

Usefulness of low dose chest CT for initial evaluation of blunt chest trauma

Sung Jung Kim, MD^a, Anjali Basnyat Bista, MD^b, Young Gi Min, MD^c, Eun Young Kim, MD, PhD^a, Kyung Joo Park, MD, PhD^a, Doo Kyoung Kang, MD^a, Joo Sung Sun, MD^{a,*}

Abstract

We aimed to compare the diagnostic performance and inter-observer consistency between low dose chest CT (LDCT) and standard dose chest CT (SDCT) in the patients with blunt chest trauma.

A total of 69 patients who met criteria indicative of blunt chest trauma (77% of male; age range, 16–85) were enrolled. All patients underwent LDCT without intravenous (IV) contrast and SDCT with IV contrast using parameters as following: LDCT, 40 mAs with automatic tube current modulation (ATCM) and 100 kVp (BMI <25, n=51) or 120 kVp (BMI >25, n=18); SDCT, 180 mAs with ATCM and 120 kVp. Transverse, coronal, sagittal images were reconstructed with 3-mm slice thickness without gap and provided for evaluation of 3 observers. Reference standard images (transverse, coronal, sagittal) were reconstructed using SDCT data with 1-mm slice thickness without gap. Reference standard was established by 2 experienced thoracic radiologists by consensus. Three observers independently evaluated each data set of LDCT and SDCT.

Multiple-reader receiver operating characteristic analysis for comparing areas under the ROC curves demonstrated that there was no significant difference of diagnostic performance between LDCT and SDCT for the diagnosis of pulmonary injury, skeletal trauma, mediastinal injury, and chest wall injury ($P > 0.05$). The intraclass correlation coefficient was measured for inter-observer consistency and revealed that there was good inter-observer consistency in each examination of LDCT and SDCT for evaluation of blunt chest injury (0.8601–1.000). Aortic and upper abdominal injury could not be appropriately compared as LDCT was performed without using contrast materials and this was limitation of this study.

The effective radiation dose of LDCT (average DLP = 1.52 mSv·mGy⁻¹ cm⁻¹) was significantly lower than those of SDCT (7.21 mSv·mGy⁻¹ cm⁻¹).

There is a great potential benefit to use of LDCT for initial evaluation of blunt chest trauma because LDCT could maintain diagnostic image quality as SDCT and provide significant radiation dose reduction. A further study of LDCT with IV contrast for evaluation of aortic and upper abdominal injury is needed.

Abbreviations: ATCM = automatic tube current modulation, AUC = areas under the ROC curves, CTDIvol = CT dose index volume, DLP = dose-length product, ICC = intraclass correlation coefficient, LDCT = low dose chest CT, MDCT = multidetector computed tomography, ROC = receiver operating characteristic, SDCT = standard dose chest CT.

Keywords: blunt chest trauma, computed tomography, emergency medicine, low dose chest CT, standard dose chest CT

1. Introduction

Multidetector computed tomography (MDCT) is now the modality of choice for evaluation of patients with multiple traumas including thoracic injury, superseding routine chest

x-ray, which could frequently miss significant thoracic injury.^[1] The routine use of CT was encouraged in blunt chest trauma, because it could increase the diagnostic yield in patients whose injuries were clinically and radiographically silent and in multitrauma patients with high-risk mechanisms.^[2–4] However, this has resulted in rapid increment of the CT examination for trauma evaluation. One study revealed that the number of chest CT examinations in the emergency department increased by 226% from 2000 to 2005, whereas the number of patients increased by 13%.^[5] Trauma patients in the acute setting have a potential to be investigated with extensive diagnostic studies due to their urgency, thereby increasing the risk of radiation overexposures in these patients.^[6,7] Therefore, it is very important to lower radiation dose according to specific indication of the examination according to the ALARA (as low as reasonably achievable) principle.^[8,9]

Low-dose chest CT (LDCT) has been used for the detection of pulmonary nodule, especially, lung cancer surveillance, because of the attenuation difference of lesion to normal parenchyma in the chest and low dose of radiation. Although radiation reduction from LDCT could limit proper evaluation of CT image data, we recently have accumulated experience of LDCT and empirically we could deduce that LDCT could be useful for the primary

Editor: George Kasotakis.

Authorship: All authors contributed to the research, writing, and preparation of this manuscript.

The authors have no funding and conflicts of interest to disclose.

^a Department of Radiology, Ajou University Hospital, Suwon, Korea, ^b Department of Radiology, B&B Hospital, Lalitpur, Nepal, ^c Department of Emergency Medicine, Ajou University Hospital, Suwon, Korea.

* Correspondence: Joo Sung Sun, Ajou University School of Medicine, Yeongtong-gu, Suwon, Korea (e-mail: sunnahn@ajou.ac.kr).

Copyright © 2017 the Author(s). Published by Wolters Kluwer Health, Inc. This is an open access article distributed under the terms of the Creative Commons Attribution-Non Commercial-No Derivatives License 4.0 (CCBY-NC-ND), where it is permissible to download and share the work provided it is properly cited. The work cannot be changed in any way or used commercially without permission from the journal.

Medicine (2017) 96:2(e5888)

Received: 22 August 2016 / Received in final form: 16 December 2016 /

Accepted: 20 December 2016

<http://dx.doi.org/10.1097/MD.0000000000005888>

survey of blunt chest trauma patients. One recent literature reported that the subjectively scored diagnostic interpretability of low dose CT for total body trauma was comparable to that of standard dose CT.^[10] However, to date, the direct comparison of the diagnostic performance of low dose chest CT with standard dose CT in patients with blunt chest trauma has not yet been reported. Therefore, this study aimed to compare the diagnostic performance and inter-observer consistency between low dose chest CT and standard dose chest CT in the patients with blunt chest trauma.

2. Materials and methods

2.1. Study population

This prospective study was approved by our institutional review board and written informed consent was obtained from all the patients. The current study was performed in the Emergency Department of a Tertiary Educational Hospital, the *** University Medical Centre.

From August 2012 through December 2013, we enrolled 69 patients who were carried into the emergency department with blunt chest trauma. All patients were included according to hereby inclusion criteria (Table 1). The major exclusion criteria were hemodynamic instability or pregnancy, and any condition requiring prompt surgical intervention.

Initial clinical evaluation was performed and recorded by emergency medicine residents who were supervised by the emergency medicine physician and simultaneous anteroposterior chest radiographs were obtained for all patients.

Table 1
Table of inclusion criteria.

Inclusion criteria	
Any signs of thoracic injury on initial CXR	<ul style="list-style-type: none"> –Pulmonary contusion –Hemothorax –Subcutaneous emphysema –Suspicious aortic injury including a widened mediastinum and loss of aortic contour –Spinal fracture –Rib fracture –Scapular fracture –Clavicular fracture –Diaphragmatic rupture
Any abnormal findings on physical examination of the chest wall or lungs	<ul style="list-style-type: none"> –Decreased breathing sounds at auscultation –Subcutaneous emphysema at palpation –Tenderness to palpation of the chest wall –Lacerations or hematoma of the chest wall
Respiratory insufficiency	<ul style="list-style-type: none"> –SaO₂ < 95% –Respiratory rate < 10 or > 29/min
High-energy mechanism of injury and high-energy crush injury impact to the chest wall	<ul style="list-style-type: none"> –Fall from height >3 m –Motor vehicle accident >50 km/h –Ejection from vehicle –Car rollover –Severe impact damage to car –Struck pedestrian >10 km/h –Struck bicyclist >30 km/h –Squeezed under or between heavy objects

CXR=chest radiography.

2.2. CT examination

All examinations were performed using a 16-detector-row CT scanner (Sensation 16; Siemens, Erlangen, Germany) that was located in the emergency department. The CT scans were obtained with end-inspiration state, as far as possible, in a supine position. Chest CT scans were performed from the thoracic inlet to the upper abdomen. CT examination was obtained with LDCT without intravenous contrast agent and standard dose CT (SDCT) after intravenous injection of nonionic contrast media (2.5 mL/s, 100 mL Iomeprol—Iomeron 300; Bracco, Milan, Italy) using a power injector. The parameters of LDCT scans were as follows: 0.75 mm-collimation; pitch, 1.0; reference effective tube current time product of 40 mAs with automatic tube current modulation (ATCM); tube voltage of 100 kV (BMI<25) or 120 kV (BMI≥25). The parameters of SDCT scans were as follows: 0.75 mm-collimation; pitch, 1.0; reference effective tube current time product of 180 mAs with ATCM; tube voltage of 120 kV. Coronal, sagittal multi planar reformatted images were reconstructed in both LDCT and SDCT with 3-mm slice thickness without gap. All CT scans were reconstructed using a soft filter kernel. Vendor providing CT dose index volume (CTDIvol) and dose-length product (DLP) were recorded and CT radiation dose descriptor for LDCT and SDCT.

2.3. Image evaluation

Two board-certified radiologists and a 3rd year radiology trainee independently performed retrospective analysis of the images of these prospectively collected data. They were unaware of any clinical information, except that the CT data were from patients with blunt chest trauma. LDCT and SDCT image data sets were evaluated separately. The order of each image sets was randomized using a standard random number generator. First, LDCT image data sets were reviewed by 3 observers. Then, the image sets of SDCT were evaluated in the same manner after a month to avoid potential recall bias.

All the observers were requested to mark the check box for list of categorized injury. The check box comprised of 4-point confidence scale as follows: 1 point, definitely negative; 2 point, probably negative; 3 point, probably positive; 4 point, definitely positive. After evaluation, if multiple lesions were identified in the same kind of category, the highest confidence scale was selected. For example, if multiple rib fractures were identified (e.g., confidence scale for multiple rib fractures range from 2 to 4), the highest score of the lesions was selected to represent (e.g., rib fracture, confidence scale 4).

Injuries that could be identified on chest CT scan were categorized as follows: (1) pulmonary and tracheobronchial injury (lung contusion, pneumatocele, pneumothorax, hemothorax, and tracheobronchial injury); (2) skeletal trauma (fractures of the ribs, clavicle, scapula, sternum and thoracic vertebra); (3) mediastinal injury (esophageal injury, pneumomediastinum, hemomediastinum, pneumopericardium, hemo-pericardium); (4) chest wall injury (chest wall hematoma, chest wall emphysema); (5) diaphragmatic injury; (6) aortic injury; (7) upper abdominal injury (liver, splenic, adrenal gland, and renal injury, pneumoperitoneum and hemoperitoneum). Each injury was defined as follows: pulmonary contusion was defined as “geographic ground-glass or nodular opacities or consolidation not confined within the segmental and lobar boundaries.” Pneumatocele was defined as “round or oval shape, thin-walled, gas-filled space within the lung.” Tracheobronchial tree injury was defined as “direct cut-off of the trachea or the bronchus with

extraluminal air collection.” Fracture of bone was defined as “definitely visible radiolucent line.” The observers were requested to be vigilant of frequently missed buckle fractures of the rib. Esophageal injury was defined as “direct cut-off of the esophagus or peri-esophageal air or fluid leakage.” Diaphragmatic injury was defined as “the defect or discontinuation of the diaphragm or waist-like stricture of herniated structures (stomach or bowel or fat) or contrast extravasation at diaphragm.” Aortic injury was defined as “direct signs (intimal flap, pseudoaneurysm, abnormal aortic contour, intraluminal thrombus, contrast extravasation)” or “indirect sign (periaortic haematoma with periaortic mediastinal fat plane obliteration).” Liver and splenic injuries were defined as “laceration, intraparenchymal, or subcapsular hematoma or contrast extravasation.” Pneumothorax, pneumomediastinum, pneumopericardium, chest wall emphysema, and pneumoperitoneum were defined as “air density within the pleural cavity, mediastinum, pericardium, chest wall and abdominal cavity,” respectively. Pneumomediastinum was differentiated from pneumothorax by the presence of the internal septa.^[11–15] Hemothorax, hemopericardium, hemoperitoneum were defined as “blood density (30–100 HU) within the pleural cavity, pericardium and abdominal cavity,” respectively. Mediastinal hematoma was defined as “inhomogeneous soft tissue density within the mediastinal fat, with obscuration or obliteration.” Chest wall hematoma was defined as “area of soft tissue density causing anatomical alteration.” We are aware of the critical limitation for assessment of aortic injury and upper abdominal injury using non-contrast CT, so LDCT without contrast enhancement of this current study was not appropriate for proper evaluation of aortic injury and upper abdominal injury.

2.4. Reference standard

Axial, coronal, and sagittal images were used as reference standard images using standard post-contrast chest CT data with 1-mm slice thickness without gap. The consensus interpretations by 2 experienced thoracic radiologists were used as the reference standard.

2.5. Radiation dose assessment

For quantifying and comparing radiation dose reduction, vendor-provided volume CT dose index (CTDIvol) and dose-length product (DLP) of the console of the CT were recorded as CT radiation dose descriptors for all chest CT examinations. The

effective dose (in mSv) was estimated by multiplication of DLP by the conversion coefficient *k* (i.e., 0.014 mSv mGy⁻¹ cm⁻¹).^[16]

2.6. Statistical analysis

For the evaluation of diagnostic performance of each injury of both LDCT and SDCT, a multiple-reader receiver operating characteristic (ROC) was used for comparing areas under the ROC curves (AUC) from the observers. To assess the inter-observer agreement, the intraclass correlation coefficient (ICC) was calculated with 95% confidence intervals and application of a 1-way ICC with random rater assumption in each reconstruction algorithm. The ICCs ranged from 0 to 1.00, and values closer to 1.00 represented better reproducibility. The ICCs were interpreted as follows: 0.00 to 0.20, slight reproducibility; 0.21 to 0.40, mild reproducibility; 0.41 to 0.60, moderate reproducibility; 0.61 to 0.80, good reproducibility; and 0.81 to 1.00, excellent reproducibility.^[17] 95% level of confidence was used between the AUCs and a *P* value of .05 was considered as statistically significant difference.

3. Result

3.1. Patient demographics

Total 69 patients who met inclusion criteria and gave consent to our study were enrolled. There were 53 men and 16 women (age range, 16–85 years; mean age, 48 years). Fifty-one patients (BMI<25) underwent LDCT with the use of 100 kVp and 18 patients (BMI≥25) underwent LDCT with the use of 120 kVp. The causes of blunt chest trauma were car accidents (42%, 29/69), pedestrian accident (20%, 20/69), fall down (24.6%, 17/69), and motorbike accident (4.3%, 3/69). Most common injuries were rib fracture (n=54), lung contusion (n=34), hemothorax (n=30), and pneumothorax (n=18) (Table 2).

3.2. Radiation dose reduction

The use of lower tube voltage and tube current with ATCM in chest MDCT of blunt chest trauma patients could provide substantial dose reduction. The average CTDIvol and DLP on LDCT was 2.72 mGy and 108.8 mGy cm, respectively. The average CTDIvol and DLP on SDCT was 13.2 mGy and 514.8 mGy cm, respectively. Effective dose of LDCT and SDCT was estimated to be 1.52 and 7.21 mSv mGy⁻¹ cm⁻¹. About 78.9% of dose reduction was achieved in LDCT, compared with SDCT.

Table 2
Injuries of blunt chest trauma (n=69).

Pulmonary and tracheobronchial injury		Mediastinal injury	
	n (%)		n (%)
Pulmonary contusion	34 (49.3%)	Pneumomediastinum	3 (4.3%)
Hemothorax	30 (43.5%)	Hemomediastinum	5 (7.2%)
Pneumothorax	18 (26.15)	Pneumopericardium	0 (0%)
Pneumatocele	8 (11.6%)	Hemopericardium	0 (0%)
Tracheobronchial injury	0 (0%)		
Skeletal injury		Chest wall injury	
	n (%)		n (%)
Rib	54 (78.3%)	Chest wall hematoma	4 (5.8%)
Clavicle	9 (13%)	Chest wall free air	12 (17.4%)
Scapular	7 (10.1%)	Diaphragmatic injury	1 (1.4%)
Sternum	5 (7.2%)	Aortic injury	1 (1.4%)
Vertebra	13 (18.8%)	Upper abdomen	
		Liver	16 (23.2%)
		Spleen	2 (2.9%)

Table 3**Intraclass correlation coefficient of LDCT and SDCT.**

	LDCT	SDCT
Pulmonary and tracheobronchial injury		
Lung contusion	0.9611 (0.9420–0.9747)	0.9631 (0.9450–0.9760)
Pneumatocele	0.8955 (0.8441–0.9320)	0.8815 (0.8232–0.9228)
Pneumothorax	0.9576 (0.9368–0.9724)	0.9859 (0.9790–0.9908)
Hemothorax	0.9226 (0.8845–0.9456)	0.9210 (0.8821–0.9485)
Skeletal injury		
Rib	0.9074 (0.8619–0.9397)	0.8601 (0.7982–0.9065)
Clavicle	0.9077 (0.8669–0.9384)	0.9396 (0.9128–0.9596)
Scapula	0.9123 (0.8734–0.9414)	0.9201 (0.8848–0.9467)
Sternum	0.8859 (0.8354–0.9238)	0.9071 (0.8660–0.9380)
Vertebra	0.8995 (0.8551–0.9329)	0.8918 (0.8439–0.9277)
Mediastinal injury		
Pneumomediastinum	1.000	0.9592 (0.9390–0.9734)
Hemomediastinum	0.9664 (0.9499–0.9781)	0.9682 (0.9526–0.9793)
Aortic injury	–	0.9844 (0.9767–0.9898)
Chest wall and diaphragmatic injury		
Hematoma	0.9628 (0.9446–0.9758)	0.8959 (0.8446–0.9229)
Free air	0.9843 (0.9766–0.9898)	0.9975 (0.9963–0.9984)
Diaphragmatic injury	1.000	1.000
Upper abdominal injury		
Liver	–	0.9430 (0.9150–0.9629)
Spleen	–	0.9532 (0.9302–0.9695)

LDCT = low dose chest CT, SDCT = standard dose chest CT.

3.3. Intraclass correlation coefficient (ICC)

The ICC values of each injury are summarized in Table 3. ICC analysis revealed that there was an excellent inter-observer consistency for the evaluation of the pulmonary injury (0.8815–0.9859), skeletal trauma (0.8601–0.9396), mediastinal injury (0.9592–1.0), and chest wall injury (0.8959–0.9975) in both LDCT and SDCT. ICC of 3 observers for diagnosis of aortic injury using SDCT was also very good (0.9594).

3.4. Diagnostic performance of LDCT and SDCT for blunt chest trauma

The diagnostic performance for the diagnosis of pulmonary injury using LDCT and SDCT was good to excellent (LDCT, 0.887–1.0; SDCT, 0.890–1.0) (Fig. 1). AUC comparison analysis demonstrated no significant difference of diagnostic performance between LDCT and SDCT in all observers (Table 4). Concerning the diagnostic performance for the evaluation of skeletal and

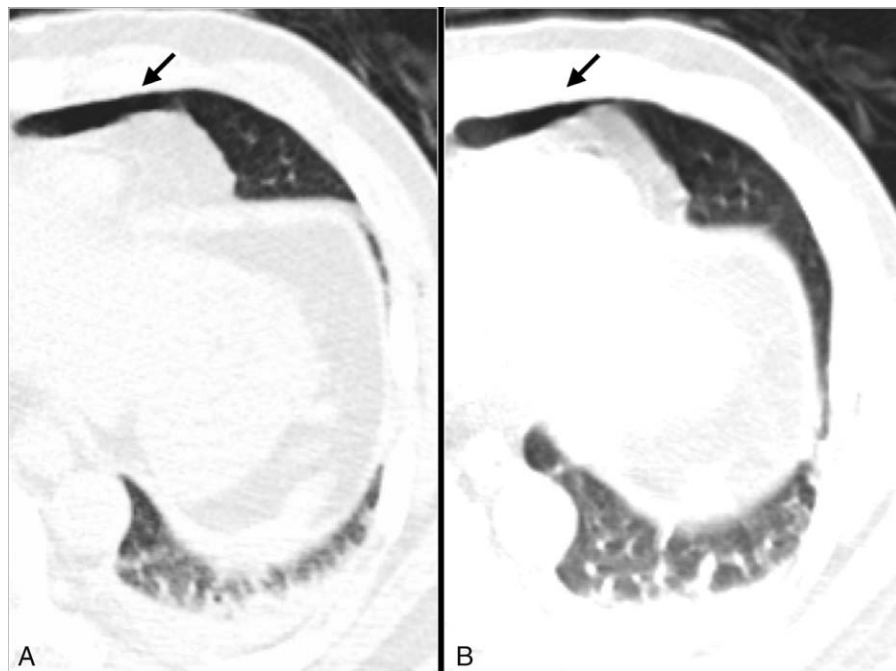


Figure 1. A 43-year-old man who had a driver traffic accident. All observers could detect small amount of left pneumothorax (arrows) on the axial 3-mm image of (A) SDCT (120 kVp and 180 mAs with ATCM) with 3–4 confidence. However, only 1 observer identified pneumothorax on the 3-mm axial image of (B) LDCT (100 kVp and 40 mAs with ATCM) with confidence 3. ATCM = automatic tube current modulation, LDCT = low dose chest CT, SDCT = standard dose chest CT.

Table 4
AUC comparison in each observer between LDCT vs SDCT for pulmonary and tracheobronchial injuries.

	Observer 1		Observer 2		Observer 3	
	LDCT	SDCT	LDCT	SDCT	LDCT	SDCT
Lung contusion	0.979 (0.912–0.999)	0.972 (0.900–0.997)	0.918 (0.827–0.970)	0.890 (0.792–0.953)	1.0 (0.948–1.000)	1.0 (0.948–1.000)
<i>P</i> value		0.332		0.306		1.000
Pneumatocele	0.887 (0.788–0.951)	0.903 (0.807–0.961)	0.888 (0.789–0.951)	0.903 (0.807–0.961)	0.923 (0.833–0.974)	0.938 (0.852–0.982)
<i>P</i> value		0.833		0.836		0.865
Pneumothorax	0.972 (0.901–0.997)	1 (0.948–1.000)	0.944 (0.861–0.985)	0.972 (0.901–0.997)	0.917 (0.825–0.970)	0.972 (0.901–0.997)
<i>P</i> value		0.317		0.571		0.173
Hemothorax	1.0 (0.948–1.000)	0.999 (0.946–1.000)	0.906 (0.811–0.963)	0.933 (0.847–0.979)	1.0 (0.948–1.000)	0.975 (0.906–0.98)
<i>P</i> value		0.412		0.398		0.186

AUC=areas under the receiver operating characteristic curves, LDCT=low dose chest CT, SDCT=standard dose chest CT.

mediastinal injury using LDCT and SDCT, the results were good to excellent and showed no significant difference of diagnostic performance (Figs. 2 and 3) (Tables 5 and 6).

Comparative evaluation of diagnostic performance of LDCT and SDCT to assess injury of aorta, upper abdominal solid organ was limited as LDCT was performed without intravenous contrast and SDCT was done with intravenous contrast in the current study protocol.

4. Discussion

Our study demonstrates several key results. First, there was good to excellent inter-observer consistency for the assessment of LDCT image data in patients of blunt chest trauma compared with assessment of SDCT in all observers. Second, there was no

significant difference of diagnostic performance between LDCT and SDCT for the evaluation of pulmonary injury, skeletal trauma, and mediastinal injury in all observers (except injuries that require post-contrast CT for proper evaluation such as aortic injury). Third, radiation dose reduction could be achieved up to about 79% of SDCT in LDCT.

Although chest radiography plays an important role in the evaluation and management of patients with blunt chest trauma, chest CT has become the most important imaging modality in the evaluation of patients with blunt chest trauma, since chest CT scan is able to provide accurate and additional information quickly, especially since the introduction of the MDCT.^[3,4,18] Several studies supported a harmful effect of low-dose exposure of radiation. One study reported that radiation exposure induced by medical imaging had significant relevance to cancer risk,

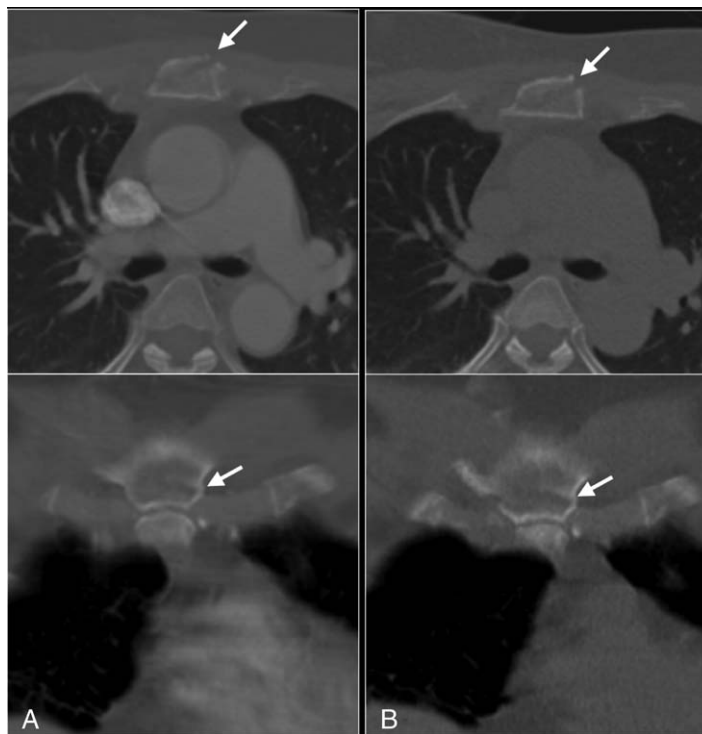


Figure 2. A 54-year-old woman who had blunt chest trauma from driver accident. All 3 observers identified this sternal fracture (arrows) on 3-mm axial and coronal images of both (A) LDCT (100 kVp and 40 mAs with ATCM) and (B) SDCT (120 kVp and 180 mAs with ATCM) with confidence 4 (definite fracture). ATCM = automatic tube current modulation, LDCT = low dose chest CT, SDCT = standard dose chest CT.

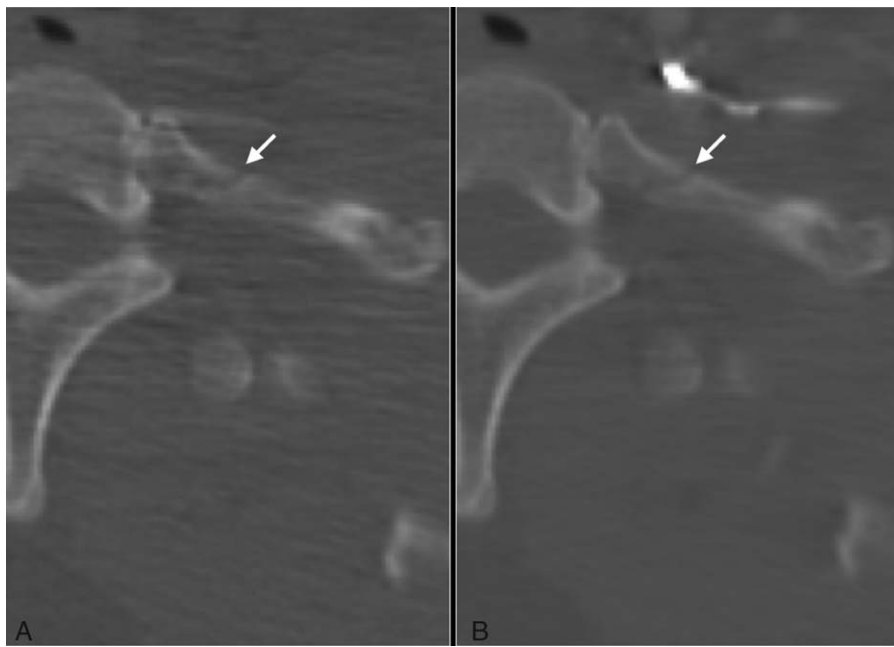


Figure 3. A 48-year-old man who had fallen from 3-m height. Axial 3-mm image of (A) LDCT (100 kVp and 40 mAs with ATCM) and (B) SDCT (120 kVp and 180 mAs with ATCM) shows fracture of left 1st rib (arrows). Although there is more artifact at the image of LDCT, all observers could identify rib fracture. ATCM = automatic tube current modulation, LDCT = low dose chest CT, SDCT = standard dose chest CT.

Table 5

AUC comparison in each observer between LDCT vs SDCT for bony thoracic cage injuries.

	Observer 1		Observer 2		Observer 3	
	LDCT	SDCT	LDCT	SDCT	LDCT	SDCT
Rib	0.928 (0.840–0.977)	0.936 (0.851–0.981)	0.833 (0.724–0.912)	0.781 (0.665–0.872)	0.884 (0.784–0.949)	0.936 (0.850–0.981)
<i>P</i> value		0.855		0.365		0.324
Clavicle	0.880 (0.779–0.946)	0.885 (0.786–0.949)	0.833 (0.724–0.912)	0.936 (0.850–0.981)	0.885 (0.786–0.949)	0.944 (0.861–0.985)
<i>P</i> value		0.352		0.356		0.301
Scapular	0.849 (0.743–0.924)	0.917 (0.825–0.970)	0.786 (0.670–0.875)	0.786 (0.670–0.875)	0.833 (0.724–0.912)	1 (0.948–1.0)
<i>P</i> value		0.349		1		0.073
Sternum	0.872 (0.770–0.940)	0.959 (0.882–0.992)	0.900 (0.804–0.959)	0.884 (0.785–0.949)	0.898 (0.802–0.958)	0.878 (0.777–0.945)
<i>P</i> value		0.323		0.154		0.898
Vertebra	0.953 (0.874–0.989)	0.980 (0.913–0.999)	0.755 (0.636–0.850)	0.828 (0.718–0.908)	0.823 (0.713–0.905)	0.826 (0.715–0.906)
<i>P</i> value		0.536		0.343		0.981

AUC=areas under the receiver operating characteristic curves, LDCT=low dose chest CT, SDCT=standard dose chest CT.

Table 6

AUC comparison in each observer between LDCT vs SDCT for mediastinal and chest wall injuries.

	Observer 1		Observer 2		Observer 3	
	LDCT	SDCT	LDCT	SDCT	LDCT	SDCT
Pneumomediastinum	1.000 (0.948–1.000)	0.992 (0.934–1.000)	1.000 (0.948–1.000)	1.000 (0.948–1.000)	1.000 (0.948–1.000)	1.000 (0.948–1.000)
<i>P</i> value		0.3173		1.000		1.000
Hemomediastinum	1.000 (0.948–1.000)	1.000 (0.948–1.000)	1.000 (0.948–1.000)	0.991 (0.931–1.000)	1.000 (0.948–1.000)	1.000 (0.948–1.000)
<i>P</i> value		1.000		0.324		1.000
Chest wall free air	1.000 (0.948–1.000)	1.000 (0.948–1.000)	1.000 (0.948–1.000)	1.000 (0.948–1.000)	0.958 (0.881–0.992)	1.000 (0.948–1.000)
<i>P</i> value		1		1		0.317
Chest wall hematoma	0.998 (0.944–1.000)	1.000 (0.948–1.000)	1.000 (0.948–1.000)	0.992 (0.933–1.000)	1.000 (0.948–1.000)	0.988 (0.927–1.000)
<i>P</i> value		0.479		0.317		0.198
Diaphragmatic injury		NC		NC		NC

AUC=areas under the receiver operating characteristic curves, LDCT=low dose chest CT, NC=not calculable, SDCT=standard dose chest CT.

causing 0.6% to 3.2% of malignant tumors in developed countries^[19] and Hall et al estimated that the lifetime cancer risk increased 4% per Sievert from low-dose exposure.^[20]

It is clear that radiologists have to make much effort to reduce unnecessary exposure of ionizing radiation from CT according to the principle of ALARA (as low as reasonably achievable) by the International Commission of Radiological Protection.^[8,9] The radiation dose could be reduced by application of the appropriate criteria for CT examination. Several published guidelines were available and American College of Radiology appropriateness criteria asserted that in the patients with high-mechanism injury, abnormal chest radiographs, altered mental status, distracting injuries, or clinically suspected thoracic injury, routine use of chest CT should be strongly considered.^[21] Another method for CT radiation dose reduction is adjustment of the scanning parameters.^[22] Our major concern is not to study whether MDCT should be performed routinely or selectively for evaluation of blunt chest trauma patients, but to evaluate feasibility of LDCT instead of SDCT for the initial survey of blunt chest trauma patients. Therefore, our study tried to evaluate the diagnostic performance of LDCT in blunt chest trauma patients, with the aim of direct comparison with SDCT.

In terms of evaluation of pulmonary and tracheobronchial tree injury, our study revealed that no significant difference of diagnostic performance for the diagnosis of lung contusion between LDCT and SDCT in all observers with good inter-observer consistency. Lung contusion is the most important contributing factor of mortality and morbidity in polytrauma patients with thoracic trauma.^[23–25] It may result in severe respiratory failure, adult respiratory distress syndrome, septic conditions, and multiple organs failure. Lung contusions may be frequently missed in chest x-ray especially early phase taken in supine position, and some contusions are not visible in the first few hours after trauma. On the other hand, chest CT can accurately visualize lung contusions immediately after injuries and detects even small pulmonary contusions.^[1]

Chest CT is superior to chest x-ray for detection of fractured rib, scapula, sternum, and vertebra.^[26] Our study also demonstrated that LDCT is comparable with SDCT in detection of the fractures in bony thorax. This result is consistent with previous reports that dose-reduced CT was sufficient for diagnosis of fracture in cervical spine trauma^[27] and in the experimental animal model.^[28] However, subtle rib contour abnormality (buckle fracture) could not be easily detected using low-dose CT. Thus, additional coronal and sagittal reformatted images can be helpful for detection of fractures that are missed on axial images.^[15]

With regard to pneumothorax and pneumomediastinum, it is not surprising that CT is extremely accurate in detecting of abnormal accumulation of air density.^[1,14,29,30] In this current study, diagnostic performance of MDCT was excellent, AUC of LDCT and SDCT for diagnosing pneumothorax was 0.887–1.0 and 0.890–1.0, respectively. Furthermore, there was excellent inter-observer consistency in both LDCT (ICC=0.9576) and SDCT (ICC=0.9859) in all observers.

Soft tissue injuries in the chest wall are rarely life-threatening.^[31] However, chest wall injuries are frequently overlooked in daily practice and chest wall hematoma may become life-threatening in the patient with anticoagulant therapy. In low-dose CT scan, evaluation of mediastinum and soft tissue of chest wall has limitations. It is because of the inherent limited tissue contrast of these areas, which is intensified in dose reduction techniques.^[32,33] In this study, only 4 cases of chest wall

hematoma were identified and these were well detected in both LDCT (AUC=0.998–1.0) and SDCT (AUC=0.988–1.0). Inter-observer consistency for evaluation of chest wall hematoma was also good at LDCT (ICC=0.9628) and SDCT (ICC=0.8959).

There were a few limitations in our prospective study. First, comparative evaluation of aortic and upper abdominal solid organ injury was limited due to noncontrast LDCT. Second, our study did not apply the iterative reconstruction (IR) technique. Using the IR technique could provide substantial improvement of image quality with reduced radiation dose.^[34]

Our study is the first prospective comparison study of LDCT with SDCT in initial evaluation of blunt chest trauma. It has strength of direct intraobserver comparison of diagnostic performance between LDCT and SDCT. This preliminary study suggests that LDCT could maintain diagnostic performance for the initial evaluation of blunt chest trauma patients with significant reduction of radiation dose. Further larger study of low-dose CT is needed with intravenous contrast for evaluation of aortic injury and upper abdominal solid organ injury.

References

- Trupka A, Waydhas C, Hallfeldt KK, et al. Value of thoracic computed tomography in the first assessment of severely injured patients with blunt chest trauma: results of a prospective study. *J Trauma* 1997;43:405–11. discussion 11–2.
- Plurad D, Green D, Demetriades D, et al. The increasing use of chest computed tomography for trauma: is it being overutilized? *J Trauma* 2007;62:631–5.
- Brink M, Deunk J, Dekker HM, et al. Added value of routine chest MDCT after blunt trauma: evaluation of additional findings and impact on patient management. *Am J Roentgenol* 2008;190:1591–8.
- Deunk J, Brink M, Dekker HM, et al. Routine versus selective computed tomography of the abdomen, pelvis, and lumbar spine in blunt trauma: a prospective evaluation. *J Trauma* 2009;66:1108–17.
- Broder J, Warshauer DM. Increasing utilization of computed tomography in the adult emergency department, 2000–2005. *Emerg Radiol* 2006;13:25–30.
- Kim PK, Gracias VH, Maidment AD, et al. Cumulative radiation dose caused by radiologic studies in critically ill trauma patients. *J Trauma* 2004;57:510–4.
- Winslow JE, Hinshaw JW, Hughes MJ, et al. Quantitative assessment of diagnostic radiation doses in adult blunt trauma patients. *Ann Emerg Med* 2008;52:93–7.
- 1990 Recommendations of the International Commission on Radiological Protection. *Ann ICRP* 1991;21:1–201.
- Slovis TL. Children, computed tomography radiation dose, and the As Low As Reasonably Achievable (ALARA) concept. *Pediatrics* 2003;112:971–2.
- Grupp U, Schafer ML, Meyer H, et al. Reducing radiation dose in emergency CT scans while maintaining equal image quality: just a promise or reality for severely injured patients? *Emerg Med Int* 2013;2013:984645.
- Shuman WP. CT of blunt abdominal trauma in adults. *Radiology* 1997;205:297–306.
- Dyer DS, Moore EE, Mestek MF, et al. Can chest CT be used to exclude aortic injury? *Radiology* 1999;213:195–202.
- Steenburg SD, Ravenel JG, Ikonomidis JS, et al. Acute traumatic aortic injury: imaging evaluation and management. *Radiology* 2008;248:748–62.
- Oikonomou A, Prassopoulos P. CT imaging of blunt chest trauma. *Insights Imaging* 2011;2:281–95.
- Cho SH, Sung YM, Kim MS. Missed rib fractures on evaluation of initial chest CT for trauma patients: pattern analysis and diagnostic value of coronal multiplanar reconstruction images with multidetector row CT. *Brit J Radiol* 2012 1018;85:e845–50.
- Mayo JR, Aldrich J, Muller NL, et al. Radiation exposure at chest CT: a statement of the Fleischner Society. *Radiology* 2003;228:15–21.
- Landis JR, Koch GG. The measurement of observer agreement for categorical data. *Biometrics* 1977;33:159–74.
- Brenner DJ, Hall EJ. Computed tomography—an increasing source of radiation exposure. *N Engl J Med* 2007;357:2277–84.

- [19] Hall EJ. Scientific view of low-level radiation risks. *Radiographics: a review publication of the Radiological Society of North America, Inc* 1991;11:509–18.
- [20] Pierce DA, Shimizu Y, Preston DL, et al. Studies of the mortality of atomic bomb survivors. Report 12, Part I. Cancer: 1950–1990. *Radiat Res* 1996;146:1–27.
- [21] Chung JH, Cox CW, Mohammed TL, et al. ACR appropriateness criteria blunt chest trauma. *J Am Coll Radiol* 2014;11:345–51.
- [22] Kubo T, Lin PJ, Stiller W, et al. Radiation dose reduction in chest CT: a review. *Am J Roentgenol* 2008;190:335–43.
- [23] Gaillard M, Herve C, Mandin L, et al. Mortality prognostic factors in chest injury. *J Trauma* 1990;30:93–6.
- [24] Gavelli G, Canini R, Bertaccini P, et al. Traumatic injuries: imaging of thoracic injuries. *Eur Radiol* 2002;12:1273–94.
- [25] Ganie FA, Lone H, Lone GN, et al. Lung contusion: a clinico-pathological entity with unpredictable clinical course. *Bull Emerg Trauma* 2013;1:7–16.
- [26] Traub M, Stevenson M, McEvoy S, et al. The use of chest computed tomography versus chest X-ray in patients with major blunt trauma. *Injury* 2007;38:43–7.
- [27] Mulkens TH, Marchal P, Daineffe S, et al. Comparison of low-dose with standard-dose multidetector CT in cervical spine trauma. *Am J Neuroradiol* 2007;28:1444–50.
- [28] Moritz JD, Hoffmann B, Sehr D, et al. Evaluation of ultra-low dose CT in the diagnosis of pediatric-like fractures using an experimental animal study. *Kor J Radiol* 2012;13:165–73.
- [29] Dissanaikie S, Shalhub S, Jurkovich GJ. The evaluation of pneumomediastinum in blunt trauma patients. *J Trauma* 2008;65:1340–5.
- [30] Scaglione M, Pinto A, Pedrosa I, et al. Multi-detector row computed tomography and blunt chest trauma. *Eur J Radiol* 2008;65:377–88.
- [31] Collins J. Chest wall trauma. *J Thorac Imaging* 2000;15:112–9.
- [32] Baker SP, O’Neill B, Haddon WJr, et al. The injury severity score: a method for describing patients with multiple injuries and evaluating emergency care. *J Trauma* 1974;14:187–96.
- [33] Prasad SR, Wittram C, Shepard JA, et al. Standard-dose and 50%-reduced-dose chest CT: comparing the effect on image quality. *Am J Roentgenol* 2002;179:461–5.
- [34] Noel PB, Fingerle AA, Renger B, et al. Initial performance characterization of a clinical noise-suppressing reconstruction algorithm for MDCT. *Am J Roentgenol* 2011;197:1404–9.