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ORIGINAL ARTICLE

Single-Pass Split-Bolus Whole-Body Contrast-Enhanced Computed Tomography Protocol for Trauma Patients

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ABSTRACT

Objective: *We sought to improve the aortic enhancement to allow proper assessment and detection of vascular injury in whole-body contrast-enhanced computed tomography (WBCT) of trauma patients without increasing the radiation dose by using a single-pass combined arterial and venous phase split-bolus protocol, instead of a conventional venous phase single-bolus protocol.*

Methods: *A retrospective study assessed consecutive trauma patients who underwent WBCT in two 6-month periods, one in which patients underwent the single-bolus protocol and one in which they underwent the split-bolus protocol. In the split-bolus group, 80 mL iohexol (300 mgI/mL) was injected after the plain CT scan and additional 40 mL iohexol was injected 60 s later. Post-contrast CT images were acquired at 90 s after starting the first contrast injection. Enhancement of the aorta, liver, spleen and kidneys and dose-length product (DLP) of WBCT were measured and compared between patients in the two scan protocols.*

Results: *A total of 95 patients were included. There was statistically significant improvement of the enhancement of the ascending aorta, descending thoracic aorta (177±36 vs. 249±63 HU, $p < 0.001$), infrarenal aorta, spleen (123±16 vs. 146±21 HU, $p < 0.001$), right renal cortex (194±34 vs. 227±42 HU, $p < 0.001$) and left renal cortex (193±37 vs. 228±40 HU, $p < 0.001$) in the split-bolus group. In the split-bolus group, the aortic enhancement was >200 HU, which was considered to be sufficient for proper assessment and detection of vascular injury in literature. There was no statistically significant difference in the DLP (3406±1076 vs. 3194±1261 mGycm, $p = 0.152$), which is an effective dose of 64.7 mSv in the single-bolus group and 60.7 mSv in the split-bolus group.*

Conclusion: *The split-bolus protocol increased the aortic enhancement to allow proper assessment and detection of vascular injury of trauma patients without increasing the radiation dose. Our study used the lowest possible contrast dose to achieve diagnostic images among different studies.*

Key Words: *Contrast media; Radiation dosage; Tomography, X-ray computed; Vascular system injuries; Whole body imaging*

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Ethics Approval: This study was approved and supervised by the Hong Kong East Cluster Research Ethics Committee (Ref HKECREC-2019-083). The requirement for informed consent was waived because this retrospective study used anonymous clinical data.

中文摘要

用於創傷患者的全身顯影電腦斷層掃描單程分次推注方案

呂錦浩、李騰飛、鄭希敏、鄧業勤、朱志揚、梁錦榮、簡偉權

目的：在不增加輻射劑量的情況下，使用單程動靜脈期分次推注分案（而非傳統靜脈期單次推注分案）對創傷患者進行全身顯影電腦斷層掃描（WBCT），尋求改善主動脈造影強化，從而正確評估和檢測血管損傷。

方法：這項回顧性研究評估創傷患者於兩段6個月期間分別接受WBCT單次推注方案和分次推注方案。分次推注方案組患者在平掃CT掃描後注射80毫升非離子造影劑iohexol（300 mgI/mL），60秒後再注射40毫升iohexol。注射第一次造影劑後 90 秒採集造影後CT圖像。測量並比較兩種掃描方案中患者的主動脈、肝、脾和腎的造影結果以及WBCT的劑量長度乘積（DLP）。

結果：共納入95例患者。相比單次推注方案，分次推注方案使升主動脈、胸降主動脈（177±36比249±63 HU，$p < 0.001$）、腎下主動脈、脾（123±16比146±21 HU，$p < 0.001$）、右腎皮質（194±34比227±42 HU，$p < 0.001$）和左腎皮質（193±37比228±40 HU，$p < 0.001$）的造影強化均有顯著改善。在分次推注組中，主動脈造影強化超過200 HU，這在文獻中被認為足以正確評估和檢出血管損傷。DLP沒有明顯差異（3406±1076比3194±1261 mGycm，$p = 0.152$）。單次推注組的有效劑量為 64.7 mSv，分次推注組的有效劑量則為60.7 mSv。

結論：分次推注方案改善主動脈造影強化，允許在不增加輻射劑量的情況下正確評估和檢出創傷患者的血管損傷。本研究在不同檢查中使用盡可能少的造影劑量採集到可以適合診斷的圖像。

INTRODUCTION

Whole-body contrast-enhanced computed tomography (WBCT) is a well-established tool for the rapid diagnosis of trauma patients.[1-4] Different WBCT protocols have been published for the detection of truncal vascular and organ injury. However, there is no single universally accepted protocol, as different patients' demographic data, contrast dose, scan timing, and computed tomography (CT) scanner models affect the image quality and radiation dose significantly. In our centre, the standard WBCT protocol for traumatic truncal injury was a conventional venous phase single-bolus protocol that included unenhanced and venous phase scans of the chest, abdomen, and pelvis.

It has been suggested that an additional arterial phase scan increases the accuracy of truncal vascular and splenic injury when compared with the venous phase scan alone.[5-10] However, an extra set of arterial phase images will increase the radiation dose, workload of the radiologists, imaging software requirements, and imaging storage capacity requirements. This study was aimed at improving the diagnostic accuracy in truncal vascular and splenic injury in trauma patients without increasing the radiation dose by using a single-pass combined arterial and venous phase split-bolus protocol[11-20] instead of a conventional venous phase single-bolus protocol.

METHODS

Patient clinical records were retrieved to review data of mechanism of injury, clinical outcome, and any adverse reactions to intravenous contrast. All data were measured or retrieved by fellows of The Royal College of Radiologists. Enhancement of the vasculature and solid organs was measured by a radiologist with 5 years' experience in CT imaging.

This was a retrospective study in which consecutive trauma patients who underwent WBCT with a single-bolus protocol between October 2018 and March 2019 (single-bolus group) were compared with consecutive trauma patients who underwent WBCT with a split-bolus protocol between May 2019 and October 2019 (split-bolus group). All patients were scanned with the same scanner (Toshiba Aquilion 64, 1-mm section thickness,

120 kVp, 0.7 pitch, and automatic exposure control) in our centre. Patients aged <18 years or who had an extra set of arterial phase images were excluded. Iohexol 300 mgI/mL (Omnipaque 300, GE Healthcare, Waukesha [WI], United States) was used as an intravenous contrast agent.

In the single-bolus protocol, 90 mL iohexol was injected after the plain CT chest, abdomen and pelvis scan. Post-contrast venous phase images were acquired 90 s after starting the contrast injection.

In the split-bolus protocol, 80 mL iohexol was injected after the plain CT chest, abdomen and pelvis scan. An additional 40 mL contrast agent was injected 60 s later. Post-contrast combined arterial and venous phase images were acquired at 90 s after starting the first contrast injection (Figure 1).

Post-contrast enhancement (in Hounsfield units; HU) of vasculature and abdominal solid organs was measured to provide an objective assessment of image quality.[11,15] Enhancement of the ascending and descending aorta (at the level of the pulmonary trunk), infrarenal aorta (between the right renal artery and inferior mesenteric artery), common iliac arteries (1 cm from the aortic bifurcation), liver (segment 7), spleen (superior to the splenic hilum), and kidneys (posterior cortex of the upper poles) was measured using commercial software (Carestream PACS Client Version 11.1) on the PACS monitor.

The dose-length products (DLPs) of plain and post-contrast CT chest, abdomen and pelvis were recorded. The two protocols were compared in terms of the post-contrast enhancement and DLP, using the Mann-Whitney *U* test. A p value <0.05 was considered statistically significant.

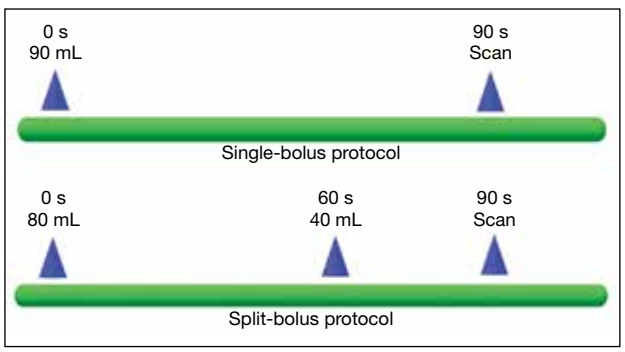

Figure 1. Comparison of single-bolus and split-bolus protocols with iohexol.

RESULTS

In the single-bolus group, there were 44 patients (9 women, 35 men) with median age 48.5 years (range, 22-91 years). In the split-bolus group, there were 41 patients (12 women, 29 men) with median age 48 years (range, 20-96 years).

In the single-bolus group, there were 28 road traffic accident cases, 15 cases of falling from a height, and one blunt trauma case. In the split-bolus group, there were 31 road traffic accident cases, eight cases of falling from a height, one penetrating trauma case, and one blunt trauma case (Table 1). In the WBCT findings, the majority of trauma patients in both groups had no vascular injury, solid organ injury, or pelvic fracture. In the single-bolus group, there were two cases of vascular injury, one case of solid organ injury (liver and right kidney) and three cases of pelvic fracture with no contrast extravasation. In the split-bolus group, there were four cases of vascular injury, two cases of solid organ injury (right kidney; liver and right adrenal gland) and two cases of pelvic fracture. One of the pelvic fracture cases had an active haemorrhage and underwent pelvic embolisation (Figure 2). In each group, there were two deaths due to severe neurological injury or prolonged intubation-related infection.

There were two patients in the single-bolus group with elevated serum creatinine levels on admission with a transient increase in creatinine level within 48 hours after WBCT and subsequent normalisation of renal function after rehydration. There was one patient in the split-bolus group with normal renal function on admission with a transient increase in creatinine level within 48 hours after WBCT and subsequent normalisation of renal function after rehydration. Otherwise, there were no documented adverse reactions related to the intravenous contrast injection.

Table 1. Injury mechanism of the patients.*

	Single-bolus group (n = 44)	Split-bolus group (n = 41)
Road traffic accident	28 (63.6%)	31 (75.6%)
Fall from height	15 (34.1%)	8 (19.5%)
Penetrating trauma	0	1 (2.4%)
Blunt trauma	1 (2.3%)	1 (2.4%)

* Data are shown as No. (%) of patients.

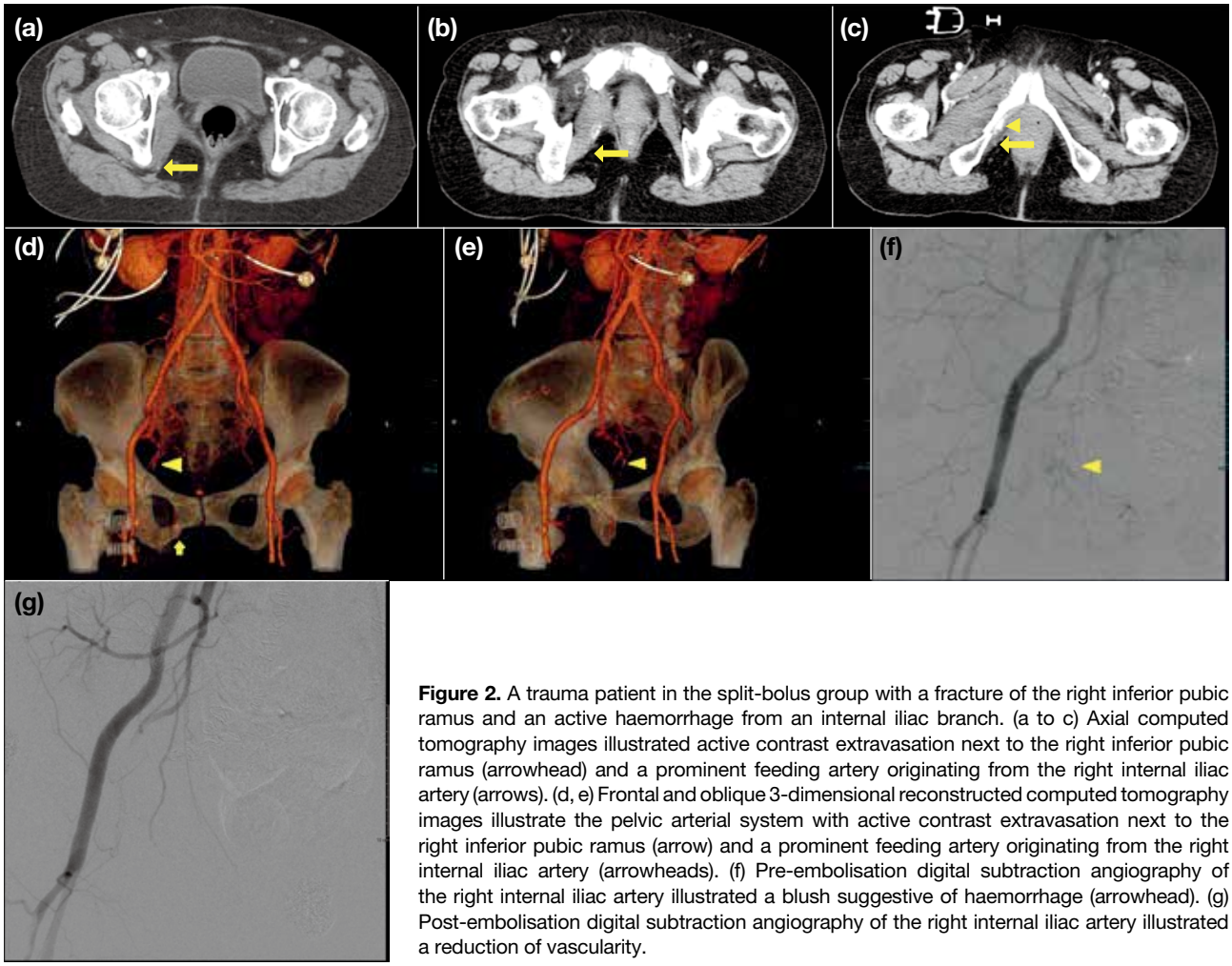

Figure 2. A trauma patient in the split-bolus group with a fracture of the right inferior pubic ramus and an active haemorrhage from an internal iliac branch. (a to c) Axial computed tomography images illustrated active contrast extravasation next to the right inferior pubic ramus (arrowhead) and a prominent feeding artery originating from the right internal iliac artery (arrows). (d, e) Frontal and oblique 3-dimensional reconstructed computed tomography images illustrate the pelvic arterial system with active contrast extravasation next to the right inferior pubic ramus (arrow) and a prominent feeding artery originating from the right internal iliac artery (arrowheads). (f) Pre-embolisation digital subtraction angiography of the right internal iliac artery illustrated a blush suggestive of haemorrhage (arrowhead). (g) Post-embolisation digital subtraction angiography of the right internal iliac artery illustrated a reduction of vascularity.

There was no statistically significant difference in mean (± standard deviation) DLP between the single-bolus and split-bolus groups (3406±1076 vs. 3194±1261 mGycm, p = 0.152), which is an effective dose of 64.7 mSv in the single-bolus group and 60.7 mSv in the split-bolus group.[21]

There were statistically significant increases between the single-bolus and split-bolus groups in the enhancement of ascending aorta (171 vs. 242 HU, p < 0.001); descending thoracic aorta (177 vs. 249 HU, p < 0.001); infrarenal aorta (174 vs. 236 HU, p < 0.001); right common iliac artery (171 vs. 230 HU, p < 0.001); left common iliac artery (172 vs. 230 HU, p < 0.001); spleen (123 vs. 146 HU, p < 0.001); right renal cortex (194 vs. 227 HU, p < 0.001); units of liver (115 vs. 122 HU, p = 0.083) demonstrated no statistically significant difference (Table 2). All of the non-injured solid abdominal organs demonstrated homogenous parenchymal enhancement.

Table 2. Vascular and intra-abdominal organ mean attenuation measurements.*

Site	Attenuation (HU)		p Value
	Single-bolus group	Split-bolus group	
Ascending aorta	171±36	242±65	<0.001
Descending thoracic aorta	177±36	249±64	<0.001
Infrarenal aorta	174±41	236±65	<0.001
Right common iliac artery	171±43	230±67	<0.001
Left common iliac artery	172±41	230±66	<0.001
Spleen	123±16	146±21	<0.001
Right renal cortex	194±34	227±42	<0.001
Left renal cortex	193±37	228±40	<0.001
Liver	115±16	122±15	0.083

Abbreviation: HU = Hounsfield unit.
* Data are presented as mean±standard deviation.

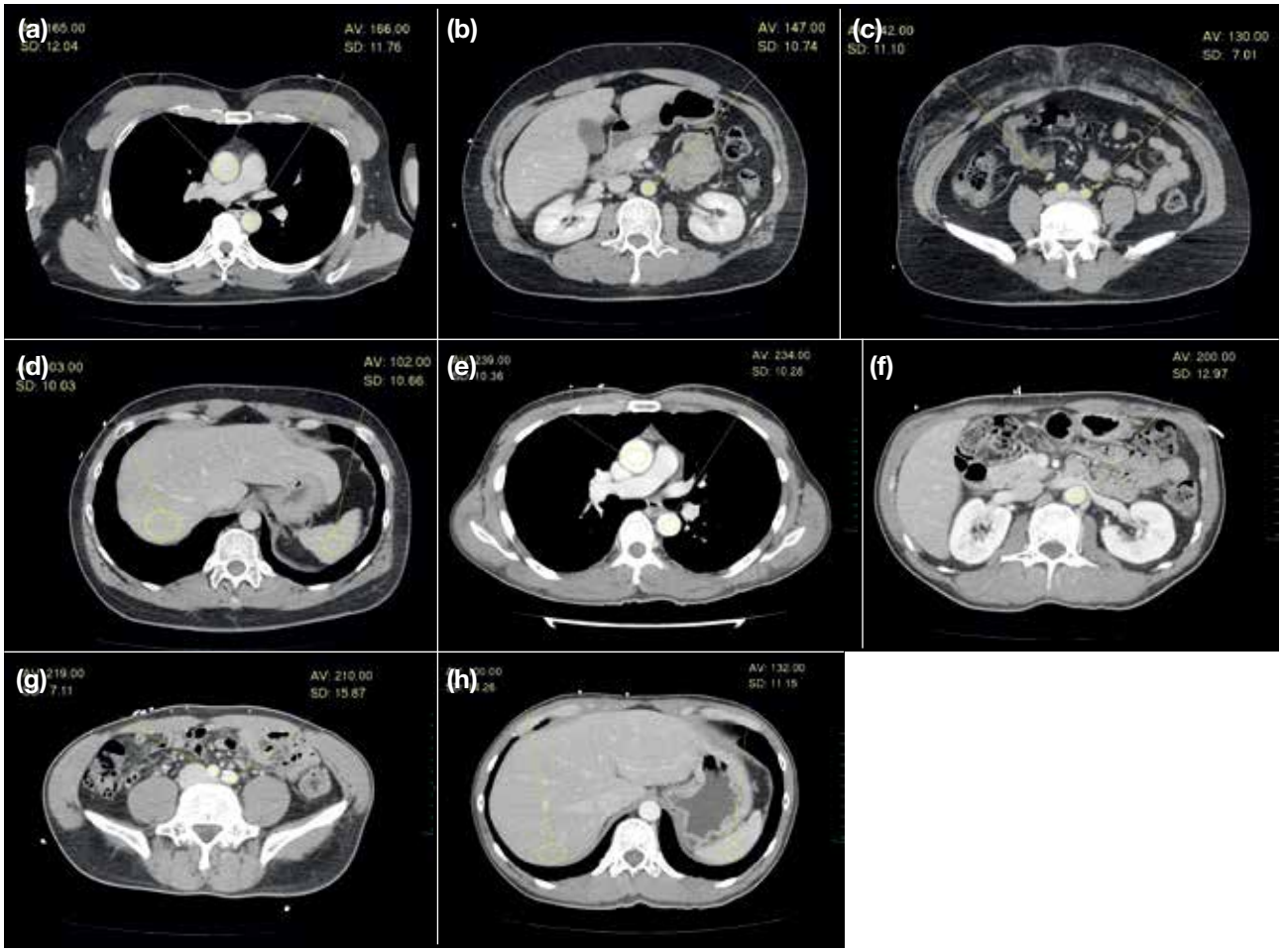

Figure 3. (a-d) A series of single-bolus protocol whole-body contrast-enhanced computed tomography (WBCT) images at different levels. The mean attenuation (in Hounsfield units; HU) of ascending thoracic aorta is 165±12 HU; descending thoracic aorta is 166±12 HU; infrarenal aorta is 247±11 HU; bilateral common iliac arteries are 142±11 HU for the right side and 130±7 HU for the left side; liver is 103±10 HU and spleen is 102±11 HU. (e-h) A series of split-bolus protocol WBCT images at different levels. The mean attenuation of ascending thoracic aorta is 239±10 HU; descending thoracic aorta is 234±10 HU; infrarenal aorta is 200±13 HU; bilateral common iliac arteries are 219±7 HU for the right side and 210±16 HU for the left side; liver is 100±14 HU and spleen is 132±11 HU.

DISCUSSION

Aortic enhancement >200 HU is considered to be sufficient for proper assessment and detection of vascular injury.[22,23] In our study, there was a statistically significant improvement of the aortic enhancement in the included segments, from <200 HU in the single-bolus group to >200 HU in the split-bolus group (Figure 3).

Multiple factors can affect the enhancement of the aorta and solid abdominal organs in CT, including the patient's body weight, cardiac function, contrast dose, injection rate, tube voltage, and scan timing.[24,25] In our study, a standardised protocol instead of an individualised protocol was used to reduce the complexity of workflow and allow unstable trauma patients to complete the CT scan and to be managed within a short period. Therefore, no individual adjustment of the contrast dose, tube voltage, or scan time was done based on the patients' body weight or cardiac function. This is a limitation of the study. Using bolus tracking may minimise these individual variances and achieve optimal enhancement. This is a topic for future research.

Aortic time-attenuation curves from the literature demonstrated a rapid increase in aortic enhancement after contrast injection with peak enhancement at 30 to 50 s, followed by a rapid decrease.[25] The mean aortic enhancement is significantly affected by the scan timing after contrast injection. In our study, the split-bolus protocol post-contrast images were acquired 30 s

after the second bolus, which explains the statistically significant improvement in aortic enhancement.

In the split-bolus group, renal and splenic enhancement demonstrated a statistically significant increase as venous parenchymal enhancement was superimposed on the arterial parenchymal enhancement.

The hepatic time-attenuation curve was relatively steady with a delayed peak from portal venous system supply.[25,26] As a result, there was no statistically significant change in hepatic enhancement between the two groups.

The DLP between the two groups had no statistically significant difference as no extra image data were captured. For centres using a WBCT protocol with separate arterial phase images acquisition, the split-bolus significantly reduces the radiation dose.[11,19]

According to the United States Food and Drug Administration, the recommended intravascular dose of iohexol for body CT is 15 to 60 g iodine (50-200 mL). Contrast doses used in multiple studies ranged from 42 g iodine (120 mL, 350 mgI/mL) to 51.8 g iodine (140 mL, 370 mgI/mL).[11,12,14,15,17-19,27] The use of 36 g iodine (120 mL iohexol) in our protocol was the lowest among the different studies. In our study, only a few cases in both protocol groups had transient renal dysfunction, which did not require renal replacement therapy. These findings may have been the result of confounding factors that could alter renal function, such as blood loss from limb fracture or inadequate hydration. Otherwise, there was no documented adverse reaction related to the intravenous contrast injection.

Some studies have suggested that it is important to differentiate pelvic arterial and venous bleeding, as the management is different.[28] In our centre, we adopted a '3-in-1 Pelvic Damage Control Protocol'.[29] Patients with a hemodynamically unstable open pelvic fracture undergo immediate external fixation, preperitoneal packing, pelvic digital subtraction angiography, and pelvic embolisation, regardless of whether the bleeding source is venous or arterial. Therefore, differentiating pelvic arterial from venous bleeding is not essential and will not affect patient management in our centre. (Figure 2).

A study conducted by Stedman et al[27] reported that there was heterogeneous splenic parenchymal enhancement in 49% of patients who had been imaged with a split-bolus protocol WBCT (70 mL + 70 mL, iopamidol 370 mgI/mL). In our study, all cases had homogenous splenic parenchymal enhancement in the combined phase. This can be explained by the difference in the split portion. In the study by Stedman et al,[27] the second bolus was 50% of the overall contrast dose. Therefore, the usual heterogeneous arterial phase splenic parenchymal enhancement was superimposed on the background uniform venous phase enhancement. In our study, the second bolus was 33% of the overall contrast dose, so the arterial phase splenic parenchymal enhancement was masked by the venous phase enhancement.

CONCLUSION

A single-pass combined arterial and venous phase split-bolus protocol increased the aortic enhancement to allow proper assessment and detection of vascular injury of trauma patients without increasing the radiation dose. Different split-bolus protocols have been published. Our study was the one with the lowest contrast dose among different studies. Further work on the optimal contrast dose is recommended.

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