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Original Contribution

Optimal CT protocol for the diagnosis of active bleeding in abdominal trauma patients

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ABSTRACT

Objectives: The aim of this study is to compare the radiologic diagnostic performance of arterial phase, portal phase and combined phase computed tomography (CT) for traumatic abdominal injury. In addition, this study is attempted to decrease lifetime attributable risks (LARs) of cancer due to radiation exposure by using optimal CT protocol.
Materials and methods: A total of 114 consecutive patients with a traumatic abdominal injury and an abdominal hematoma on CT were enrolled at a single tertiary regional trauma center between January 2016 and March 2017. Each CT protocol set was independently reviewed by three radiologists, and the diagnostic performance of all three CT phases were compared with regard to the capability to detect active bleeding, contained vascular injuries, and organ injuries. Additionally, LARs for cancer incidence and mortality were calculated using dose-length product values, for each phase of CT.
Results: The pooled area under the receiver operating characteristic curves for the diagnosis of active bleeding, contained vascular injuries, and organ injuries ranged from 0.910 to 0.922, 0.643 to 0.723, and 0.948 to 0.915 for arterial, portal, and combined phase CT, respectively. There was no statistically significant difference in the diagnosis of active bleeding and organ injuries for any combination of two phase sets. The mean LARs for cancer incidence was 0.059%, 0.062% and 0.121% during arterial, portal and combined phase CT, respectively.
Conclusion: Single phase CT could be a potential protocol for abdominal trauma patients. Use of single phase CT could significantly decrease the incidence of radiation-associated cancer in the future.

1. Introduction

Currently, abdominal pelvic computed tomography (CT) is most commonly used as the imaging modality to evaluate patients with abdominal trauma [1]. CT provides a rapid and accurate diagnosis of active bleeding and organ damage in trauma patients [2-7]. The detection of active bleeding and vascular injuries is crucial in identifying the need for optimal intervention (surgery or transcatheter embolization) [1,8-11].

The classic pattern of active bleeding is focal extravasation of contrast media in the initial CT phase, and enlarged and faded contrast media within the hematoma in delayed images [12]. In the emergency department, physicians usually perform multiphase CT scans due to concern over misdiagnosis of active bleeding or organ injuries in patients with trauma. However, there are no regulated CT protocols for patients with abdominal trauma [1,8]. Hence, effective radiation doses of conventional multiphase abdominal pelvic CT scans exceed 10-mSv or even 30-mSv at some institutions [13,15]. Cohort studies have shown that radiation exposure from CT is associated with carcinogenesis, especially in children and young adults. The use of the biphasic CT scans before the age of 40 years caused one additional cancer in an estimated 1000 patients as compared with using single phase CT scan. Because traumatic injury is the leading cause of death in young adults, it is important to reduce the radiation dose in patients with trauma [17].

It is important to balance the risk of radiation exposure with the benefits of making a clinically accurate diagnosis. An incomplete or suboptimal study may lead to repeat or additional tests, ultimately adding to the total radiation dose. Thus, every effort should be made to decrease the radiation dose delivered using a revised protocol or low-radiation setting without compromising the diagnostic capability of the CT study [18-20]. The aim of this study is to compare the radiologic diagnostic performance between single phase (arterial or portal venous phase) and combined (both) phase CT for traumatic abdominal injury. In addition, this study is attempted to decrease lifetime attributable

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risks (LARs) of cancer due to radiation exposure by using optimal CT protocol.

2. Material and methods

2.1. Patient population

Our retrospective study was approved by institutional review board, which waived the requirement for informed consent. The trauma registry and the picture archiving and communication system were queried to identify 201 consecutive patients (age ≥ 16 years) who sustained abdominal injury from blunt or penetrating trauma between January 2016 and March 2017, and were seen at our regional trauma center. Patients were excluded if: 1) there was no visible hematoma within the abdominopelvic cavity on CT ($n = 78$), 2) the CT protocol did not include both arterial and portal venous phase ($n = 6$), 3) the CT imaging was delayed beyond 48 h of admission ($n = 3$). Finally, 114 patients were included in the study.

2.2. CT protocol

In our hospital, a 64 detector CT scanner (Somatom Definition Edge; Siemens Medical Solutions, Forchheim, Germany) has been used exclusively for emergency patients. The images of the arterial and portal venous phases were obtained using a bolus tracking method, with delays of 18 and 50 s, respectively, after 100 Hounsfield Units enhancement of the descending aorta were reached. We included seven patients who underwent outside two phase abdomino-pelvis CT scans.

2.3. CT image interpretation

Two board-certified abdominal radiologists (S.J.A and S.J.C, with 4 and 7 years of experience, respectively), and one board-certified general radiologist (D.H.P with 4 years of experience) reviewed all the images; they had no access to other images or clinical information. The radiologists interpreted three different sequences of image sets, each time in a random order: (1) first interpreting arterial phase only, (2) second interpreting portal venous phase only and (3) finally interpreting both phases. Each interpretation was separated by >6 weeks to reduce recall bias. During each interpretation session, the three radiologists assessed the images to diagnose whether there was active bleeding or contained vascular injury.

2.4. Reference standards

Abdominal hematoma was defined as high attenuation (45–70 HU) fluid adjacent to and directly abutting the injured organ on CT scans. Active bleeding on CT scans was defined as extravasation of contrast enhanced blood from injured organs [8]. Contained vascular injury, including pseudoaneurysm or arteriovenous fistulas, was defined as foci of contained extravasation of contrast enhanced blood within the injured organ [8]. Active bleeding was finally confirmed by surgery or angiography within 24 h after admission. If the patient died without any further interventions or imaging, the final diagnosis was decided by reviewers' consensus.

2.5. CT effective dose estimates

Age- and sex-specific effective doses were analyzed for each body region. Effective dose was used for the quantitative risk assessment of radiation exposure. Effective dose of each CT examination was calculated using dose-length product (DLP, mGy ∗ cm) values, and the normalized values of conversion factors (*E*DLP) found in the International Commission on Radiological Protection (ICRP) publication 103 [21].

The formula used for calculating the effective dose was as follows:

$$\text{Effective dose(mSv)} = \text{DLP} \times E\text{DLP}$$

The cumulative effective dose (cED) value in two-phase CT was calculated by summing the effective doses for each CT scan (arterial and portal venous).

2.6. Estimation of LARs of radiation-induced Cancer

The DLP values of both single CT phases, conversion constant (*E*DLP) from ICRP publication 103, and age- and sex-specific factors based on Biological Effects of Ionizing Radiation VII methodology, were used to estimate the LARs for radiation-induced cancer incidence and mortality [21,22]. Biological Effects of Ionizing Radiation VII data points were interpolated to the nearest integer age of exposure by using linear interpolation [23]. The DLP value of the two phases CT was calculated as the sum of each single phase DLP value. The probability of reducing cancer incidence and mortality could be predicted by comparing the LAR values obtained in the two- phase and single-phase CT, respectively.

2.7. Statistical analysis

The diagnostic performance, in terms of detecting active bleeding, was measured in terms of area under the receiver operating characteristic (ROC) curve (AUC), as well as sensitivity and specificity. McNemar's test was used to compare for differences in diagnostic performance with different modality sets. Mean values of continuous variables with normal distributions were compared using Student's *t*-test. We used statistical

Table 1
Patient demographics.

Characteristics	Study sample, n (%)
Age (years)—mean ± SD	
Male	40.5 ± 18.9
Female	56.3 ± 22.3
Sex ratio (M/F)	82 (72%)/32 (28%)
Injury mechanism, n (%)	
Traffic collision	79 (79/114, 70%)
Fall	19 (19/114, 16%)
Penetrating injury	9 (9/114, 8%)
Blunt injury	7 (7/114, 6%)
Injured solid organ, n (%)	58/114 (51%)
Liver	27 (27/58, 47%)
Spleen	21 (21/58, 36%)
Adrenal gland	15 (15/58, 26%)
Kidney	13 (13/58, 22%)
Pancreas	4 (4/58, 7%)
Testis	1 (1/58, 2%)
Actively bleeding patients, n (%)	48/114(42%)
Angiography and embolization	33 (33/48, 69%)
Branches of internal iliac artery	14 (14/33, 42%)
Hepatic artery and inferior phrenic artery	10 (10/33, 30%)
Splenic artery	9 (9/33, 27%)
Renal artery	7 (7/33, 21%)
Surgery	13 (13/48, 27%)
Mesentery	5 (5/13, 38%)
Small bowel	2 (2/13, 15%)
Liver	2 (2/13, 15%)
Spleen	2 (2/13, 15%)
Stomach	1 (1/13, 8%)
Colon	1 (1/13, 8%)
No treatment	2 (4%)
Contained vascular injuries	8/114(7%)
Angiography and embolization	7 (7/8, 87%)
Hepatic artery and inferior phrenic artery	3 (3/7, 42%)
Splenic artery	2 (2/7, 29%)
Renal artery	2 (2/7, 29%)
Surgery	1 (1/8, 13%)
Spleen	1 (1/1, 100%)

Table 2
Diagnostic performance of each CT phase for detecting active bleeding.

Readers	CT Phase	Sensitivity (%)	Specificity (%)	AUC	95% CI	*p*-Value
Reader 1	Arterial	93.5	91.1	0.923	0.858, 0.965	<0.001
	Portal	95.7	91.2	0.934	0.872, 0.972	<0.001
	Combined	95.7	89.7	0.927	0.863, 0.967	<0.001
Reader 2	Arterial	91.3	91.2	0.912	0.845, 0.957	<0.001
	Portal	91.3	91.2	0.912	0.845, 0.957	<0.001
	Combined	95.7	91.2	0.934	0.872, 0.972	<0.001
Reader 3	Arterial	89.1	89.7	0.894	0.823, 0.944	<0.001
	Portal	89.1	94.1	0.916	0.849, 0.960	<0.001
	Combined	91.3	89.7	0.905	0.836, 0.952	<0.001
Pool	Arterial	91.3	90.7	0.910	0.874, 0.938	<0.001
	Portal	92.0	92.2	0.921	0.887, 0.947	<0.001
	Combined	94.2	90.2	0.922	0.888, 0.948	<0.001

Note – CI = confidence interval.

software (MedCalc Software bvba, Ostend, Belgium) for analysis, and *p*-values of <0.05 were considered statistically significant.

3. Results

Patient demographics and clinical presentations of the study population are shown in Table 1. Patients included 82 men and 32 women, with ages ranging from 16 to 92 years (mean age, 47.2 years). Traffic collision were the most common cause of injury ($n = 79$, 70%). All penetrating injuries were stab wounds ($n = 9$, 8%). Blunt injuries included those resulting from violence, or crush injury by heavy machinery equipment or forklift truck. Forty-eight patients (48/114, 42%) had active bleeding in the abdominal cavity. Thirty-three patients (33/48, 69%) received transcatheter arterial embolization, and thirteen patients (13/48, 27%) underwent surgical exploration. Contained vascular injuries, including pseudoaneurysms or arteriovenous fistulas, were seen in 8 of the 114 patients (7%). Six patients (6/8, 75%) received transcatheter arterial embolization and 2 patients (2/8, 25%) underwent surgical exploration.

3.1. Diagnostic performance

The results of diagnostic performance of arterial, portal venous, and combined phase CT with regard to detecting active bleeding are presented in Table 2. The diagnostic AUC of the three readers ranged from 0.894 to 0.934. Pooled data showed an AUC of 0.910, 0.921 and 0.922 for arterial, portal venous, and combined phase CT, respectively ($p < 0.001$). There was no significant differences between the diagnostic performance of arterial, portal venous, and combined phase CT in terms of detecting active bleeding ($p > 0.112$). Missed cases for detecting active bleeding at the arterial, portal, and combined phases were five, six, and four cases, respectively, by all readers. These cases were reassessed by two abdominal and interventional radiologists (H.S.K and J.H.K, with 25 and 16 years of experience, respectively) who did not participate as readers. They judged that participant readers misinterpreted the active bleeding in one case in the arterial and three cases in the portal phase. In another case, active bleeding occurred only in the portal phase. However, since the bleeding was confined to the abdominal wall with stable vital signs, they judged that this patient could be treated using conservative management sufficiently. Another one case showed severe liver injuries (American Association for the Surgery of Trauma, AAST Grade V) with hepatic infarction in both lobes of liver. However, active bleeding focus was equivocal in both CT phases. The patient received surgical treatment regardless of active bleeding. Hence, it is likely that there was discordant interpretation between readers with regard to active bleeding in this case. In the remaining two cases, there was no visible active bleeding in both arterial and portal phases.

The results for diagnostic performance of the arterial, portal venous, and combined phase CT with regard to detecting contained vascular injuries are presented in Table 3. Contained vascular injuries were seen in 8 of the 114 patients (7%). The diagnostic AUC of the three readers ranged from 0.643 to 0.803. Pooled data showed an AUC of 0.723, 0.643, and 0.723 for arterial, portal venous, and combined phase CT, respectively ($p < 0.003$). The arterial or combined phase and portal venous phase of pooled data showed only slightly significant diagnostic performance ($p = 0.039$). Missed cases for detecting contained vascular injuries at arterial, portal, and combined phases were five each, respectively, by all readers. These cases were reassessed by two radiologists (H.S.K and J.H.K). In two cases, there were discordant interpretations with regard to contained vascular injuries between participant readers. These two cases showed severe liver injuries (AAST Grade V) with hepatic infarction in both lobes of liver. However, contained vascular injuries were equivocal at both CT phases. The patient received surgical treatment regardless of active bleeding. Hence, it was likely that there

Table 3
Diagnostic performance of each CT phase for detecting contained vascular injuries.

Readers	CT Phase	Sensitivity (%)	Specificity (%)	AUC	95% CI	*p*-Value
Reader 1	Arterial	62.5	98.1	0.803	0.718, 0.872	0.001
	Portal	37.5	99.1	0.683	0.589, 0.767	0.046
	Combined	62.5	98.1	0.803	0.718, 0.872	0.001
Reader 2	Arterial	37.5	100	0.688	0.594, 0.771	0.04
	Portal	37.5	100	0.688	0.594, 0.771	0.04
	Combined	37.5	100	0.688	0.594, 0.771	0.04
Reader 3	Arterial	50	98.1	0.741	0.650, 0.818	0.011
	Portal	37.5	99.1	0.683	0.589, 0.767	0.046
	Combined	50	99.1	0.741	0.650, 0.818	0.011
Pool	Arterial	45.8	98.7	0.723	0.672, 0.770	<0.001
	Portal	29.1	99.4	0.643	0.589, 0.694	0.003
	Combined	45.8	98.7	0.723	0.672, 0.770	<0.001

Note – CI = confidence interval.

Table 4
Diagnostic performance of each CT phase for detecting organ injuries.

Readers	CT Phase	Sensitivity (%)	Specificity (%)	AUC	95% CI	*p*-Value
Reader 1	Arterial	98.2	93.3	0.957	0.915, 1.000	<0.001
	Portal	96.3	93.3	0.948	0.901, 0.995	<0.001
	Combined	96.3	93.3	0.948	0.901, 0.995	<0.001
Reader 2	Arterial	96.3	93.3	0.948	0.901, 0.995	<0.001
	Portal	96.3	93.3	0.948	0.901, 0.995	<0.001
	Combined	96.3	93.3	0.948	0.901, 0.995	<0.001
Reader 3	Arterial	96.3	93.3	0.948	0.901, 0.995	<0.001
	Portal	96.3	93.3	0.948	0.901, 0.995	<0.001
	Combined	96.3	93.3	0.948	0.901, 0.995	<0.001
Pool	Arterial	96.9	93.3	0.951	0.925, 0.977	<0.001
	Portal	96.3	93.3	0.948	0.921, 0.977	<0.001
	Combined	96.3	93.3	0.948	0.921, 0.977	<0.001

Note – CI = confidence interval.

were discordant interpretations with regard to contained vascular injuries of the case between readers. In the remaining three cases, there were no visible active bleeding at both arterial and portal phases.

The results for diagnostic performance of arterial, portal venous, and combined phase CT with regards to detecting organ injuries are presented in Table 4. The diagnostic AUC of the three readers ranged from 0.948 to 0.957. Pooled data showed an AUC of 0.951, 0.948, and 0.948 for arterial, portal venous, and combined phase CT, respectively ($p < 0.001$). There was no significant difference between the diagnostic performance of arterial, portal venous, and combined phase CT in terms of detecting organ injuries ($p > 0.317$). Only six patients received surgery for organ injury, without visible active bleeding on CT. Two patients had a large liver laceration, two patients had a large kidney laceration, and two patients had diaphragmatic rupture. Missed cases for detecting solid organ injuries at arterial, portal, and combined phases were two each, respectively, by all readers. These cases were reassessed by two radiologists (H.S.K and J.H.K). In two cases, there were discordant interpretations between participant readers with regard to organ injuries. These two cases showed suspicious subcapsular low density lesions in liver at both arterial and portal phases, and follow-up CT revealed that these lesions were decreased. They were judged as liver injuries (AAST Grade I), and these patients were not needed any additional interventions.

3.2. Estimation of cED and LAR values

The cED of each CT phase is presented in Table 5. The average cEDs of 114 patients exposed to arterial and portal venous phase abdominal CT were 8.835 mSv (median, 7.575 mSv; interquartile range [IQR], 5.95–11.30 mSv) and 9.305 mSv (median, 8.108 mSv; IQR, 6.31–11.77 mSv), respectively. The estimated mean LARs for cancer incidence and mortality with arterial phase CT were 0.059% (median, 0.050%; IQR, 0.03–0.07%) and 0.034% (median, 0.027%; IQR, 0.02–0.04%), respectively (Table 6). In portal venous phase CT, the estimated mean LARs for cancer incidence and mortality were 0.062% (median, 0.053%; IQR, 0.03–0.08%) and 0.036% (median, 0.030%; IQR, 0.02–0.04%), respectively. In combined phase CT, the estimated mean LARs for cancer incidence and mortality were 0.121% (median, 0.104%; IQR, 0.06–0.15%) and 0.070% (median, 0.057%; IQR, 0.04–0.08%), respectively.

4. Discussion

In this study, we found that the diagnostic performance of combined phase CT, with regards to detecting active bleeding, did not show a significant advantage compared to diagnosis using single (arterial or portal venous) phase CT protocol. For all CT protocols, the sensitivities and specificities were >90%, and each protocol had an AUC >0.9. We found that there was no significant difference in diagnostic performance between two CT protocol sets (arterial vs portal venous, arterial vs combined, portal venous vs combined), with regards to active bleeding.

In the pooled analysis, arterial and combined CT phases were slightly superior for identification of contained vascular injuries, compared to portal venous phase CT; however, the small sample size limits generalization of results. The detection of pseudoaneurysm is important because these injuries have an unfavorable outcome with conservative management. Pseudoaneurysms are associated with an increased incidence of overt bleeding necessitating blood transfusions, increased mortality with associated infection, and delayed diagnosis and treatment [18,22]. Previous studies have shown that contained vascular injuries are identified more accurately at the arterial phase of image acquisition compared to portal venous phase, in more than half of these cases [1,8].

Combined arterial and portal venous phase CT, is being commonly used to evaluate patients with abdominal hemorrhage or organ damage in the emergency and trauma departments for rapid and accurate diagnosis. However, physicians should not forget that the higher the number of CT phases, the greater the patient's exposure to radiation. Therefore, it is important to reduce the number of CT phases exposures as much as possible. In order to solve this problem, we have studied the diagnostic performance of two single phase CTs (arterial and portal venous phase) and combined phase CT, and compared the performance of each phase.

Table 5
Average cED of each CT phase.

CT phase	cED (mSv) [IQR]	*p*-Value
Arterial	8.835 [5.95–11.30]	
Portal venous	9.305 [6.31–11.77]	
Combined	18.140 [12.20–22.97]	
Arterial vs. portal		0.186
Arterial vs. combined		<0.001
Portal vs. combined		<0.001

Note –cED = cumulative effective dose, IQR = interquartile range.

Table 6
Average LAR of cancer incidence and mortality for each CT phase.

CT phase	Incidence (%) [IQR]	*p*-Value	Mortality (%) [IQR]	*p*-Value
Arterial	0.059 [0.03–0.07]		0.034 [0.02–0.04]	
Portal venous	0.062 [0.03–0.08]		0.036 [0.02–0.04]	
Combined	0.121 [0.06–0.15]		0.070 [0.04–0.08]	
Arterial vs. portal		0.327		0.287
Arterial vs. combined		<0.001		<0.001
Portal vs. combined		<0.001		<0.001

Note –LAR = lifetime attributable risks, IQR = interquartile range.

The cED was significantly reduced with single phase CT used alone compared to combined phase CT. Projected cancer incidence and mortality were also significantly lower with single phase protocol. According to the linear no-threshold theory [22], for single phase CT, exposure was estimated to result in a lifetime excess risk of 34 cancers per 100,000 patients, and for the biphasic CT, the estimated risks were 59 cancers per 100,000 patients. These results predict that the use of biphasic CT at the age of 45 years caused one additional cancer in an estimated 4000 patients as compared single phase CT. For the solution of high dose radiation exposure in patients with trauma, radiologists and physicians have strived to apply optimal CT protocol to reduce radiation dose while maintaining good image quality. Yaniv et al. reported that revised single phase body CT showed better vascular and abdominal parenchymal imaging with reduction in radiation dose, compared with conventional protocol in patients with trauma [20]. Single phase protocol decreased mean (±standard deviation, SD) effective radiation dose from 18.2 ± 8.2 mSv to 12.4 ± 4.4 mSv. These results predict that the use of conventional CT at the age of 40 years caused one additional cancer in an estimated 2500 patients as compared with single phase CT. However, this study did not compare diagnostic performance of active bleeding or abdominal organ injury between the two protocols. Alagic et al. demonstrated that multiphase low-radiation protocol improved diagnostic accuracy of arterial injuries with reduced radiation [19]. Low-radiation protocol decreased mean (±SD) effective radiation dose from 1932 ± 247 mGy ∗ cm to 1681 ± 183 mGy ∗ cm, compared with conventional single phase CT. These results predict that the use of conventional CT at the age of 45 years caused one additional cancer in an estimated 5000 patients as compared with low-dose CT. On the basis of these studies, further studies on optimization of CT such as single phase low-radiation dose CT protocol for use in patients with trauma are expected in future.

The role of emergency physicians is important for radiation dose reduction in traumatic injury patients who visit the emergency department. Considerable number of young adults undergo traumatic injury, and trauma patients frequently need whole body CT scans. It is generally accepted that younger patients are more susceptible to carcinogenesis associated with radiation [17,24-26] From the recent survey, emergency physicians have greater interest in radiation dose reduction, and would like to discuss cancer risk with their patients. Concerns of cancer risks from radiation will increase the applicability of using single phase CT to the ordering physicians [27].

Our study has some limitations. The small sample size of contained vascular injuries limits the conclusions that may be drawn from this study, and reduces the statistical power of our results. Secondly, we included only the patients who underwent both phases of CT scan. Dual phase CT is performed in patients with severe injuries, but minor trauma patients usually undergo single phase CT scan. This population is not representative of all patients with trauma, and hence, there is a selection bias.

In conclusion, single phase CT could be a potential protocol for abdominal trauma patients. Use of single phase CT could significantly decrease the incidence of radiation-associated cancer in the future.

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