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ABDOMINAL IMAGING

ORIGINAL ARTICLE

Computed tomography arterial portography for assessment of portal vein injury after blunt hepatic trauma

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PURPOSE
Intrahepatic portal vein injuries secondary to blunt abdominal trauma are difficult to diagnose and can result in insidious bleeding. We aimed to compare computed tomography arterial portography (CTAP), reperfusion CTAP (rCTAP), and conventional computed tomography (CT) for diagnosing portal vein injuries after blunt hepatic trauma.

METHODS
Patients with blunt hepatic trauma, who were eligible for nonoperative management, underwent CTAP, rCTAP, and CT. The number and size of perfusion defects observed using the three methods were compared.

RESULTS
A total of 13 patients (seven males/six females) with a mean age of 34.5±14.1 years were included in the study. A total of 36 hepatic segments had perfusion defects on rCTAP and CT, while there were 47 hepatic segments with perfusion defects on CTAP. The size of perfusion defects on CT (239 cm^3; interquartile range [IQR]: 129.5, 309.5) and rCTAP (238 cm^3; IQR: 129.5, 310.5) were significantly smaller compared with CTAP (291 cm^3; IQR: 136, 371) (both, $P = 0.002$).

CONCLUSION
Perfusion defects measured by CTAP were significantly greater than those determined by either rCTAP or CT in cases of blunt hepatic trauma. This finding suggests that CTAP is superior to rCTAP and CT in evaluating portal vein injuries after blunt liver trauma.

The liver is one of the most frequently injured solid abdominal organs in the setting of blunt abdominal trauma (1). Fortunately, most patients with blunt hepatic trauma have relatively stable vital signs and need only supportive treatment or transarterial embolization (TAE) (1–9). Only 15% of patients, who present with hemodynamic instability or fail with nonoperative management, require operative intervention to manage their liver injury.

Embolic therapy has been shown to have a high success rate in hemodynamically stable patients with blunt hepatic injury. TAE is associated with decreased abdominal infections, decreased transfusions, and decreased length of hospital stay compared with operative management (2, 3, 7). However, angiography can only detect bleeding from the hepatic artery; it cannot locate bleeding from the hepatic or portal vein. In the literature, portal vein injuries are not commonly described and most are the result of penetrating injuries to the extrahepatic portal veins. Mortality after a portal vein injury due to trauma is primarily due to hypovolemic shock and can be as high as 50% or greater (10, 11).

Since the intrahepatic portions of the hepatic and portal veins are low pressure systems, they can bleed insidiously. Nevertheless, this subtle bleeding may require multiple transfusions and result in a prolonged hospital stay. Relative to an extrahepatic portal vein injury, patients with an intrahepatic portal vein injury may have relatively stable vital signs and slowly decreasing hemoglobin levels (10, 11). In addition, traumatic occlusion and/or thrombosis of the portal vein may cause large hepatic parenchymal infarction.

Computed tomography arterial portography (CTAP) is a useful method based on portal enhancement of the liver by infusion of contrast material through the superior mesenteric artery for evaluating the portal venous system (12–15) and is widely used in patients with hepatic tumors with portal venous invasion (13, 16, 17). CTAP has a high sensitivity and specificity in the evaluation of portal vein thrombosis due to tumor (90% sensitivity, 99%

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specificity, 95% positive predictive value, 97% negative predictive value) (14). However, few studies have focused specifically on the utility of CTAP in the evaluation of portal vein injury as a result of trauma.

The liver has a dual blood supply and receives between 66% and 75% of its blood supply from the hepatic portal vein with the remainder supplied by the hepatic artery (18). CTAP reflects only portal venous perfusion while reperfusion CTAP (rCTAP) reflects hepatic arterial reperfusion. Both rCTAP and conventional computed tomography (CT) are useful for determining certain liver injuries. However, they do not specifically evaluate the portal vein.

The purpose of this study was to compare CTAP, rCTAP, and CT for diagnosing portal vein injuries after blunt hepatic trauma. We hypothesized that CTAP would be superior to rCTAP and CT in assessing portal vein injury after blunt hepatic trauma.

Methods

Patients

Patients who sustained blunt hepatic trauma and received angiography, with or without embolization, were included in the study. Exclusion criteria were <18 years of age, unconsciousness, unstable vital signs, and renal insufficiency (creatinine >2 mg/dL). All patients provided written informed consent for all procedures performed and for participation in the study. The study protocol was approved by the institutional review board of our hospital.

During the two-year period from August 2010 to July 2012, 254 patients were diagnosed with blunt hepatic trauma at our institution, a level-one trauma center. All patients received initial resuscitation and a diagnostic evaluation based upon advanced trauma life support program protocols established by the American College of Surgeons Committee on Trauma (19). All patients who had positive focused abdominal sonography for trauma scans had clinical signs of internal bleeding. Hemodynamically stable patients (i.e., systolic blood pressure ≥90 mmHg) received a CT scan with contrast for intra-abdominal injury evaluation. Patients who were not hemodynamically stable were transferred to the operating room to control internal bleeding. There were no specifically-defined criteria for abandoning nonoperative management, and decisions were based on the judgment of the attending trauma surgeon.

Forty-eight patients had known active bleeding or were suspected to have active bleeding (i.e., contrast extravasation detected by CT). Of those patients, 23 received surgery and 25 received transarterial embolization (TAE). Four patients failed operative management and subsequently required TAE. Of the 29 total patients who received TAE, sixteen patients agreed to undergo CTAP (Fig. 1). Bleeding was initially stopped in all 29 patients; however, four experienced rebleeding which required either surgery or repeat TAE.

Imaging technique

Celiac, hepatic, and superior mesenteric angiographies were performed to evaluate hepatic arterial injury. TAE was performed for control of bleeding if either contrast extravasation or pseudoaneurysm formation were observed. After angiography with/without TAE, and in the presence of stable vital signs, a 4F or 5F catheter was placed in the proximal trunk of the superior mesenteric artery. The patient was then transferred to the CT unit for CTAP.

CTAP was performed with a helical CT scanner (Aquilion 64, Toshiba Medical Systems). The images were obtained in a craniocaudal direction with a slice collimation of 1.5 mm, slice thickness of 5 mm, and field of view of 300 mm during a single breath-hold helical acquisition. A total of 60 mL of nonionic contrast material (Ultravist 300, Bayer Healthcare) was injected with a power injector at a rate of 2.5 mL/s. CT scanning was performed at 25 s and 45 s after the start of the injection to obtain portal vein phase (CTAP; liver parenchymal enhancement only by the portal vein) and reperfusion phase (rCTAP; perfusion of the hepatic arteries) images, respectively. The interval between CT and CTAP/rCTAP ranged 2–8 hours.

Imaging analysis

A region of interest (ROI) designated the perfusion defect on CTAP and rCTAP. Each ROI was drawn freehand around the peripheral margin of the perfusion defect using an electronic cursor. Decreased enhancement of ≥50 HU (as compared with a region of good enhancement) was presumed to be related to decreased perfusion (15). An automated imaging analysis program was then used to apply a thresholding technique to each image which sorted pixels representing healthy liver from perfusion defects into separate masks. The upper threshold was defined as the "CT value of normal liver parenchyma minus 50 HU" and the lower threshold as "0 HU" in order to avoid including normal parenchymal perfusion and vascular structures.

Two experienced radiologists consensually reviewed the CT images without prior knowledge of the final results. The radiologists recorded the hepatic injury grade, number, and size of perfusion defects within the liver parenchyma during the portal

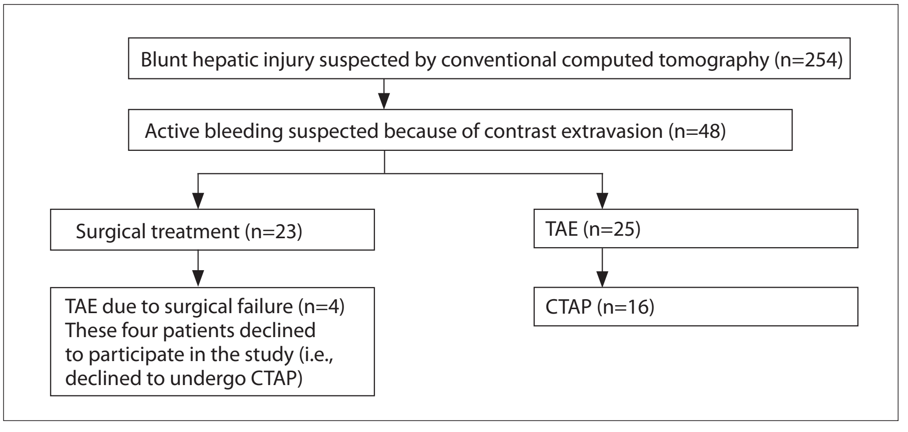

Figure 1. Flow diagram showing patient disposition. TAE, transcatheter arterial embolization; CTAP, computed tomography arterial portography.

Main points

- Intrahepatic portal vein injuries after blunt abdominal injury are not rare, but difficult to diagnose on angiography and conventional CT .
- Computed tomography arterial portography (CTAP) is usually used to evaluate the portal vein invasion by neoplasm.
- Our study proves that CTAP is superior to angiography and conventional CT in evaluating traumatic portal vein injury.

venous phase (CTAP), reperfusion phase (rCTAP), and CT. In addition, the vascular characteristics of the portal vein were recorded. Hepatic injury was graded by CT according to the hepatic injury scale (HIS) established by the American Association for the Surgery of Trauma (AAST) (19). Vascular injuries were classified into several categories: normal, contrast extravasation, pseudoaneurysm, abrupt termination/occlusion, dissection (intimal flap defects), and arteriovenous fistula formation. The rCTAP images were also compared with the CT images.

All images were evaluated on a picture archiving and communication system monitor (GE Medical Systems Integrated Imaging Solutions). The optimal window width and level setting was adjusted for each case as the patient body size and contrast enhancement varied markedly among patients during CTAP and rCTAP.

Statistical analysis

Patient characteristics were expressed as mean±standard deviation for age and n (%) for other categorical variables. Perfusion defect sizes on CT, rCTAP, and CTAP images were graphed as a box-plot summarizing the corresponding medians and interquartile ranges (IQR; Q1 to Q3). Since the size of perfusion defects was not normally distributed, the differences among CT, rCTAP, and CTAP were compared using Wilcoxon sign-rank test. Statistical assessments were two-tailed and considered statistically significant at $P < 0.05$. Data analyses were performed using SPSS 18.0 statistics software (SPSS Inc.).

Table 1. Patient characteristics (n=13)

Age, years, mean±SD	34.5±14.1
Gender, male	7 (53.8)
Hepatic injury scale	
2	1 (7.7)
3	5 (38.5)
4	7 (53.8)
Number of hepatic segments with enhancing defects on CT and rCTAP	
1	1 (7.7)
2	5 (38.5)
3	4 (30.8)
4	2 (15.4)
5	1 (7.7)
Number of hepatic segments with enhancing defects on CTAP	
1	0 (0)
2	3 (23.1)
3	4 (30.8)
4	1 (7.7)
5	5 (38.5)
Contrast extravasation on CT	8 (61.5)
TAE	8 (61.5)

Data are expressed as n (%), unless otherwise noted.
SD, standard deviation; CT, computed tomography; CTAP, CT arterial portography; rCTAP, reperfusion CTAP; TAE, transarterial embolization.

Results

Sixteen of 29 patients who received TAE agreed to undergo CTAP (Fig. 1). Two of 16 patients were excluded from the study due to catheter dislodgement which prevented CTAP from being performed. Another patient was excluded because of extrahepatic (without intrahepatic) portal vein injury. Thus, a total of 13 patients (seven males/six females) with a mean age of 34.5±14.1 years were included in the study. Patient characteristics are summarized in Table 1, and detailed patient data are presented in the supplemental Table.

All patients had blunt hepatic injuries and most patients had either HIS grade III injuries (five patients, 38.5%) or grade IV injuries (seven patients, 53.8%). rCTAP and CT detected 36 hepatic segments with perfusion defects, while CTAP detected 47 hepatic segments with perfusion defects. The most involved segments on CT, rCTAP, and CTAP were segments 6 and 7.

The size of perfusion defects on CT, rCTAP, CTAP are shown in Fig. 2. The size of perfusion defects on CT (239 cm^3; IQR: 129.5, 309.5) and rCTAP (238 cm^3; IQR: 129.5, 310.5) were significantly smaller compared to those measured on CTAP (291 cm^3; IQR: 136, 371) (both, $P = 0.002$).

The difference between the number of hepatic segments with defects on rCTAP vs. CTAP, and size of the perfusion defects on rCTAP vs. CTAP are summarized in Table 2. Of 13 patients who underwent CTAP, five had a similar number of hepatic segments with enhancing defects on rCTAP and CTAP (group 0), five had one segment with more severe injury (larger perfusion defect) on CTAP compared with rCTAP (group 1), and three patients had two segments with more severe injury on CTAP compared with rCTAP (group 2). The median difference in size of a perfusion defect within the same injured segment as measured by rCTAP vs. CTAP was 14 cm^3 in group 0 (IQR: 11.5, 51.0), 6 cm^3 in group 1 (IQR: 4, 68.5), and 27 cm^3 in group 3 (IQR: 8, 167). There were no significant differences between rCTAP and CTAP in the number of hepatic segments with enhancing defects or in the size of perfusion defects within the same segments ($P = 0.494$).

There were no significant associations between rCTAP or CTAP with respect to contrast extravasation on CT or TAE (Table 3), between HIS grade and TAE (Table 4), or between HIS grade and type of portal vein injury (abrupt termination/occlusion, wall irregularity) (Table 5).

The size difference between perfusion defects detected by rCTAP and CTAP (stratified by HIS grade) are analyzed as well. Spearman correlation analysis showed no significant correlation between the difference in size of perfusion defects detected by rCTAP or CTAP and HIS grade (r=0.130, $P = 0.672$). Representative CT, rCTAP, and CTAP images are shown in Figs. 3–6.

Discussion

In 13 patients with blunt hepatic trauma evaluated in this study, perfusion defects

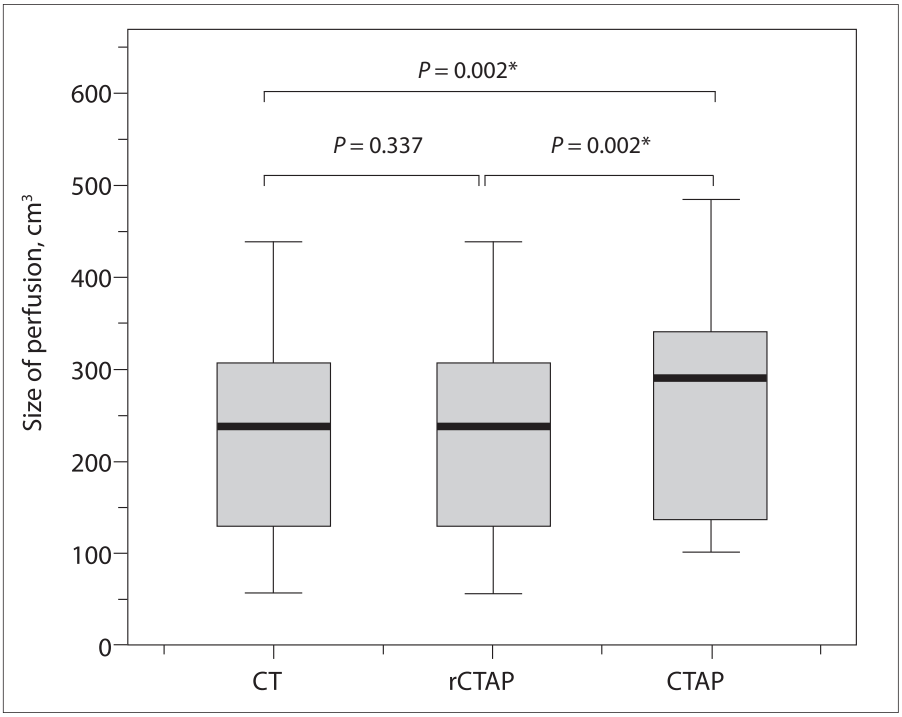

Figure 2. Size of perfusion defects on conventional CT, CT arterial portography (CTAP), and reperfusion CTAP (rCTAP). The size of perfusion defects on CT (239 cm^3; IQR: 129.5, 309.5) and rCTAP (238 cm^3; IQR: 129.5, 310.5) were significantly smaller than that on CTAP (291 cm^3; IQR: 136, 371) (both, $P = 0.002$).

Table 2. Perfusion defect size and difference in the number of hepatic segments with defects detected on rCTAP vs. CTAP

	Difference in the number of hepatic segments with defects detected on rCTAP vs. CTAP			
	Group 0	Group 1	Group 2	*P*
Number of patients	5	5	3	
Size of perfusion defect on rCTAP, cm^3	238 (96, 383.5)	268 (13.5, 304.5)	128 (87, 309)	0.598
Size of perfusion defect on CTAP, cm^3	291 (109, 413.5)	301 (136.5, 358.5)	136 (114, 476)	0.838
Difference between rCTAP and CTAP, cm^3	14 (11.5, 51.0)	6 (4, 68.5)	27 (8, 167)	0.494

Data are expressed as median (interquartile range) and compared using the Kruskall-Wallis test.
Group 0, same number of segments with defects detected on both CTAP and rCTAP; group 1, one additional segment with severe injury detected on CTAP compared with rCTAP; group 2, two additional segments with severe injury detected on CTAP compared with rCTAP.
CTAP, CT arterial portography; rCTAP, reperfusion CTAP.

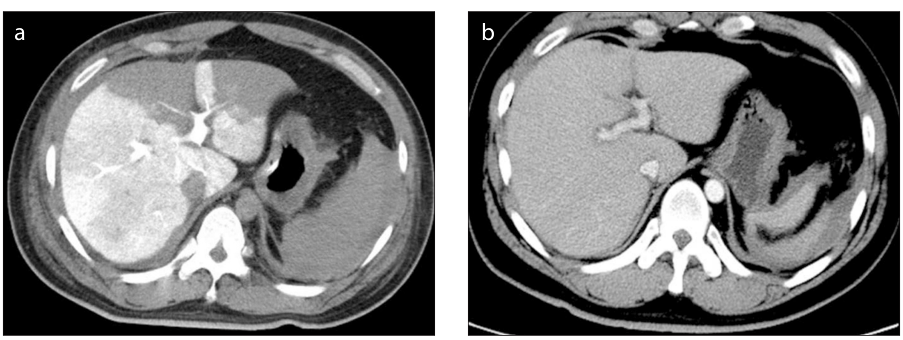

Figure 3. a, b. Case 7, a 33-year-old male. CTAP **(a)** shows a perfusion defect in segments 2–4, but only a small perfusion defect in segment 2 is noted on CT **(b)**.

measured by CTAP were significantly larger than those determined by either rCTAP or CT, suggesting that CTAP is superior to both rCTAP and CT in evaluating liver parenchymal perfusion and portal vein injuries after blunt liver trauma.

We speculated that the difference in size of perfusion defects was due to thrombosis within the portal vein, external compression by hematoma, or portal vein dissection. Thrombosis within the main trunk or main branch of the portal vein may result in portal hypertension. However, anticoagulant therapy was not administered in our patients as most had active bleeding. Therefore, the risk-benefit ratio of anticoagulant therapy was equivocal. After a clinical follow-up of more than two years, there was no evidence of portal hypertension (i.e., splenomegaly or variceal bleeding) in our patients (data on file). This result was likely due to the small size of portal vein branches involved in the injuries. In addition, we would like to mention the findings of three patients in this cohort who required surgery. The patients had active bleeding from injured hepatic arteries as well as portal veins. These caused the failure of TAE and patients underwent surgery, as repeated TAE for hepatic artery bleeding is not helpful.

Nonoperative management of blunt hepatic trauma, with or without TAE, has become the primary method of treatment for hemodynamically stable patients (7–9). While nonoperative management is associated with late complications such as persistent bleeding, fistulas, bile leakage, hepatic necrosis, and abscess formation, such complications can usually be managed with laparoscopic/endoscopic techniques or interventional radiology (9). Various imaging methods are used to evaluate hepatic injury after trauma (20), but few studies have focused specifically on evaluating portal vein injury.

CTAP is a valuable technique for detecting liver tumors in patients undergoing evaluation for possible segmentectomy. The technique is very sensitive for detecting liver parenchymal abnormalities; however, its specificity is low since it is prone to identifying pseudolesions (21), as well as other artifacts. Most pseudolesions are located within the perihilar and periligamentous areas and gallbladder fossa; however, all perfusion defects evaluated in this study were outside these regions. In addition, although severe liver cirrhosis can also result in pseudolesions from arterio-portal shunting (13, 21), none of our patients had CT evidence of cirrhosis. All perfusion defects evaluated in our patients were wedge-shaped on CTAP and, therefore, suspicious for ischemia secondary to portal vein injury (22).

Additional artifacts, such as perfusion defects originating from laminar flow, can

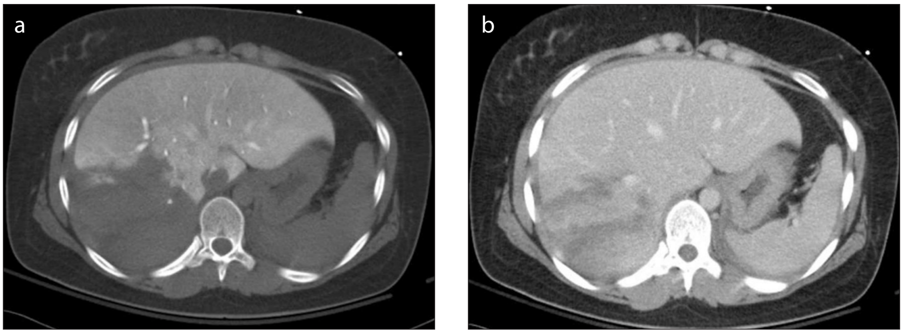

Figure 4. a, b. Case 12, a 19-year-old female. A larger perfusion defect is seen on CTAP **(a)** compared with rCTAP **(b)**.

Table 3. Difference in defect size between rCTAP and CTAP regarding contrast extravasation on CT or TAE

	Difference in defect size between rCTAP and CTAP, cm^3, median (IQR)	*P* *
Contrast extravasation on CT		0.127
Yes	11.5 (4.5, 40.3)	
No	48.0 (17.5, 128.0)	
TAE		0.127
Yes	11.5 (4.5, 40.3)	
No	48.0 (17.5, 128.0)	

*Mann-Whitney U test.
CTAP, computed tomography arterial portography; rCTAP, reperfusion CTAP; IQR, interquartile range; CT, computed tomography; TAE, transarterial embolization.

Table 4. Association of hepatic injury scale grade with TAE

	Hepatic injury scale			
	II	III	IV	*P*
TAE				0.435
Yes	0 (0)	3 (37.5)	5 (62.5)	
No	1 (20)	2 (40)	2 (40)	

Data are expressed as n (%) and compared using the Mann-Whitney U test.
TAE, transarterial embolization.

Table 5. Association of hepatic injury scale grade and type of portal vein injury

	Hepatic injury scale		
Type of portal vein injury	III	IV	*P*
Abrupt termination/occlusion			1.000
1	1 (16.7)	5 (83.3)	
2	0 (0)	1 (100)	
Wall irregularity			0.475
1	3 (42.9)	4 (57.1)	
2	0 (0)	3 (100)	

Data are expressed as number (%) and compared using the Fisher's exact test.

hamper image interpretation. This phenomenon is due to rapid venous return of blood (with insufficient mixing of opacified and nonopacified components) from a selective injection into the proximal branches of the superior mesenteric artery (13, 21–26). Also, an aberrant portal venous supply may cause uneven degrees of enhancement in a different hepatic segment. To diminish these effects, we established our criteria for a perfusion defect as a region with decreased enhancement of ≥50 HU (as compared with a region of good enhancement) (13–15), as related to decreased perfusion in the present study.

We hypothesized that injury of the proximal segment of an aberrant portal venous supply may also affect the perfusion of a hepatic segment not subjected to direct blunt injury and our findings appear to support this assumption. Out of 47 hepatic segments with perfusion defects on CTAP, 36 hepatic segments had perfusion defects secondary to blunt injury (i.e., perfusion defects on both rCTAP and CT) and 11 hepatic segments had perfusion defects not due to blunt injury. The perfusion defects in these 11 segments were likely due to aberrant portal venous supply. Thus, we indirectly proved the existence of an aberrant portal venous supply and the change of perfusion due to trauma. In addition, such an aberrant portal venous supply may explain why patients with blunt hepatic injury have large variations in their liver function (27–29). To avoid the overestimation of the effects from aberrant portal venous supply, we measured the size of perfusion defects within the same affected hepatic segments when comparing rCTAP and CTAP. The size of perfusion defects on CT (239 cm^3; IQR: 129.5, 309.5) and rCTAP (238 cm^3; IQR: 129.5, 310.5) were significantly smaller compared to those measured on CTAP (291 cm^3; IQR: 136, 371) (both, $P = 0.002$). Thus, even though we excluded the effect of normal aberrant portal venous perfusion defect, which was erroneously judged as a pathologic defect in our patients, it did not affect our results.

As TAE terminates flow downstream of an arterial branch, it may potentially increase the size and number of perfusion defects seen on rCTAP. In our study, there were no differences between rCTAP and CT regarding the number of defects. This result may have been due to the highly selective TAE within subsegmental hepatic artery branches. There were no detectable differences between rCTAP and CTAP regarding contrast extravasation on CT or TAE (Table 3).

If both hepatic arterial perfusion and hepatic portal venous perfusion were disrupted, a major perfusion defect would result which would likely lead to liver-related complications such as bile leakage, biloma, liver parenchymal necrosis, or abscess for-

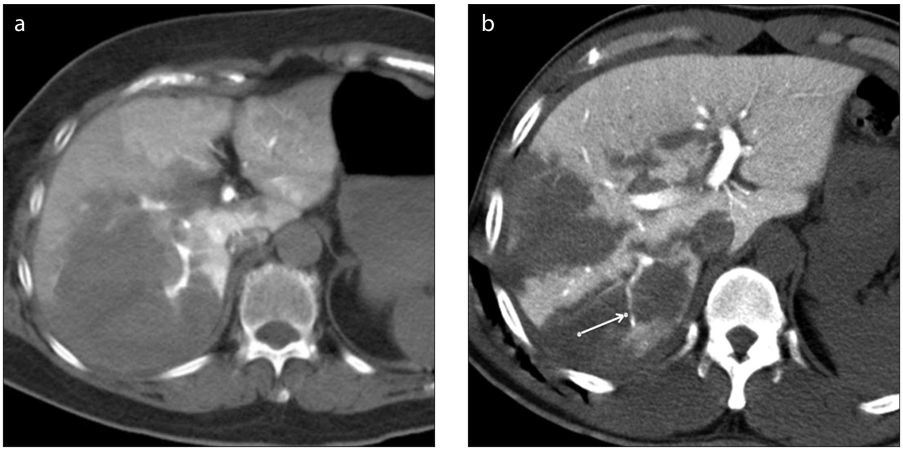

Figure 5. a, b. Case 6, a 64-year-old female. CTAP shows abrupt termination/occlusion of the portal vein branch in segments 6 and 7 **(a)**; Case 1, a 41-year-old male. Portal vein irregularity in segments 6 and 7 *(white arrow)* was noted on CTAP **(b)**.

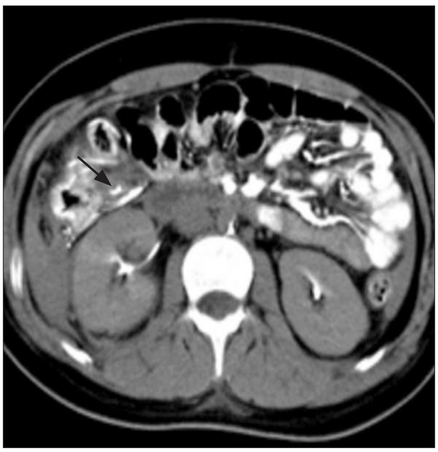

Figure 6. Case 8, an 18-year-old female. Incidental finding of right colic artery injury with mesocolon hematoma and suspected contast extravasation or pseudoaneurysm *(black arrow)*.

mation (29, 30). However, there were only two complications in this study involving bile leakage (with peritonitis) and biloma. In this study, it was difficult to distinguish primary bile duct injury that occurred from direct blunt trauma and secondary ischemic injury after TAE from portal vein injury.

There was an incidental finding of contrast pooling over the right upper quadrant mesocolon due to a right colic artery injury in one case (Fig. 6). On CT, the finding was identified as a small hematoma located over the mesocolon and was initially mistaken as a hematoma secondary to a liver laceration. The patient was stable and developed no signs of ischemic bowel and the finding did not require any treatment. This finding suggests that CTAP can identify small injuries within mesenteric vessels.

Our study had several limitations. The study was performed at a single center with a limited number of patients. The patients did not receive follow-up CT or CTAP, thus we were unable to determine whether their portal vein injuries were transient or permanent. Clinical data such as hemoglobin levels and liver function tests were not analyzed as most patients had multiple injuries and these factors would likely not have been affected by portal vein injury. In addition, the CT and angiography instruments are usually not located in the same examination room and acquisition of CTAP may be difficult in trauma patients who may need emergent evaluation and treatment in the setting of major trauma. Rotational angiography with CT-like 3D volumes (e.g., cone-beam CT with flat-panel-detector digital angiography system), which allow completion of TAE and performance of CTAP without transfer (and, thus, can save time and reduce the risks associated with transfer) should be considered in the future for care of patients with major trauma (31).

In conclusion, perfusion defects measured by CTAP were larger than those determined by either rCTAP or CT in cases of blunt hepatic trauma. This finding suggests that CTAP is superior to rCTAP and CT in evaluating liver perfusion and portal vein injuries after blunt liver trauma.

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Conflict of interest disclosure

The authors declared no conflicts of interest.

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