagic Z, Eriksson A, Drageryd E, et al. Whole body CT versus selective radiological imaging strategy in trauma: an evidence-based clinical review. Br J Radiol [Internet] 2017;89(1061):647–652. DOI: 10.1136/emermed-2016–206167.Available from: http://dx.doi.org/10.1016/j.clinimag.2014.09.011.
11. Dreizin D, Munera F. Multidetector CT for penetrating torso trauma: state of the art. Radiology 2015;277(2):338–355. DOI: 10.1148/radiol.2015142282.
12. Christner JA, Kofler JM, McCollough CH. Estimating effective dose for ct using dose-length product compared with using organ doses: Consequences of adopting international commission on radiological protection publication 103 or dual-energy scanning. Am J Roentgenol 2010;194(4):881–889. DOI: 10.2214/AJR.09.3462.
13. Mccollough CH, Schueler BA. Educational treatise: calculation of effective dose. Med Phys 2000;27(5):828–837. DOI: 10.1118/1.598948.
14. Hutter M, Woltmann A, Hierholzer C, et al. Association between a single-pass whole-body computed tomography policy and survival after blunt major trauma: a retrospective cohort study. Scand J Trauma Resusc Emerg Med [Internet] 2011;19(1):73. DOI: 10.1186/1757-7241-19-73Available from: http://www.sjtrem.com/content/19/1/73.
15. Kinoshita T, Yamakawa K, Matsuda H, et al. The survival benefit of a novel trauma workflow that includes immediate whole-body computed tomography, surgery, and interventional radiology, all in one trauma resuscitation room: a retrospective historical control study. Ann Surg 2019;269(2):370–376. DOI: 10.1097/SLA.0000000000002527.

16. Huber-Wagner S, Biberthaler P, Häberle S, et al. Whole-body CT in haemodynamically unstable severely injured patients - A retrospective, multicentre study. PLoS ONE 2013;8(7):e68880. DOI: 10.1371/journal.pone.0068880.
17. Jiang L, Ma Y, Jiang S, et al. Comparison of whole-body Computed tomography vs selective radiological imaging on outcomes in major trauma patients: A meta-analysis. Scand J Trauma Resusc Emerg Med 2014;22(54):1–11. DOI: 10.1186/s13049-014-0054-2.
18. Smith C, Woolrich-Burt L, Wellings R, et al. Major trauma CT scanning: The experience of a regional trauma centre in the UK. Emerg Med L 2011;28(5):378–382. DOI: 10.1136/emj.2009.076414.
19. Hickethier T, Mammadov K, Baeßler B, et al. Whole-body computed tomography in trauma patients: optimization of the patient scanning position significantly shortens examination time while maintaining diagnostic image quality. Ther Clin Risk Manag 2018;14:849–859. DOI: 10.2147/TCRM.S162074.
20. Boscak AR, Shanmuganathan K, Mirvis SE, et al. Optimizing trauma multidetector CT protocol for blunt splenic injury: need for arterial and portal venous phase scans. Radiology 2013;268(1):79–88. DOI: 10.1148/radiol.13121370.
21. 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(1063):20160160. DOI: 10.1259/bjr.20160160.
22. Godt JC, Eken T, Schulz A, et al. Triple-split-bolus versus single-bolus CT in abdominal trauma patients: a comparative study. Acta Radiol 2018;59(9):1038–1044. DOI: 10.1177/0284185117752522.
23. 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(1061):20150952. DOI: 10.1259/bjr.20150952.
24. Nguyen D, Platon A, Shanmuganathan K, et al. Evaluation of a single-pass continuous whole-body 16-MDCT protocol for patients with polytrauma. AJR Am J Roentgenol 2009;192(1):3–10. DOI: 10.2214/AJR.07.3702.
25. Van Vugt R, Kool DR, Deunk J, et al. 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 2012;72(3):553–559. DOI: 10.1097/TA.0b013e31822dd93b.
26. Baghdanian AH, Baghdanian AA, Armetta A, et al. Effect of an institutional triaging algorith on the use of multidetector CT for patients with blunt abdominopelvic trauma over an 8-year period. Radiology 2017;282(1):84–91. DOI: 10.1148/radiol.2016152021.
27. Huber-Wagner S, Lefering R, Qvick LM, et al. Effect of whole-body CT during trauma resuscitation on survival: a retrospective, multicentre study. Lancet [Internet] 2009;373(9673):1455–1461. DOI: 10.1016/S0140-6736(09)60232-4.
28. Wada D, Nakamori Y, Yamakawa K, et al. Impact on survival of whole-body computed tomography before emergency bleeding control in patients with severe blunt trauma. Crit Care 2013;17(4):R178. DOI: 10.1186/cc12861.
29. Ordoñez CA, Herrera-Escobar JP, Parra MW, et al. Computed tomography in hemodynamically unstable severely injured blunt and penetrating trauma patients. J Trauma Acute Care Surg 2016;80(4):597–603. DOI: 10.1097/TA.0000000000000975.
30. Sierink JC, Treskes K, Edwards MJ, et al. Immediate total-body CT scanning versus conventional imaging and selective CT scanning in patients with severe trauma (REACT-2): a randomised controlled trial. Lancet [Internet] 2016;388(10045):673–683. DOI: 10.1016/S0140-6736(16)30932-1.
31. Brenner D, Hall E. Computed tomography—an increasing source of radiation exposure. N Engl J Med 2007;357(22):2277–2284. DOI: 10.1056/NEJMra072149.
32. Pearce MS, Salotti JA, Little MP, et al. Radiation exposure from CT scans in childhood and subsequent risk of leukaemia and brain tumours: a retrospective cohort study. Lancet 2012;380(9840):499–505. DOI: 10.1016/S0140-6736(12)60815-0.
33. Abe T, Aoki M, Deshpande G, et al. Is whole-body CT associated with reduced in-hospital mortality in children with trauma? A nationwide study. Pediatr Crit Care Med 2019;20(6):e245–e250. DOI: 10.1097/PCC.0000000000001898.
34. Brenner DJ, Elliston CD. Estimated radiation risks potentially associated with full-body CT screening. Radiology 2004;232(3): 735–738. DOI: 10.1148/radiol.2323031095.
35. Brink M, de Lange F, Oostveen LJ, et al. Arm raising at exposure-controlled multidetector trauma CT of thoracoabdominal region: Higher image quality, lower radiation dose. Radiology 2008;249(2):661–670. DOI: 10.1148/radiol.2492080169.