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ABDOMINAL IMAGING

ORIGINAL ARTICLE

Comparison of MDCT protocols in trauma patients with suspected splenic injury: superior results with protocol that includes arterial and portal venous phase imaging

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PURPOSE
We aimed to determine which intravenous contrast-enhanced multidetector computed tomography (MDCT) protocol produced the most accurate results for the detection of splenic vascular injury in hemodynamically stable patients who had sustained blunt abdominal trauma.

METHODS
We retrospectively reviewed 88 patients from 2003 to 2011 who sustained blunt splenic trauma and underwent contrast-enhanced MDCT and subsequent angiography. Results of MDCT scans utilizing single phase (portal venous only, n=8), dual phase (arterial + portal venous or portal venous + delayed, n=42), or triple phase (arterial + portal venous + delayed, n=38) were compared with results of subsequent splenic angiograms for the detection of splenic vascular injury.

RESULTS
Dual phase imaging was more sensitive and accurate than single phase imaging ($P = 0.016$ and $P = 0.029$, respectively). When the subsets of dual phase imaging were compared, arterial + portal venous phase imaging was more sensitive and accurate than portal venous + delayed phase imaging ($P = 0.005$ and $P = 0.002$, respectively). Triple phase imaging was more accurate ($P = 0.015$) than dual phase; however, when compared with the dual phase subset of arterial + portal venous, there was no statistical difference in either sensitivity or accuracy.

CONCLUSION
Our results support the use of dual phase contrast-enhanced MDCT, which includes the arterial phase, in patients with suspected splenic injury and question the utility of obtaining a delayed sequence.

Intravenous contrast-enhanced multidetector computed tomography (MDCT) continues to play a critical role in the evaluation of splenic injuries among patients sustaining blunt abdominal trauma (1–4). Current accepted management algorithms stratify patients to operative or nonoperative treatment based on hemodynamic stability. For those relegated to nonoperative treatment, accurate evaluation of splenic injuries with MDCT is crucial. Parenchymal and extraparenchymal findings are of prime importance in grading splenic injuries (AAST, modified scale) (5). Peitzman et al. (6) identified that failure rates of nonoperative management increased significantly with grade of injury from 4.8% of grade I injuries to 75% of grade V. The presence of vascular injuries, such as active bleeding, pseudoaneurysm, and arteriovenous fistula, has traditionally been the primary indication for splenic angiography and embolization. Given the integral role that CT plays in patient management, it is important to have optimal sensitivity and specificity in identifying vascular injuries.

Early in the development of CT scanning for blunt trauma patients, intravenous contrast-enhanced abdominal and pelvic images were obtained using a portal venous phase technique commonly utilized in routine diagnostic studies. With the advent of faster MDCT scanners, the trauma evaluation soon incorporated intravenous contrast-enhanced imaging of the chest in the arterial phase to detect aortic and other vascular injuries. As the chest CT field of view often encompassed the upper abdomen, patients undergoing trauma chest, abdomen, and pelvic CT evaluation had two phases of contrast enhancement (arterial and portal venous phase) available to evaluate upper abdominal injuries. Radiologists quickly noticed that certain splenic injuries, particularly vascular injuries, were often detected only in the arterial phases of imaging.

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Despite the potential advantages of multiple phases of contrast enhancement, MDCT protocols for abdominal trauma vary widely, and may only include a single contrast-enhanced phase, often the portal venous phase. Marmery et al. (7) and Boscak et al. (8) showed that arterial and portal venous phase imaging improved overall accuracy in detection of both splenic pseudoaneurysms and active bleeding. Additionally, dual phase imaging with portal venous and delayed phase scans of the spleen has been found useful in differentiating between active bleeding and other types of contained vascular injury such as pseudoaneurysm (4). The aim of our study was to determine the sensitivity and overall accuracy of single, dual, and triple phase contrast-enhanced MDCT for detecting splenic vascular injuries. This data can potentially optimize current imaging protocols by evaluating the utility of delayed venous phase imaging in detection of splenic vascular injury and support previous studies in the necessity of arterial phase imaging in trauma protocols.

Methods

Following Institutional Review Board approval, our study included a retrospective review of 88 adult patients (aged 18–89 years) from 2003 to 2011 who sustained blunt splenic trauma evaluated with contrast-enhanced MDCT and subsequent angiography. Cases were collected from the picture archiving and communication system (PACS) and a trauma registry at the authors' hospital, a Level I trauma center. The patients were evaluated with single, dual, or triple phase contrast-enhanced CT scans on admission. Dual phase imaging included patients evaluated with either arterial and portal venous phases, or portal venous and delayed phases. Patients undergoing chest and abdominopelvic CT received arterial and portal venous phase images of the spleen with selective acquisition of a delayed phase. Patients undergoing abdominopelvic CT received portal venous phase imaging of the spleen with selective acquisition of a delayed phase.

An attending interventional radiologist evaluated each patient's admission CT scan and subsequent angiogram independently. All information regarding clinical outcome and final diagnosis was withheld from the reviewer at the time of interpretation. The scans were reviewed for phase classification, grade of splenic injury, and presence of vascular injury. Phases were described as arterial, portal venous, and delayed based on time of image acquisition after intravenous contrast bolus and appearance of intravenous contrast in the vasculature. The protocol intended to capture early arterial phase images; however, due to different factors, some studies were imaged in the late arterial phase. All studies that included "arterial" phase images of the spleen were included and labeled as such, whether early or late. The studies were performed on Siemens Somatom Sensation 16 and 64 slice CT scanners. For the arterial phase images, a chest CT was performed with 150 mL Omnipaque 300 iodinated contrast injected intravenously at 4 mL/s. Bolus tracking off the aortic arch triggered scanning at 150 HU. Scanning continued through the upper abdomen to include the spleen. For portal venous phase images acquired with a concomitant chest CT, scans were acquired from the diaphragm to the symphysis pubis using a 70 s delay from the initiation of the contrast injection. For portal venous phase images acquired without a concomitant chest CT, an abdominopelvic CT was performed with 150 mL Omnipaque 300 iodinated contrast injected intravenously at 3 mL/s. The scans were acquired from the diaphragm to the symphysis pubis using a 70 s delay from the initiation of the contrast injection. Delayed phase images were acquired at the interpreting radiologist's discretion using a 200 s delay from the initiation of the contrast injection. Axial images were acquired in 5 mm thickness and reconstructed in 2 mm. Coronal and sagittal reconstructions were available for some but not all the patients; however, for the current study, primary image interpretation was performed in the axial plane.

Injuries were graded using the American Association for the Surgery of Trauma (AAST) splenic injury scale, 1994 revision (8) (Table 1). Vascular injuries included pseudoaneurysms (foci of hyperattentuation within the splenic parenchyma), active bleeding (contrast pooling outside the borders of splenic parenchyma), and arteriovenous fistula (typically seen as opacification of the splenic vein early in the arterial phase). The splenic angiograms were reviewed independently and noted for the presence or absence of vascular injury. The CT findings were then compared with the splenic angiograms, which served as the reference standard, for the determination of sensitivity, specificity, and accuracy in detecting vascular injuries. A chi-square test was used to analyze and compare the data of true positives and false negatives amongst the different MDCT protocols. A P value of <0.05 was considered statistically significant.

Main points

- Intravenous contrast-enhanced multidetector computer tomography plays a critical role in the evaluation of splenic injuries among patients sustaining blunt abdominal trauma.
- The presence of vascular injuries on CT such as active bleeding, pseudoaneurysm, and arteriovenous fistula, has traditionally been the primary indication for splenic angiography and embolization.
- Single phase CT, which typically includes the portal venous phase, suffers from low sensitivity and accuracy for the detection of splenic vascular injuries.
- When using dual phase CT, arterial + portal venous phase is more sensitive and accurate than portal venous + delayed phase imaging for detecting vascular injury.
- Triple phase CT is not more accurate or sensitive in detection of splenic vascular injury when compared with dual phase imaging including the arterial + portal venous phases.

Table 1. Frequency of splenic injury grades

Grade of splenic injury	% (n/N)
1	1.14 (1/88)
2	14.8 (13/88)
3	57.9 (51/88)
4	19.3 (17/88)
5	6.82 (6/88)

Results

The majority (57.9%) of splenic injuries in the cohort were grade 3 (Table 1). Table 2 summarizes the results of single vs. dual vs. triple phase contrast-enhanced MDCT imaging for the detection of splenic vascular injuries. Of note, all single phase examinations were obtained in the portal venous phase.

For diagnosing splenic vascular injury, dual phase CT was more sensitive (80.0% vs. 37.5%, $P = 0.016$) and more accurate (76.2% vs. 37.5%; $P = 0.029$) compared with single phase CT. Dual phase CT included studies with arterial + portal venous phases (n=20) or portal venous + delayed phases (n=22). When these subsets of dual phase CT were compared, arterial + portal venous phase CT was more sensitive (100% vs. 56.3%,

Table 2. MDCT phase imaging protocols and corresponding splenic vascular injury detection rates compared with angiography

	True positive	False positive	True negative	False negative	Sensitivity	Specificity	Overall accuracy
Single phase (portal venous only)	37.5 (3/8)	0 (0/8)	0 (0/8)	62.5 (5/8)	37.5 (3/8)	0 (0/8)	37.5 (3/8)
Dual phase (arterial + portal venous)	95.0 (19/20)	0 (0/0)	5 (1/20)	0 (0/0)	100 (19/19)	100 (1/1)	100 (20/20)
Dual phase (portal venous + delayed)	40.9 (9/22)	13.6 (3/22)	13.6 (3/22)	31.8 (7/22)	56.3 (9/16)	50.0 (3/6)	54.5 (12/22)
Dual phase combined (arterial + portal venous and portal venous + delayed)	66.7 (28/42)	7.1 (3/42)	9.5 (4/42)	16.7 (7/42)	80 (28/35)	57.1 (4/7)	76.2 (33/42)
Triple phase (arterial + portal venous + delayed)	84.2 (32/38)	0 (0/38)	13.2 (5/38)	2.6 (1/38)	97.0 (32/33)	100 (5/5)	97.4 (37/38)

Data are presented as % (n/N).
MDCT, multidetector computed tomography.

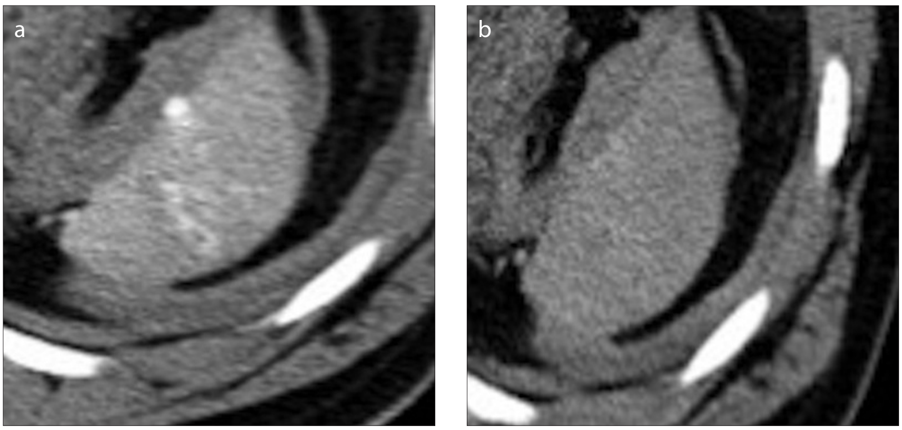

Figure 1. a, b. Arterial phase **(a)** CT image of abdomen shows multiple areas of hyperattenuation within the splenic parenchyma consistent with pseudoaneurysms. CT image at the same level in the portal venous phase **(b)** demonstrates no evidence of vascular injury.

P = 0.005) and more accurate (100% vs. 54.5%, *P* = 0.002) than portal venous + delayed phase imaging.

Triple phase CT was more accurate (97.4% vs. 76.2%, *P* = 0.015) than dual phase CT, only when compared with the dual phase combined group (arterial + portal venous or portal venous + delayed, n=42). When triple phase CT was compared with the dual phase subset of arterial + portal venous, there was not a statistically significant difference in either sensitivity (97.0% vs. 100%, *P* = 0.778) or accuracy (97.4% vs. 100%, *P* = 0.742).

In our study, 13 of 88 patients had false negative CT scans on admission. Five of 13 were sent for angiography immediately based solely on the grade of injury. The remaining eight patients had either a drop in hematocrit or persistent abdominal pain that triggered a follow-up CT scan anywhere from 24 hours to one week after initial injury. These follow-up scans were positive for vascular injury and the patients were subsequently sent to angiography for embolization. No repeat diagnostic angiograms were required.

Discussion

The results of this retrospective study support the use of multiphase contrast-enhanced MDCT for the evaluation of splenic vascular injuries among patients with blunt abdominal trauma. Current management algorithms stratify patients to operative or nonoperative treatment based on hemodynamic stability. For those who are hemodynamically stable, accurate evaluation of splenic injuries with MDCT protocol is crucial. Single phase CT, which typically includes the portal venous phase, suffers from low sensitivity (37.5%) and accuracy (37.5%) for the detection of splenic vascular injuries. Missing the diagnosis of contained or noncontained vascular injury in single phase CT can negatively impact patient outcomes, given that the mere presence of either type of injury on CT is associated with failure of nonsurgical management (8, 10). In addition, the study also provides evidence for the importance of arterial phase CT in a multiphase protocol (Fig. 1). Triple phase CT (arterial + portal venous + delayed) was not statistically more sensitive or more accurate than dual phase CT, as long as the two phases were arterial + portal venous. When dual phase imaging employed portal venous + delayed phases, sensitivity and accuracy plummeted. This discrepancy has been demonstrated in other series. A recent paper published by Uyeda et al. (11) comparing various CT protocols without the routine confirmation of arteriography revealed that 59% of contained splenic vascular injuries were present only in the arterial phase of CT. The study is limited in its significance as the authors excluded patients with evidence of splenic vascular injury on subsequent portal venous or delayed phases. Boscak et al. (8) also reported similar results concluding that arterial phase imaging was more accurate than portal venous for detection of pseudoaneurysms and that portal venous phase was better for active bleeding.

The improved detection of splenic vascular injuries and pseudoaneurysms in particular on arterial phase CT likely stems from the wash in and wash out of iodinated contrast first within the arteries and the vascular injury, and later the parenchyma of the spleen. An arterial pseudoaneurysm, or contained arterial injury, is in direct connection with the arterial tree. Contrast opacifies the pseudoaneurysm in the arterial phase and as the parenchyma begins to enhance in the portal venous phase, contrast washes out of the pseudoaneurysm, making the vascular injury less apparent. The pseudoaneurysms do not increase in size on images obtained in a later phase, which further helps classify them as contained injuries (7, 8, 12).

In addition to the importance of arterial phase CT, the current study demonstrated

Figure 2. a–c. Arterial phase **(a)** CT image through the lower pole of the spleen demonstrates perisplenic hematoma, but no evidence of active bleeding. Corresponding image in the portal venous phase **(b)** reveals vascular injury with perisplenic contrast extravasation *(black arrow)* consistent with active bleeding. Delayed phase **(c)** CT image confirms the presence of active bleeding with an enlarging pool of perisplenic contrast extravasation *(black arrow)*.

the lack of importance of delayed phase CT for the detection of splenic vascular injuries. As noted above, triple phase imaging (arterial + portal venous + delayed) did not improve sensitivity or accuracy when compared with dual phase imaging (arterial + portal venous). These results do not support the routine use of triple phase CT to detect splenic vascular injuries. In the current series, there were a few patients in whom delayed phase images allowed more precise characterization of the vascular injury as active bleeding; the significance of this on clinical outcome was unknown (Fig. 2). A study by Anderson et al. (4) found that patients with hyperattenuating foci seen outside splenic parenchyma on the delayed phase helped confirm active hemorrhage and this subsequently altered their management. Additionally, Fu et al. (13) demonstrated that the presence of intraperitoneal contrast extravasation increased the probability of an injury requiring surgical intervention. However, the application of these studies may be limited given current algorithms for hemodynamically stable patients with blunt splenic trauma employ angioembolization following CT identification of any type of splenic vascular injury, either contained or noncontained (5, 13).

There were several limitations in the current retrospective analysis. First, patients were only included if both MDCT and angiography were obtained to evaluate the splenic injury. This population is not representative of all patients with blunt splenic trauma. In addition to vascular injuries, higher grade injuries (grade 3 and above) without vascular injuries present on MDCT may trigger the request for angiography by the admitting trauma surgeons at the authors' institution, biasing the selection of patients studied with angiography (84.1% of patients had injuries grade 3 and above).

Additionally, as the data were collected over eight years, physician application of the splenic trauma algorithm and evolution of radiologic technology likely impacted patient evaluation at the time of injury, as well as the ability of radiologists to diagnose vascular injuries. Although angiography was used as the "gold standard" for the presence or absence of splenic vascular injury, it is subject to limitations such as operator experience and numerous patient factors. Angiography may not always be able to identify vascular injury at the time of the study. Haan et al. (14) found that 10% of patients with blunt splenic injury who initially had negative angiography at admission later required repeat angiography or laparotomy. Finally the small sample size reduced the statistical power for certain subset comparisons.

Studies estimate that nonoperative management is attempted in 60% to 80% of patients with splenic injury (15, 16), and it is successful 85%–94% of the time (13, 17–21). The application of conservative management in hemodynamically stable patients relies upon the accurate evaluation of splenic vascular injuries; therefore, imaging protocols should be optimized for detection of vascular injury. The current study and others support the use of a multiphase MDCT protocol. More studies will be needed to determine the significance of delayed phase imaging in stable blunt splenic trauma patients as elimination of unnecessary CT phases can reduce patient exposure to radiation.

In conclusion, we propose that patients with suspected splenic injury be evaluated with at least a dual phase contrast-enhanced MDCT which includes the arterial phase, and we question the utility of obtaining a delayed phase series.

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Conflict of interest disclosure

The authors declared no conflicts of interest.

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