Segmental Bowel Hypoenhancement on CT Predicts Ischemic Mesenteric Laceration After Blunt Trauma

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OBJECTIVE. The objectives of this study were to examine the performance of CT in the diagnosis of ischemic mesenteric laceration after blunt trauma and to assess the predictive value of various CT signs for this injury.

MATERIALS AND METHODS. In this retrospective study, consecutive patients with bowel and mesenteric injury diagnosed by CT or surgery from January 2011 through December 2016 were analyzed. Two radiologists evaluated CT images for nine signs of bowel injury. The outcome evaluated was ischemic mesenteric laceration. Univariable analysis followed by logistic regression was performed.

RESULTS. The study included 147 patients (96 men and 51 women; median age, 35 years; age range, 23–52 years). Thirty-three patients had surgically confirmed ischemic mesenteric lacerations. CT signs that correlated with ischemic mesenteric laceration were abdominal wall injury, mesenteric contusion, free fluid, segmental bowel hypoenhancement, and bowel hyperenhancement adjacent to a hypoenhancing segment. The regression model developed after inclusion of clinical variables identified two predictors: segmental bowel hypoenhancement (adjusted odds ratio, 22.9 [95% CI, 7.9–66.2; $p < .001$] for reviewer 1 and 20.7 [95% CI, 7.2–59.0; $p < .001$] for reviewer 2) and abdominal wall injury (adjusted odds ratio, 5.26 [95% CI, 1.7–15.9; $p = .003$] for reviewer 1 and 5.3 [95% CI, 1.9–15.0; $p = .002$] for reviewer 2), which yielded an AUC of 0.87 for predicting injury. For reviewer 1 and reviewer 2, the sensitivities of CT in detecting the injury were 72.3% (95% CI, 54.5–86.7%) and 78.8% (95% CI, 61.0–91.0%), respectively, whereas the specificities were 94.7% (95% CI, 88.9–98.0%), and 92.1% (95% CI, 85.5–96.3%), respectively.

CONCLUSION. CT has limited sensitivity but good specificity for detecting ischemic mesenteric laceration, with segmental bowel hypoenhancement considered the most predictive imaging sign.

Ischemic mesenteric laceration is a specific type of blunt bowel and mesenteric injury that can be difficult to detect on CT [1]. It is also called bucket-handle mesenteric laceration, with the term "bucket handle" describing a linear mesenteric tear coursing parallel to the bowel and avulsing the terminal vascular supply, resulting in segmental bowel ischemia [2, 3]. The affected bowel segment is immediately devascularized but is not otherwise injured, so bowel wall edema or hematoma is not an early feature of injury, and perforation is not present (although necrosis may result in eventual perforation, if the injury goes undetected).

Diagnosis on CT remains a challenge, primarily because of the absence of typical findings of blunt bowel injury. In a systematic literature review of 20 cases of ischemic mesenteric laceration, up to 58% of injuries were missed on initial workup; CT had poor sensitivity (45%), although its specificity was high (95%) [4]. A delay in diagnosing surgical bowel injuries increases morbidity and mortality [5–7].

A mechanistic classification that discriminates ischemic from nonischemic bowel injuries and a description of associated CT findings could aid in the appraisal of this specific injury by radiologists. Such classification broadly divides bowel and mesenteric injuries into ischemic injuries caused by mesenteric laceration and nonischemic injuries such as perforation, contusion, intramural hematoma, or a combination of these injuries [8]. Ischemic bowel injuries are categorized as the highest grade of blunt bowel injuries and/or mesenteric injuries, according to the American Association for the Surgery of Trauma organ injury scale [9].

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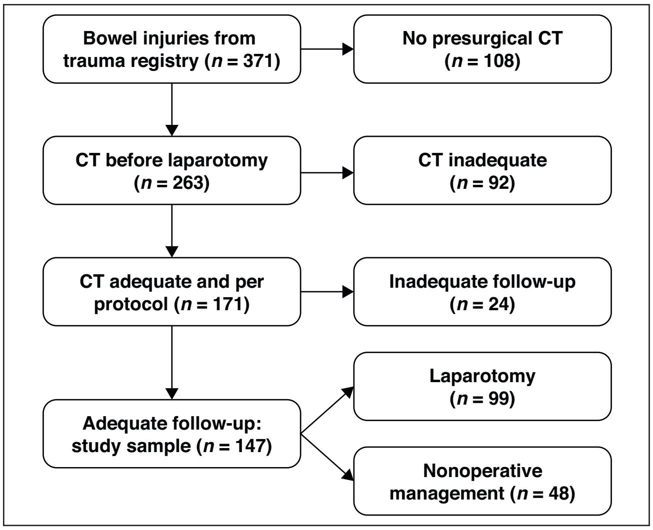

Fig. 1—Flowchart of patient selection process.

The present study aimed to examine the performance of CT in the diagnosis of ischemic mesenteric laceration by use of such mechanistic classification and to assess the value of various CT signs in predicting this specific injury.

Materials and Methods

Study Design

This retrospective study was HIPAA compliant and was approved by the institutional review board at the University of Maryland School of Medicine. A waiver of informed consent was provided.

Consecutive patients who were admitted to our level I trauma center from January 2011 through December 2016 were eligible for inclusion. Inclusion criteria were age 18 years or older, blunt force trauma, and diagnosis of bowel injury per the trauma registry (with both clinical CT and surgical diagnoses included). A review of the electronic medical records and the radiology information system was performed to exclude those patients who had undergone laparotomy before CT, had not undergone abdominopelvic CT within 6 hours of admission, had an inadequate CT examination (defined as one for which contrast injection failed, a nontrauma protocol was followed, or excessive motion or other artifact was observed), or had inadequate follow-up (defined as the absence of a surgical note or, if nonsurgical, by a lack of documentation at least 1 week after trauma). One author (a trauma and emergency radiologist with 10 years of experience), who did not perform study image interpretation, conducted reviews of the trauma registry, electronic medical records, and radiology information system to select the study sample. A flowchart of the patient selection process is presented in Figure 1.

CT Protocol

CT examinations conducted at admission to the hospital were routinely performed in accordance with our institutional blunt trauma admission protocol. Scans were obtained using 40- or 64-MDCT scanners (Brilliance, Philips Healthcare). Enteric contrast medium was not used. Administration of IV contrast material (100 mL of iohexol; 350 mg I/mL [Omnipaque 350, GE Healthcare]) was achieved by power injection of 60 mL at a rate of 6 mL/s, followed by 40 mL administered at a rate of 4 mL/s and then a 50-mL saline flush. Arterial phase imaging of the abdomen and pelvis was performed after bolus tracking using a 120-HU trigger in the descending thoracic aorta. The parameters that were used were as follows: tube voltage, 120 kVp; tube current–exposure time product, 250 mAs; collimation, 0.625 mm; and reconstruction with a 3-mm slice thickness and 3-mm intervals. Portal venous phase imaging was performed only through the upper abdomen during the early portion of the study. Because portal venous phase images through the entire abdomen and pelvis were not available for all study patients, only arterial phase images were used for review.

CT Image Interpretation and Definitions

For each study patient, arterial phase CT images were loaded to a dedicated study worklist on the PACS (AGFA IMPAX, AGFA Healthcare) by the same trauma and emergency radiologist who reviewed the trauma registry. The images were evaluated for a

TABLE 1: Unadjusted Analysis of CT Signs Predictive of Ischemic Mesenteric Lacerations for Both Reviewers

Variable	Reviewer 1		Reviewer 2	
	Unadjusted OR (95% CI)	*p*	Unadjusted OR (95% CI)	*p*
Abdominal wall injury	7.2 (2.8–17.9)	< .001[a]	6.2 (2.7–14.4)	< .001[a]
Mesenteric contusion	7.0 (2.0–24.3)	.002[a]	10.5 (2.4–46.0)	.002[a]
Mesenteric vascular lesion	2.1 (0.7–6.7)	.22	2.3 (0.8–6.4)	.11
Pneumoperitoneum	1.6 (0.6–4.1)	.32	1.5 (0.6–3.6)	.38
Free fluid	7.8 (1.8–34.1)	.007[a]	12.0 (1.6–91.0)	.01[a]
Bowel wall thickening	2.0 (0.9–4.5)	.08	1.2 (0.5–2.5)	.70
Focal wall defect	1.8 (0.15–19.9)	.65	2.4 (0.4–14.9)	.34
Segmental hypoenhancement of bowel	27.7 (10.1–75.7)	< .001[a]	22.7 (8.5–61.0)	< .01[a]
Hyperenhancement of bowel adjacent to hypoenhancing segment	11.3 (1.1–112.0)	.04[a]	6.6 (1.5–29.3)	.01[a]

Note—OR = odds ratio.
[a]Statistically significant.

total of nine CT signs of blunt bowel and mesenteric injury as described in the literature [10–13] (Table 1). CT studies were rated using a binary variable. Reviewer 1 (a trauma radiologist with 10 years of experience) and reviewer 2 (a trauma radiologist with 25 years of experience) were instructed to identify all studies as having positive or negative findings for each sign and the specific diagnosis of ischemic mesenteric laceration. For CT diagnosis of ischemic mesenteric laceration, discrepancies between the initial assessments of the two reviewers were subsequently evaluated in concert, and consensus was reached. Consensus review was not performed for individual CT signs.

Study Term Definitions

Specific study definitions of CT findings of bowel and mesenteric injury were established. Abdominal wall injury was defined as the presence on CT of seat belt sign (transverse and/or diagonal contusions across the abdomen), traumatic abdominal wall hernias (including lumbar hernias), and any abdominal wall contusions in patients who were not involved in a motor vehicle collision (MVC) (Figs. 2A and 2B). Mesenteric contusion was defined as mesenteric fat stranding with or without organized mesenteric hematoma (Figs. 2A–2C). Mesenteric vascular lesions were defined as vascular irregularity or beading (in milder forms of injury) or active bleeding (in more severe injuries). Free fluid was defined as unexplained intraperitoneal free fluid (a moderate-to-large volume of pelvic fluid, a small volume of multifocal fluid, interloop or intermesenteric fluid, or high-attenuation [≥ 15 HU] fluid) (Fig. 2C). Bowel wall thickening was defined as circumferential or eccentric bowel wall thickening. Although described as wall thickness greater than 3 mm (for small bowel) or 5 mm (for large bowel) in the presence of adequate distention of the lumen, bowel wall thickening was rated subjectively in the present study, as in routine clinical practice. Segmental hypoenhancement of bowel wall was defined as nonenhancement or hypoenhancement of a segment of bowel loop (Figs. 2A, 2C, 3A, and 3B). Hyperenhancement of bowel adjacent to a hypoenhancing segment was defined as relative segmental hyperenhancement adjacent to hypoenhancing segment.

Reference Standard

Laparotomy notes, discharge summaries, and records from follow-up clinic visits were used to determine the presence or absence of ischemic mesenteric laceration. Laparotomy findings were considered positive if mesenteric laceration was associated with adjacent segmental bowel ischemia. Patients with negative laparotomy findings or successful nonoperative management (minimum postinjury follow-up, 1 week) were considered to have findings negative for ischemic mesenteric laceration. At our study institution, management of patients with CT findings of nonsurgical bowel or mesenteric injury is usually formulated on an individual basis. Patients whose condition is stable and who have CT findings of nonsurgical injury or otherwise unexplained findings of intraperitoneal free fluid are evaluated with follow-up CT performed 4 to 6 hours after the initial CT examination or serial clinical examinations to identify radiologic or clinical deterioration.

Statistical Analysis

Data for continuous variables are summarized as mean (± SD) values for normally distributed variables and as median (first quartile and third quartile) values for nonnormally distributed variables. Categoric variables are summarized as counts and percentages. The effect of each CT predictive variable on ischemic mesenteric laceration without adjusting for other predictors was determined, and the unadjusted odds ratio (OR) and corresponding 95% CIs were calculated. Predictors for which $p < .10$ on unadjusted analysis were incorporated into the logistic regression

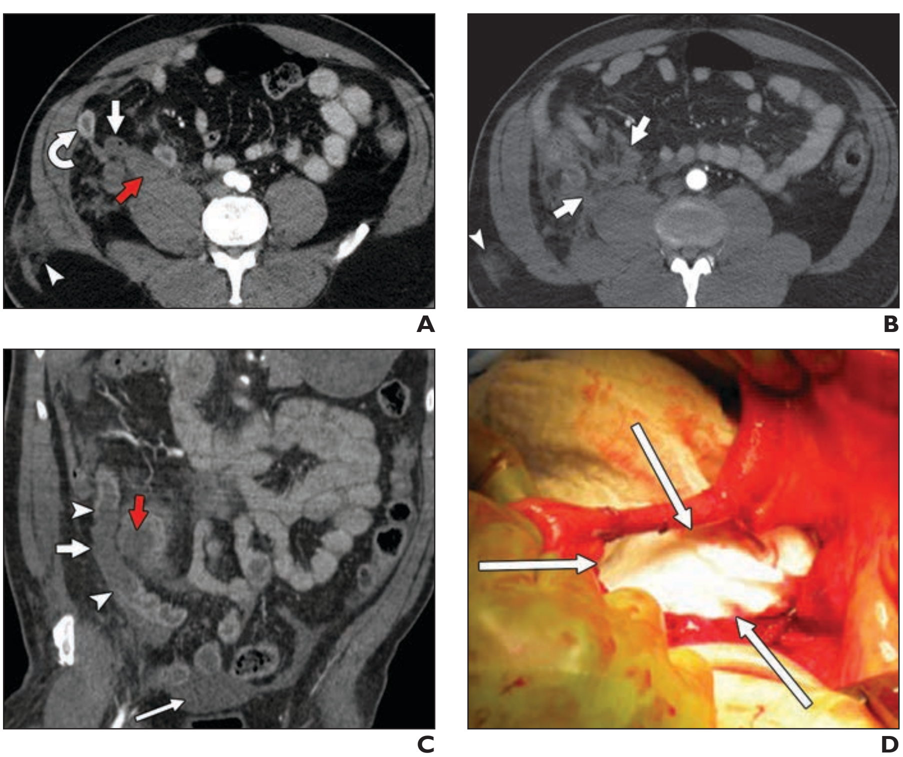

Fig. 2—60-year-old man with right flank injury after motorcycle crash.
A, Axial arterial phase CT image shows segmental hypoenhancement of ileum (*straight white arrow*), hyperenhancement of bowel adjacent to hypoenhancing segment (*curved arrow*), mesenteric contusion (*red arrow*), and abdominal wall injury (subcutaneous soft-tissue contusion) (*arrowhead*).
B, Axial arterial phase CT image shows large area of mesenteric contusion (*arrows*) and abdominal wall injury (*arrowhead*).
C, Coronal arterial phase CT image shows segmental hypoenhancement of ileum (*thick white arrow*), well-defined demarcation between normally enhancing segment and hypoenhancing segment (*arrowheads*), mesenteric contusion (*red arrow*), and free fluid in pelvic peritoneum (*thin white arrow*).
D, Intraoperative photograph of surgical specimen shows large bucket-handle tear (*arrows*) with devascularized ileum.

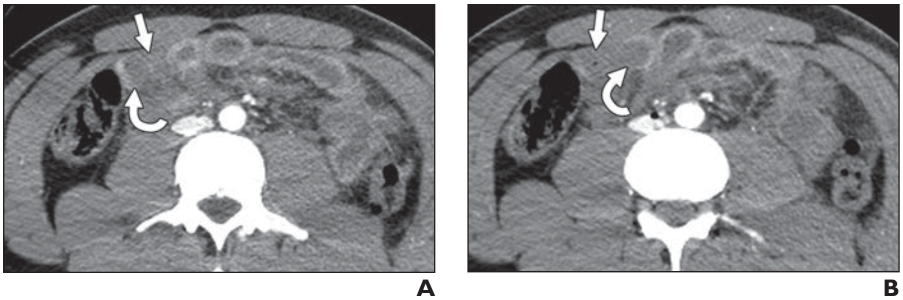

Fig. 3—24-year-old man with abdominal injury after motor vehicle collision.
A and **B,** Axial arterial phase CT images show segmental hypoenhancement of ileum (*arrow*) and sharp demarcation with enhancing wall (*curved arrow*).

model to select the best independent predictors. The final model for the diagnosis was developed using the backward elimination method based on Akaike information criterion.

For the prediction model for the specific injury, ROC analysis was performed to assess the overall predictive ability of the model using the ROC AUC and corresponding SE. Sensitivity and specificity analysis and interobserver agreement for the overall ability of CT as well as individual CT variables in diagnosing ischemic mesenteric laceration were obtained from contingency tables. The kappa coefficient (κ) was used to measure interobserver agreement. Kappa results were interpreted as follows: ≤ 0 denoted no agreement; 0.01–0.2, none to slight agreement; 0.21–0.4, fair agreement; 0.41–0.6, moderate agreement; 0.61–0.8, substantial agreement; and 0.81–1.0, almost perfect agreement. All analyses were performed using commercially available statistical software (JMP 12 software, SAS Institute).

Results

The baseline clinical characteristics of the 147 patients in the study sample (96 men and 51 women; median age, 35 years; age range, 23–52 years) are shown in Table 2. There was no significant increase in the odds of ischemic mesenteric laceration developing after an MVC (OR, 1.04; 95% CI, 0.4–2.7; $p = .90$) compared with injuries not associated with an MVC. A higher injury severity score (OR, 1.03; 95% CI, 0.99–1.06; $p = .12$) also showed no increased OR. Laparotomy was performed for bowel injuries in 99 patients, whereas nonoperative management was successful for 48 patients. A total of 33 patients had surgically proven ischemic mesenteric lacerations. The right lower quadrant mesentery was the most common site of laceration, with 17 injuries resulting in ileal devascularization, followed by jejunal mesentery ($n = 8$), the combination of jejunal and ileal mesentery ($n = 4$), sigmoid mesocolon ($n = 2$), left mesocolon ($n = 1$), and transverse mesocolon ($n = 1$).

Unadjusted and Adjusted Association of CT Signs With Ischemic Mesenteric Laceration

Without adjustment for other factors, the CT signs that correlated with a higher incidence of mesenteric laceration were abdominal wall injury (Figs. 2A and 2B) (OR, 7.1 [95% CI, 2.8–17.9; $p < .001$] for reviewer 1 and 6.2 [95% CI, 2.7–14.4; $p < .001$] for reviewer 2), mesenteric contusion (Figs. 2A–2C) (OR, 7.0 [95% CI, 2.0–24.3; $p = .002$] for reviewer 1 and 10.5 [95% CI, 2.4–46.0; $p = .002$] for re-

TABLE 2: Baseline Characteristics of Study Population

Characteristic	Patients With Ischemic Mesenteric Laceration ($n = 33$)	Patients Without Ischemic Mesenteric Laceration ($n = 114$)	All Patients ($n = 147$)
Age (y), median (Q_1, Q_3)	42 (25, 53.5)	34 (23, 52)	35 (23, 52)
Sex			
Male	17 (11.6)	79 (53.7)	96 (65.3)
Female	16 (10.9)	35 (23.8)	51 (34.7)
ISS, median (Q_1, Q_3)	29 (19, 41)	26 (17, 36)	27 (17, 41)
Mechanism of injury			
MVC	26 (17.7)	89 (60.5)	115 (78.2)
Fall	0 (0)	11 (7.5)	11 (7.5)
MCC	3 (2.0)	4 (2.7)	7 (4.8)
Pedestrian injuries	2 (1.4)	3 (2.0)	5 (3.4)
Industrial accidents	0 (0)	3 (2.0)	3 (2.0)
Assaults	0 (0)	2 (1.4)	2 (1.4)
Kicked by horse	1 (0.7)	1 (0.7)	2 (1.4)
ATV accident	0 (0)	1 (0.7)	1 (0.7)
Personal watercraft	1 (0.7)	0 (0)	1 (0.7)

Note—Except where otherwise indicated, data are number of patients (percentage of all 147 patients). Q_1 = first quartile, Q_3 = third quartile, ISS = injury severity score, MVC = motor vehicle collision, MCC = motorcycle crash; ATV = all-terrain vehicle.

TABLE 3: Sensitivity and Specificity of Overall CT Diagnosis and Individual CT Signs in the Diagnosis of Ischemic Mesenteric Laceration Along With Interobserver Agreement

Variable	Reviewer 1		Reviewer 2		Interobserver Agreement, κ (95% CI)
	Sensitivity, % (95% CI)	Specificity, % (95% CI)	Sensitivity, % (95% CI)	Specificity, % (95% CI)	
CT diagnosis of ischemic mesenteric laceration	72.3 [24/33] (54.5–86.7)	94.7 [108/114] (88.9–98.0)	78.8 [26/33] (61.0–91.0)	92.1 [105/114] (85.5–96.3)	0.66 (0.52–0.81)
Abdominal wall injury	78.8 [26/33] (61.0–91.0)	65.8 [75/114] (56.3–74.4)	63.6 [21/33] (45.0–79.6)	78.1 [89/114] (69.3–85.3)	0.7 (0.59–0.82)
Mesenteric contusion	90.9 [30/33] (75.7–98.0)	41.2 [47/114] (32.0– 50.8)	93.9 [31/33] (79.8–99.3)	40.4 [46/114] (31.3–50.0)	0.51 (0.36–0.66)
Mesenteric vascular lesion	15.1 [5/33] (5.0–31.9)	92.1 [105/114] (85.5–96.3)	21.2 [7/33] (9.0–38.9)	89.5 [102/114] (82.3–94.4)	0.63 (0.42–0.83)
Pneumoperitoneum	24.2 [8/33] (11.0–42.3)	83.3 [95/114] (75.2–89.7)	27.3 [9/33] (13.3–45.5)	79.8 [91/114] (71.3–86.8)	0.81 (0.69–0.93)
Free fluid	93.9 [31/33] (79.8–99.3)	33.3 [38/114] (24.8–42.8)	97.0 [32/33] (84.2–99.9)	27.2 [31/114] (19.3–36.3)	0.6 (0.45–0.75)
Bowel wall thickening	63.6 [21/33] (45.1–79.6)	53.5 [61/114] (43.9–62.9)	48.5 [16/33] (30.8–66.5)	55.3 [63/114] (45.6–64.6)	0.42 (0.27–0.56)
Focal wall defect	3.0 [1/33] (0.1–15.8)	98.2 [112/114] (93.8–99.8)	6.0 [2/33] (0.7–20.2)	97.4 [111/114] (92.5–99.4)	0.74 (0.4–1.0)
Segmental hypoenhancement of bowel	72.7 [24/33] (54.5–86.7)	91.2 [104/114] (84.5–95.7)	78.8 [26/33] (61.0–91.0)	86.0 [98/114] (78.2–91.8)	0.61 (0.47–0.76)
Hyperenhancement of bowel adjacent to hypoenhancing segment	9.0 [3/33] (1.9–24.3)	99.1 [113/114] (95.2–99.9)	15.1 [5/33] (5.1–31.9)	97.4 [111/114] (92.5–99.5)	0.14 (–0.15 to 0.42)

Note—Except where otherwise indicated, data are percentage [number of CT-positive patients/number of patients with injury] for Sensitivity columns and [number of CT-negative patients/number of patients without injury] for Specificity columns (95% CI). Kappa coefficient was interpreted as follows: values ≤ 0 indicated no agreement; 0.01–0.2, no to slight agreement; 0.21–0.4, fair agreement; 0.41–0.6, moderate agreement; 0.61–0.8, substantial agreement; and 0.81–1.0, almost perfect agreement.

viewer 2), free fluid (Fig. 2C) (OR, 7.8 [95% CI, 1.8–34.1; p = .007] for reviewer 1 and 12.0 [95% CI, 1.6–91.0; p = .01] for reviewer 2), segmental bowel hypoenhancement (Figs. 2A, 2C, 3A, and 3B) (OR, 27.7 [95% CI, 10.1–75.7; p < .001] for reviewer 1 and 22.7 [95% CI, 8.5–61.0; p < .001] for reviewer 2), and bowel hyperenhancement adjacent to a hypoenhancing segment (Fig. 2A) (OR, 11.3 [95% CI, 1.1–112.0; p = .04] for reviewer 2 and 6.6 [95% CI, 1.5–29.3; p = .01] for reviewer 2). There was no correlation with mesenteric vascular lesion, pneumoperitoneum, focal bowel wall defect, and bowel wall thickening. Age (OR, 0.99; 95% CI, 0.97–1.02; p < .60), sex (OR, 0.47; 95% CI, 0.21–1.00; p < .06), and mechanism of injury (OR, 1.04; 95% CI, 0.4–2.7; p < .93) were clinical variables that were not correlated with a higher incidence of mesenteric laceration. Complete details are provided in Table 1.

Logistic regression analysis performed after inclusion of clinical and CT variables for which p < .10 identified two independent predictors with significance in identifying injury: segmental bowel hypoenhancement (adjusted odds ratio, 22.9 [95% CI, 7.9–66.2; p < .001] for reviewer 1 and 20.7 [95% CI, 7.2–59.0; p < .001] for reviewer 2) and abdominal wall injury (adjusted odds ratio, 5.26 [95% CI, 1.7–15.9; p = .003] for reviewer 1 and 5.3 [95% CI, 1.9–15.0; p = .002] for reviewer 2), which yielded an AUC of 0.87 for predicting injury. On average, the finding of segmental bowel hypoenhancement increased the odds of ischemic mesenteric laceration (Fig. 2D) by 20–22 times (adjusted OR, 22.9 [95% CI, 7.9–66.2; p < .001] for reviewer 1 and 20.7 [95% CI, 7.2–59.0; p < .001] for reviewer 2). The presence of abdominal wall injury on CT increased the odds by four to five times (adjusted OR, 5.26 [95% CI, 1.7–15.9; p = .003] for reviewer 1 and 5.3 [95% CI, 1.9–15.0; p = .002] for reviewer 2). ROC analysis performed using the combination of the two CT predictors yielded an AUC (standard error) of 0.87 (0.04) for both reviewers 1 and 2 in identifying the injury.

Sensitivity and Specificity of CT and Individual CT Signs in Diagnosing of Ischemic Mesenteric Laceration

The overall sensitivity of CT in detecting the injury was 72.3% (24/33; 95% CI, 54.5–86.7%) for reviewer 1 and 78.8% (26/33; 95% CI, 61.0–91.0%) for reviewer 2, whereas the specificity was 94.7% (108/114; 95% CI, 88.9–98.0%) for reviewer 1 and 92.1% (105/114; 95% CI, 85.5–96.3%) for reviewer 2, respectively. The overall sensitivity of CT in diagnosing the injury improved to 81.8% (27/33; 95% CI, 64.5–93.0%), and specificity improved to 98.2% (112/114; 95% CI, 93.8–99.8%) after the discrepant interpretations were reviewed together by the two radiologists and a final decision made based on consensus. Individual sensitivities and specificities of each CT signs are presented in Table 3.

The interobserver agreement between the two reviewers in detecting the ischemic mesenteric lacerations was reflected by a kappa coefficient of 0.66 (95% CI, 0.52–0.81). The degree of agreement for each of the CT signs is shown in Table 3. Of the 147 studies reviewed, nine studies had no CT signs of bowel and mesenteric injury identified by reviewer 1, six studies had no such signs identified by reviewer 2, and three studies had concordant findings according to both reviewers.

Discussion

The major findings from the present study are that segmental hypoenhancement of the bowel was the CT sign with the highest OR for injury, segmental hypoenhancement of the bowel and abdominal wall injury on CT were independent predictors of injury on regression analysis, and the sensitivity of CT in detecting ischemic mesenteric laceration ranged from 72.3% (95% CI, 54.5–86.7%) to 78.8% (95% CI, 61.0–91.0%), whereas specificity ranged from 94.7% (95% CI, 88.9–98.0%) to 92.1% (95% CI, 85.5–96.3%).

To our knowledge, this is the first study to report the accuracy of CT in the specific diagnosis of ischemic mesenteric laceration. A previous study by Matsushima et al. [8] showed that the incidence of ischemic mesenteric laceration was 39% in a sample of 67 patients, which is in contrast to the incidence of 22% seen in our study sample. This discrepancy might be due to the selection bias introduced in the earlier study, which resulted from the narrow inclusion criteria that required laparotomy as the reference standard. Our broader selection criterion resulted in the inclusion of all patients with CT findings of bowel injury with both laparotomy and clinical follow-up used as the reference standard. The inclusion of patients with unexplained intraperitoneal free fluid in the absence of solid organ injury likely helped minimize the probability of missed injuries because intraperitoneal free fluid is the CT sign with the highest reported sensitivity (range, 81–100%) for detecting bowel and mesenteric injuries [10, 12–14]. The same study also found no CT findings that differed significantly between ischemic injury and nonischemic injury [8]. However, the present study found various CT signs to be more prevalent in ischemic mesenteric laceration, including abdominal wall injury, mesenteric contusion, free fluid, segmental bowel hypoenhancement, and bowel hyperenhancement adjacent to a hypoenhancing segment.

The most common mechanism of ischemic mesenteric laceration, which is associated with use of a seat belt restraint, is a rapid deceleration force caused by a motor vehicle collision (MVC) [1, 7]. Our results are consistent with those of prior reports, with the highest number of injuries occurring after MVC, although the results also showed that there was no significant increase in the odds of injury after MVC. Mesenteric lacerations seem to result from shearing forces at the junction of mobile and fixed bowel segments, with the most common injury site involving the right lower quadrant [2, 15, 16]. Similar results were obtained in the present study, which noted that the most common site of injury was the right lower quadrant with ileal devascularization, followed by the jejunal mesentery and mesocolon.

The two CT signs (segmental hypoenhancement of the bowel and abdominal wall injury) that were the independent predictors of injury had kappa values of 0.61 and 0.7 (indicating substantial agreement), respectively. The present study relied on subjective assessment of bowel wall attenuation and did not formally quantify differential enhancement. Dual-energy CT may increase the sensitivity and diagnostic confidence in detecting bowel wall hypoenhancement through the use of low-kiloelectron-volt virtual monoenergetic images and iodine maps, by accentuating the subtle enhancement differences [10]. Quantitative measurements of bowel wall enhancement (expressed as Hounsfield units) or iodine content are also possible on dual-energy CT iodine maps but can be extremely challenging because of the difficulty of placing ROIs on relatively thin bowel walls. The abdominal wall injury CT sign in our study encompassed a broad range of injuries (seat belt sign, traumatic abdominal wall hernias including lumbar hernias, and any abdominal wall contusions). Evidence exists that characterization of seat belt sign in relation to the anterior superior iliac spine and the contusion depth has a better ability to predict the need for abdominal surgery, although the study did not specifically look at ischemic mesenteric lacerations [17]. However, the present study did not characterize abdominal wall injuries on the basis of their anatomic relations and morphologic features; therefore, the best precision may not have been achieved.

The CT finding of segmental bowel hypoenhancement after blunt trauma reflects focal interruption of vascular inflow, as a result of transection of terminal arteries at the site of mesenteric laceration. The affected bowel segment parallels the mesenteric laceration, with abrupt transition from normal to abnormal bowel wall enhancement at the margins of injury. The associated phenomenon of relative bowel wall hyperenhancement adjacent to a hypoenhancing segment may reflect inflammatory hyperemia (increased contrast inflow), venous congestion (decreased contrast outflow), a pathologic increase in endothelial permeability (interstitial contrast accumulation), or a combination of these findings [18].

It is important to note that several classic CT signs of surgical bowel and mesenteric injury are not strongly associated with ischemic mesenteric laceration. These include signs of direct bowel trauma and perforation, such as bowel wall edema or thickening, extraluminal gas, and focal bowel wall defect, which are not features of ischemic mesenteric laceration in its early stages. Mesenteric contusion may be present but is nonspecific. Mesenteric vascular lesions (including vascular beading and active bleeding) are more specific but show very low sensitivity.

In the present study, only arterial phase CT images were reviewed. To our knowledge, no published reports have compared the utility of arterial versus portal venous phase CT in bowel and mesenteric injury. However, previous studies that compared the enhancement of ischemic versus nonischemic bowel segments in nontraumatic disease have described a greater difference in attenuation in the arterial phase, providing higher contrast and improving lesion conspicuity [19]. Extrapolating these findings, we think that arterial phase imaging is adequate for evaluating ischemic mesenteric laceration. There is no consensus regarding whole-body CT protocol in trauma patients. Studies have indicated that biphasic image acquisition is optimal for detecting traumatic vascular lesions in the spleen [20, 21]. Such a protocol includes arterial phase imaging from the thoracic inlet to the greater trochanters, to screen for vascular injuries, and portal venous phase imaging through the upper abdomen, to screen for solid organ injuries during peak parenchymal enhancement. However, the sensitivity of CT for some abnormalities, especially active bleeding, may be decreased if portal venous phase imaging is not extended through the injury site [12].

Based on the results of this study, the limitations of CT in the diagnosis of ischemic mesenteric laceration must be emphasized, despite improved awareness of this injury among radiologists [1]. Because delayed surgical repair increases morbidity and mortality, maximizing the accuracy of CT is essential to optimize outcomes. Increased scrutiny for the predictive and associated CT signs described in the present study should improve the sensitivity and specificity of CT diagnosis.

The present study has a number of limitations. It has a retrospective single-center design, which introduces selection and institutional biases. The sample was limited to patients with bowel injury who underwent CT followed by laparotomy or close clinical follow-up; this was done to capture most patients with both surgical and nonsurgical bowel injuries with the use of reliable reference standards. The study also had a variety of exclusion criteria, as previously described, and it is of note that the study could not include patients who underwent immediate laparotomy after blunt trauma without presurgical CT. As such, the specificity data from this nonrandom sample may not be generalizable to all trauma patients. The study sample had a high incidence of bowel injury, likely introducing both attribution and availability biases into CT interpretation, particularly because ischemic mesenteric laceration is a relatively uncommon injury. Finally, only arterial phase CT images were reviewed. The authors acknowledge that CT protocols are diverse and that many centers do not routinely acquire arterial phase images through the abdomen and pelvis. Our results do not establish diagnostic performance in the portal venous phase, thereby limiting the applicability of our study.

Conclusion

Ischemic mesenteric laceration presents a diagnostic challenge to radiologists interpreting CT images of the abdomen and pelvis obtained after blunt trauma. Increased attention to bowel wall hypoenhancement as a specific CT finding predictive of this injury, knowledge of the association with abdominal wall injury, and awareness of the typical absence of several classic CT signs of blunt bowel and/or mesenteric injuries should inform the interpretation of blunt trauma CT for patients at risk for this surgical lesion.

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