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EMERGENCY RADIOLOGY

Diagnostic accuracy of triple-contrast multi-detector computed tomography for detection of penetrating gastrointestinal injury: a prospective study

Nitima Saksobhavivat[1] · Kathirkamanathan Shanmuganathan[2] · Alexis R. Boscak[2] · Clint W. Sliker[2] · Deborah M. Stein[3] · Uttam K. Bodanapally[2] · Krystal Archer-Arroyo[2] · Lisa A. Miller[2] · Thorsten R. Fleiter[2] · Melvin T. Alexander[2] · Stuart E. Mirvis[2] · Thomas M. Scalea[3]

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Abstract

Purpose Neither the performance of CT in diagnosing penetrating gastrointestinal injury nor its ability to discriminate patients requiring either observation or surgery has been determined.

Materials and methods This was a prospective, single-institutional observational study of patients with penetrating injury to the torso who underwent CT. Based on CT signs, reviewers determined the presence of a gastrointestinal injury and the need for surgery or observation. The primary outcome measures were operative findings and clinical follow-up. CT results were compared with the primary outcome measures.

Results Of one hundred and seventy-one patients (72 gunshot wounds, 99 stab wounds; age range, 18–57 years; median age, 28 years) with penetrating torso trauma who underwent CT, 45 % were followed by an operation and 55 % by clinical follow up. Thirty-five patients had a gastrointestinal injury at surgery. The sensitivity, specificity, and accuracy of CT for diagnosing a gastrointestinal injury for all patients were each 91 %, and for predicting the need for surgery, they were 94 %, 93 %, 93 %, respectively. Among the 3 % of patients who failed observation, 1 % had a gastrointestinal injury.

Conclusion CT is a useful technique to diagnose gastrointestinal injury following penetrating torso injury. CT can help discriminate patients requiring observation or surgery.

Key Points

- *The most sensitive sign is wound tract extending up to gastrointestinal wall.*
- *The most accurate sign is gastrointestinal wall thickening.*
- *Triple-contrast CT is a useful technique to diagnose gastrointestinal injury.*
- *Triple-contrast CT helps to discriminate patients requiring observation and surgery.*

Keywords Multidetector computed tomography · Penetrating · Injuries · Wounds, stab · Gastrointestinal tract

✉ Kathirkamanathan Shanmuganathan
kshanmuganathan@umm.edu

1 Department of Diagnostic and Therapeutic Radiology, Faculty of Medicine Ramathibodi Hospital, Mahidol University, 270 Rama VI Rd., Ratchathewi, Bangkok 10400, Thailand

2 Department of Diagnostic Radiology & Nuclear Medicine, University of Maryland School of Medicine, 22 S. Greene Street, Baltimore, MD 21201, USA

3 R. Adams Cowley Shock Trauma Center, University of Maryland School of Medicine, 22 S. Greene Street, Baltimore, MD 21201, USA

Introduction

Emergent laparotomy is the standard of care for patients with hemodynamic instability or peritonitis following penetrating injury to the torso [1–3]. Selective non-operative management (SNOM) is a safe option for patients who are without indication for immediate laparotomy [1–5]. Computed tomography (CT) with administration of oral, rectal, and intravenous contrast material (triple contrast) facilitates successful SNOM [6–8]. CT is highly accurate in demonstrating peritoneal violation and solid organ injury, and is useful in diagnosing gastrointestinal and mesenteric injuries [1, 6–8]. Gastrointestinal injuries may be asymptomatic initially and missed injuries can lead to morbidity and mortality from peritonitis, sepsis, and abscess formation [2, 9–11].

Recent literature indicates CT did not alter the clinical management of stab wounds to the torso. The majority of these patients had missed gastrointestinal injuries and developed peritonitis [2, 3]. The performance of individual CT signs of bowel injury seen on multi-detector row CT (MDCT) in diagnosing penetrating bowel injury has not been studied before. This prospective, observational study was performed to determine the performance of triple-contrast MDCT in diagnosing and characterizing bowel injuries in patients with penetrating torso trauma. Our hypothesis is that MDCT can accurately discriminate penetrating bowel injuries that require surgery from those safe to observe.

Materials and methods

Our institutional review board approved this prospective observational HIPPA compliant study with a waiver of informed consent. This study was performed between October 2011 and April 2013.

Subjects

All patients with penetrating wounds between the nipple line and upper third of the thigh were prospectively screened for inclusion. The inclusion criteria were: 1. age 18 years or older; 2. gunshot or stab wound; 3. wound site in the torso (i.e., region between nipple line and upper third of thighs); 4. the patient was haemodynamically stable to undergo MDCT. Exclusion criteria were: 1. age 17 or less; 2. blunt trauma; 3. entry site outside torso; 4. MDCT not obtained following

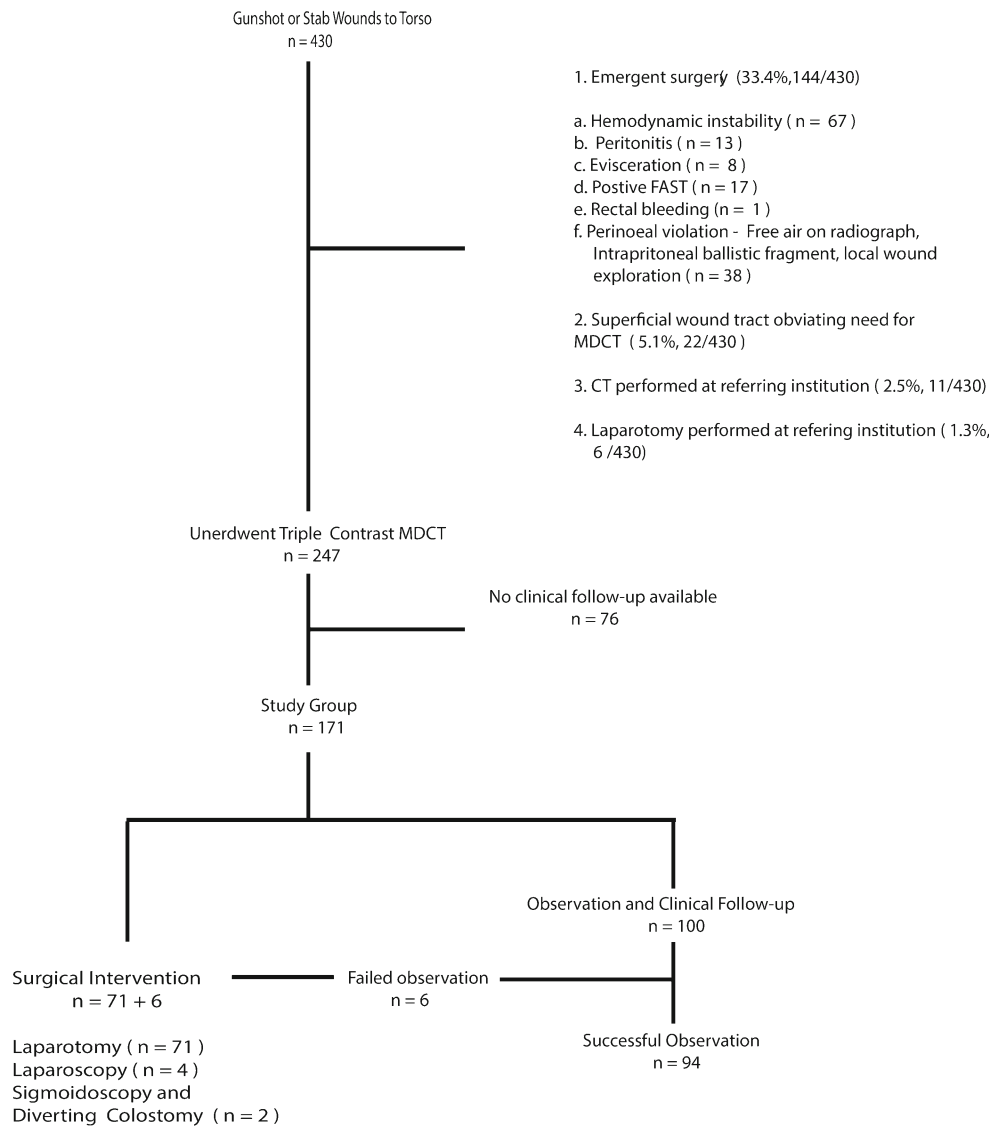

Fig. 1 Study group

admission; 5. patient lost to follow-up. Figure 1 shows how the study group was formed. Figure 2 shows the institutional protocol for triaging patients with penetrating torso injury.

CT protocol

All patients underwent CT examinations using our institutional protocol for penetrating torso injuries (Table 1) on either a 40- or 64-slice MDCT scanner (Brilliance; Phillips Healthcare, Andover, MA, USA). Triple contrast is routinely administered.

CT image interpretation

All CT images were interpreted on the picture archiving and communication system. Six attending emergency radiologists (U.K.B., K.L.A., A.R.B., L.A.M., C.W.S., T.R.F.), with 2, 3, 4, 12, 12, 21 years of experience, respectively, interpreted the CT images prospectively and completed the data collection form. All six readers used the form to enter data for a 1-month period prior to study initiation to obtain high intra-observer reliability. Case distribution among the six radiologists was 32 %, 27 %, 29 %, 29 %, 32 %, and 22 %, respectively. By randomization using a balanced incomplete block design (BIBD), the remaining two out of the six radiologists were assigned to independently interpret each scan on a dedicated work list without access to other imaging or clinical data. The radiologists were not aware of each patient's management option and outcome following their CT scan at the time of interpretation.

The CT images were evaluated for a total of 16 CT signs based on our prior clinical experience with seven signs

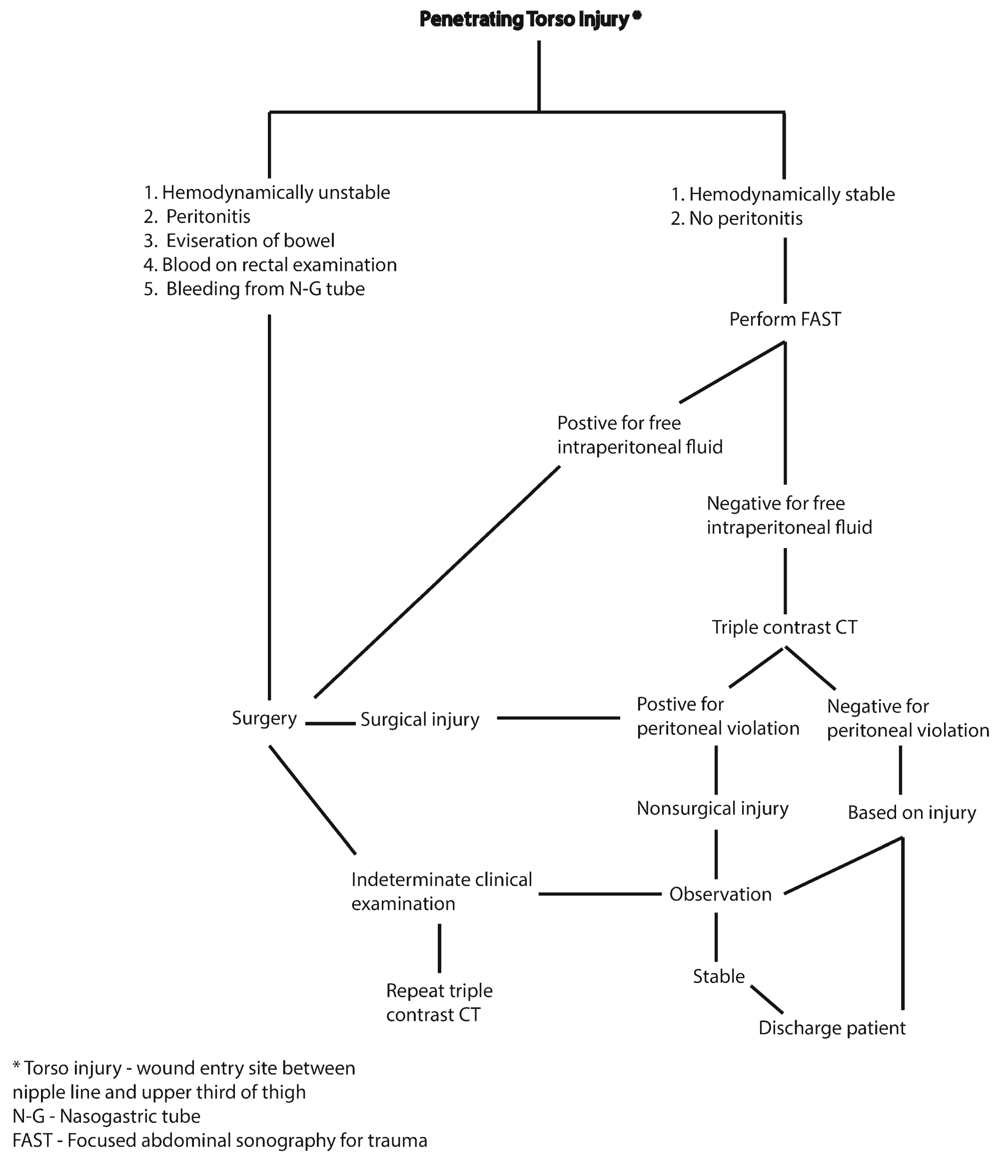

Fig. 2 Algorithm for triage of penetrating torso trauma

Table 1 MDCT and injection techniques

	Contrast volume	I_2 mg/mL	Injection rate	Saline chase	Initiation of IV injection	Detector width	Rotation time	Kvp	mAs
Abdominal and pelvic MDCT	100 mL	350	60 mL @ 6 mL/sec 40 mL @ 4 mL/sec	50 mL @ 4 mL/sec	ROI*	0.625 mm	0.5 sec	120	350

ROI* - upper abdominal aorta threshold 120 HU

Routine use of attenuation-based dose tube current modulation

Scan range - arterial phase from nipple line to ischeal tuberosities, portal venous phase from diaphragm to iliac crest

Scan direction - craniocaudal with patient lying supine

Axial images - 3 mm, sagittal and coronal images; 4 mm @ 3-mm interval.

Delayed images are obtained in the excretory phase in patients with renal or collecting system injury

A total volume of 600 mL of oral contrast material (50 mL of contrast material 300 mg I_2/mL, diluted in 950 cc of water) is administered 30 minutes before acquiring the scan. An enema total volume of 1.0 – 1.5 L of contrast material (50 mL of contrast material 300 mg I_2/mL, diluted in 950 cc of water) water is administered in the CT suite prior to scanning

If urgent scans are required based on the attending surgeon's clinical judgment, oral or rectal contrast material can be excluded for clinical necessity

considered direct and nine indirect for GI injury (Table 2). Each CT sign and the overall CT diagnosis of GI injury were rated using a five-point confidence scale (definitely absent, possibly present but unlikely, equivocal, likely present, definitely present). The radiologists were asked to score for a binary variable of whether the patient would require surgical intervention or observation specifically for GI injury.

Reference standard

The operative notes and follow-up clinic visit records were reviewed independently by one author (D.M.S.) without the knowledge of CT interpretations. These two records were considered to be the primary outcomes to determine the presence or absence of a GI injury. Laparotomy for GI injury was considered therapeutic if the GI injury required surgical repair, non-therapeutic if the injury did not require surgical repair, and negative if no injury was found. According to institutional protocol, patients were evaluated for symptoms and signs of missed GI injury or its complications. SNOM was considered successful if the patient did not require surgery for a GI injury or a complication secondary to missed GI injury, such as peritonitis or intra-abdominal abscess.

Statistical analysis

Statistical analysis was performed with the assistance of a dedicated study statistician (M.A). A sample size of at least 138 patients was determined to be necessary to achieve an accuracy of 90 % on preliminary studies with a 95 % confidence interval (CI) of $\pm$5 %. The presence of any GI injury was considered a single positive condition, regardless of the number and locations of injuries in each patient. Measures of diagnostic performance including the sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and accuracy of each CT sign and the overall CT diagnostic accuracy for presence of a GI injury were estimated, based on the first reader's prospective rating. For the purpose of calculation, "definitely present" and "likely present" were considered as positive responses while "definitely absent" and "possible but unlikely present" were considered as negative responses. Equivocal responses were considered a positive response. Twenty of 171 patients (11.7 %) who did not have enteric contrast administration due to clinical conditions or technical reasons were excluded from the calculation of diagnostic performance for leakage of enteric contrast material. Computation of area under the receiver operating characteristic curves (AUC) with a 95 % CI was performed using Wald's method, based on the 5-level confidence for all CT signs and the overall diagnosis. AUC values between 0.5 and 0.75 have little to no discriminatory power, while values between 0.75 and 0.85 have moderate discriminatory power, and values above 0.85 show strong discriminatory power [12]. Stepwise logistic regression by using AUC criterion was performed to determine the best predictors of GI tract injury among the CT signs [13]. Inter-observer variability was evaluated by computation of weighted k with CIs using Fleiss' method. Those k values exceeding 0.8 were considered near complete agreement, 0.61 – 0.8 strong, 0.41 – 0.6 moderate, 0.21 – 0.4 fair, and less than 0.2 poor agreement. Calculations were performed by using JMP software version 11 (SAS Institute, Carry, NC, USA)

Results

Four hundred thirty adult patients with a penetrating wound to the torso were admitted between October 2011 and April 2013. Emergent surgery following admission without preceding CT was required in 33.4 % (144/430) based on clinical

Table 2 Diagnostic measures with 95 % confidence intervals for all CT signs, the overall CT diagnosis of GI injury, and prediction of the need for surgery for GI injury

All patients	Sensitivity		Specificity		Accuracy		PPV		NPV	
	%	95 % CI	%	95 % CI	%	95%CI	%	95 % CI	%	95 % CI
Direct signs										
Leakage of enteric contrast *	**29**	15-47	**100**	97-100	**87**	81-92	**100**	68-100	**86**	79-91
Leakage of GI content	**34**	21-51	**99**	96-100	**86**	81-91	**92**	67-99	**85**	79-90
Bleeding into GI lumen	**9**	3-23	**99**	95-100	**81**	75-87	**60**	23-88	**81**	75-86
Discontinuity of GI wall	**43**	28-59	**99**	95-100	**87**	82-92	**88**	66-97	**87**	81-91
Intramural air	**11**	5-26	**98**	94-99	**80**	74-86	**57**	25-84	**81**	74-86
GI wall thickening †	**74**	58-86	**95**	90-97	**91**	86-95	**79**	62-89	**93**	88-97
Wound track extending up to GI wall **	**94**	81-98	**80**	73-86	**83**	77-89	**55**	42-67	**98**	94-100
Indirect signs										
Peritoneal violation	**86**	71-94	**60**	52-68	**65**	58-73	**36**	26-46	**94**	87-98
Retroperitoneal violation	**60**	44-74	**75**	67-82	**72**	65-79	**38**	27-51	**88**	81-93
Free air at injury site	**77**	61-88	**75**	67-82	**75**	69-82	**44**	33-57	**93**	86-96
Free air away from injury site	**54**	38-70	**90**	84-94	**65**	60-71	**59**	42-74	**88**	82-93
Free intraperitoneal fluid	**60**	44-74	**74**	66-80	**71**	64-78	**37**	26-50	**88**	80-93
Mesenteric hematoma	**54**	38-70	**97**	93-99	**88**	83-93	**83**	63-93	**89**	83-93
Active mesenteric hemorrhage	**3**	1-15	**99**	96-100	**80**	74-86	**50**	9-91	**80**	74-86
Solid organ injury	**34**	21-51	**72**	64-79	**64**	57-72	**24**	14-37	**81**	73-87
Peritoneal thickening or enhancement	**3**	1-15	**100**	97-100	**80**	74-86	**100**	21-100	**80**	73-85
Overall CT diagnosis	**91**	78-97	**91**	85-95	**91**	87-95	**73**	58-84	**98**	93-99
Stab injury	**77**	46-95	**91**	82-96	**84**	72-96	**56**	31-78	**96**	90-99
Ballistic injury	**100**	85-100	**92**	81-98	**96**	92-100	**85**	65-96	**100**	92-100
Prediction for the need for surgery	**94**	81-98	**93**	87-96	**93**	89-97	**76**	61-87	**98**	95-100
Surgically proven group (77/171 patients)	Sensitivity		Specificity		Accuracy		PPV		NPV	
	%	95 % CI	%	95 % CI	%	95 % CI	%	95 % CI	%	95 % CI
Direct signs										
Leakage of enteric contrast *	**29**	15-47	**100**	91-100	**69**	58-81	**100**	68-100	**65**	52-76
Leakage of GI content	**34**	21-51	**98**	88-100	**69**	59-79	**92**	67-99	**64**	52-75
Bleeding into GI lumen	**9**	3-23	**98**	88-100	**58**	47-69	**75**	30-95	**57**	45-68
Discontinuity of GI wall	**43**	28-59	**95**	84-99	**71**	61-82	**88**	66-97	**67**	54-77
Intramural air	**11**	5-26	**93**	81-98	**56**	45-67	**57**	25-84	**56**	44-67
GI wall thickening †	**74**	58-86	**88**	75-95	**82**	73-90	**84**	67-93	**80**	67-89
Wound track extending up to GI wall **	**94**	81-98	**57**	42-71	**74**	64-84	**65**	51-76	**92**	76-98
Indirect signs										
Peritoneal violation	**86**	71-94	**24**	14-39	**52**	41-63	**48**	36-61	**67**	42-85
Retroperitoneal violation	**60**	44-74	**60**	45-73	**60**	49-71	**55**	40-70	**64**	48-77
Free air at injury site	**77**	61-88	**62**	47-75	**69**	59-79	**63**	48-76	**77**	60-88
Free air away from injury site	**54**	38-70	**86**	72-93	**71**	61-82	**76**	57-89	**69**	56-80
Free intraperitoneal fluid	**60**	44-74	**48**	33-62	**53**	42-64	**49**	35-63	**59**	42-74
Mesenteric hematoma	**54**	38-70	**95**	84-99	**77**	67-86	**91**	71-97	**71**	59-82
Active mesenteric hemorrhage	**3**	1-15	**100**	92-100	**57**	45-68	**100**	21-100	**56**	45-67
Solid organ injury	**34**	21-51	**50**	36-65	**43**	32-54	**36**	22-53	**48**	34-64
Peritoneal thickening or enhancement	**3**	1-15	**100**	92-100	**56**	45-67	**100**	21-100	**55**	44-66
Overall CT diagnosis	**91**	78-97	**76**	62-87	**82**	75-92	**76**	62-87	**91**	78-97
Prediction for the need for surgery	**94**	81-98	**79**	65-89	**86**	78-94	**78**	63-88	**94**	82-99

Bold represents the percentages

* Most specific CT sign

**Most sensitive CT sign

† Most accurate CT sign

Table 3 Demographics and clinical parameters of the study group

	Study group n = 171	Ballistic injury n = 72	Stab wounds n = 99	*P* value	Surgical intervention n = 77	Observation n = 94	*P* value
Age, median (range)	27 (18–57)	28 (18–50)	27 (18–57)	0.98	29 (18–57)	25 (18–49)	0.026
Male	157 (91.81 %)	66 (91.67 %)	91 (91.92 %)	0.95	70 (90.91 %)	87 (92.55 %)	0.70
Wound entry site							
Abdomen	45 (26.32 %)	14 (19.44 %)	31 (31.31 %)	0.08	25 (32.47 %)	20 (21.28 %)	0.10
Thoraco-abdomen	47 (27.49 %)	20 (27.78 %)	27 (27.27 %)	0.94	22 (28.57 %)	25 (26.60 %)	0.77
Flank	59 (34.5 %)	22 (30.56 %)	37 (37.37 %)	0.35	24 (31.17 %)	35 (37.23 %)	0.41
Back	43 (25.15 %)	16 (22.22 %)	27 (27.27 %)	0.45	18 (23.38 %)	25 (26.60 %)	0.63
Pelvis	25 (14.62 %)	22 (30.56 %)	3 (3.03 %)	<0.001	12 (15.58 %)	13 (13.83 %)	0.75
Single entry site	89 (52.05 %)	37 (51.39 %)	52 (52.53 %)	0.88	39 (50.65 %)	50 (53.19 %)	0.74
Multiple entry site	82 (47.95 %)	35 (48.61 %)	47 (47.47 %)	0.88	38 (49.35 %)	44 (46.81 %)	0.74
Surgery	77 (45.03 %)	35 (48.61 %)	42 (42.42 %)	0.42			
Observation	94 (54.97 %)	37 (51.39 %)	57 (57.58 %)	0.42			
SBP, median (range)	136 (59–216)	140 (91–216)	134 (59–204)	0.04	136 (59–216)	137 (92–197)	0.31
MAP, median (range)	101 (45–153)	103 (68–141)	99 (45–153)	0.08	100 (45–153)	101 (62–138)	0.53
Heart rate, median (range)	95 (52–150)	97 (52–146)	92.5 (57–150)	0.50	95 (53–150)	97 (52–146)	0.41
RR, median (range)	22 (5–42)	22 (6–41)	21 (5–42)	0.70	22 (11–42)	21.5 (5–37)	0.40
Hematocrit, median (range)	39.5 (22.6–49)	39 (25.6–48.2)	40 (22.6–49)	0.23	39.5 (22.6–49)	40.3 (27.7–48.2)	0.70
INR, median (range)	1.1 (0.8–1.8)	1 (0.8–1.3)	1.1 (0.9–1.8)	0.83	1.1 (0.9–1.8)	1 (0.8–1.3)	0.49
Prothrombin time, median (range)	13.7 (11.9–21.5)	13.8 (11.9–16)	13.6 (11.9–21.5)	0.53	13.7 (11.9–21.5)	13.6 (11.9–16.5)	0.26
Lactate, median (range)	3.8 (0.8–12.8)	3.8 (0.9–10.6)	3.8 (0.8–12.8)	0.80	3.5 (1.1–10.5)	4.2 (0.8–12.8)	0.15
GCS, median (range)	15 (3–15)	15 (3–15)	15 (3–15)	0.74	15 (3–15)	15 (3–15)	0.97
RTS, median (range)	7.84 (3.22–7.84)	7.84 (4.09–7.84)	7.84 (3.22–7.84)	0.95	7.84 (4.09–7.84)	7.84 (3.22–7.84)	0.020
ISS, median (range)	10 (1–35)	15.5 (1–35)	10 (1–35)	<0.001	14 (1–35)	9 (1–35)	<0.001
High ISS (≥16)	51 (29.82 %)	36 (50.00 %)	15 (15.15 %)	<0.001	36 (46.75 %)	15 (15.96 %)	<0.001
Abdominal AIS, median (range)	1 (0–5)	2 (0–5)	1 (0–5)	<0.001	3 (0–5)	1 (0–5)	<0.001
High abdominal AIS (≥**3)**	51 (29.82 %)	31 (43.06 %)	20 (20.20 %)	0.001	41 (53.25 %)	10 (10.64 %)	<0.001
Thoracic AIS, median (range)	1 (0–5)	0 (0–4)	1 (0–5)	0.13	3 (0–5)	1 (0–4)	0.24
Brain AIS, median (range)	0 (0–4)	0 (0–4)	0 (0–3)	0.79	0 (0–4)	0 (0–1)	0.20
TRISS, median (range)	0.99 (0.573–0.997)	0.984 (0.573–0.994)	0.99 (0.646– 0.997)	<0.001	0.983 (0.573–0.994)	0.99 (0.646–0.997)	<0.001
ASCOT, median (range)	0.994 (0.317–1)	0.99 (0.317–1)	0.995 (0.962–1)	<0.001	0.99 (0.317–1)	0.995 (0.907–1)	<0.001
Length of stay (days), median (range)	3.5 (0.2–41.9)	6.6 (0.2–41.9)	2.7 (0.2–25.6)	<0.001	6.6 (0.5–41.9)	1.75 (0.2–30.9)	<0.001
ICU length of stay (days), median (range)	0 (0–25.7)	0 (0–25.7)	0 (0–9.93)	0.021	0 (0–25.7)	0 (0–14.6)	0.006

SBP - systolic blood presseure, MAP - mean arterial pressure, RR - respiratory rate, GCS - Glasgow coma scale, RTS - revised trauma score, ISS - injury severity score, AIS - abbreviated injury scale, TRISS - trauma and injury severity score, ASCOT - a severity characterization of trauma, *P* value by Wilcoxson rank-sum test and chi-square test or Fisher's exact test indications, as shown in Fig. 1. The most common cause for surgery was hemodynamic instability. Superficial injuries in 5.1 % (22/430) of patients obviated the need for CT. Two hundred forty-seven consecutive patients (57.4 %, 247/430,) with potential injuries to the GI tract identified prospectively underwent CT following admission. The attending trauma surgeon determined the need for operative management based on the CT results and clinical findings with concern for the presence of GI injury, diaphragmatic injury, high-grade solid organ injury, or vascular injury. The remaining patients were managed non-operatively. Seventy-six patients 30.8 % (76/247) were lost to follow-up and were excluded from the study. The study group consisted of 171 patients; the demographic and clinical parameters collected from the trauma registry are shown in Table 3.

Forty-five percent (77/171) of patients underwent operative management. Surgery was performed for suspicion of GI injury in 49 patients, GI and another injury in five patients, and non-GI injury in 23 patients. Among the surgeries for the suspected GI injury group (n = 54), GI injury was indicated by CT in 42 patients, and despite negative CT for bowel injury, it was indicated by clinical or laboratory results in 12 patients. For patients who underwent surgery based only on clinical or laboratory results, surgery was performed on admission in six patients and for failed observation in six patients. Table 4 shows the outcome, radiological, and surgical findings.

Ninety-one percent (70/77) of patients undergoing operative management had CT signs of peritoneal and/or retroperitoneal violation that was confirmed at surgery in 92 % of patients (71/77). Thirty-five patients (35/171, 20.5 %) had surgically proven injuries to the GI tract (22/35 ballistic, 63 %; 13/35 stab, 37 %; $p = 0.005$), consisting of 85 injury sites, including 18 gastric, 34 intraperitoneal small intestinal, one retroperitoneal duodenal, 23 intraperitoneal colonic, five retroperitoneal colonic, and four rectal injuries. Nineteen patients had a single and 16 had multiple GI injury sites. Partial-thickness GI injury occurred in 11 % (4/35) of patients and only 3 % (1/35) had an intestinal wall aberration that did not require repair. Thirty of the 94 patients (31.9 %) selected for observation based on MDCT had CT signs of peritoneal and/or retroperitoneal violation. None of these 94 patients had a missed GI injury on clinical follow up. Median follow-up time was 16 days (range, 5–150 days).

Diagnostic performance of MDCT signs

Table 2 summarize the diagnostic measures of the CT signs (Figs. 3 and 4) and the overall CT diagnosis for GI injury compared to clinical outcomes. CT had a high sensitivity, specificity, and accuracy for the overall diagnosis of GI injury and the radiologist's prediction for the need of surgical intervention for GI injury among all patients who underwent CT. However, among the patients who required surgery, overall performance of CT in predicting a GI injury and need for surgery decreased.

Table 5 displays the AUCs for each CT sign and the overall CT diagnosis for GI injury. Overall, CT had a strong discriminatory power for the diagnosis of GI injury: AUCs were 0.97 (95 % CI: 0.95, 1.0) for all patients and 0.94 (95 % CI: 0.88, 0.99) for those with surgically proven injuries.

Table 4 Outcome, MDCT, and surgical findings of patients who underwent laparotomy based on clinical or laboratory results

Case	Mechanism	Five-point confidence scale	Indication for surgery	Injuries detected by CT	Injuries detected at surgery	Outcome
1	SW (M)	1	Peritonitis	Superficial wounds	Peritoneal SH	NT
2	SW	2	Worsening abdominal pain	Retrocecal hematoma	Caecal perforation	T
3	SW	1	Worsening abdominal pain and tenderness	Right diaphragm injury, hemothorax, hemoperitoneum	Right diaphragm and liver injury	T
4	SW	1	Lack of abdominal fat and indeterminate CT for peritoneal violation	Superficial wound	No peritoneal violation	Neg
5	SW (M)	1	Hypotension and tachycardia	Right diaphragm injury	Liver and right diaphragm injury	T
6	SW	1	Hypotension	Active bleeding liver injury	Active bleeding liver injury	T
7	SW	1	Fever and abdominal pain	Abdominal wall hematoma	Negative	Neg
8	SW	1	Drop in hematocrit and hyperlactemia	Moderate low attenuation fluid	Peritoneal violation and SH	NT

NT - non-therapeutic laparotomy, M - multiple SW, Neg - negative laparotomy, SW - stab wound, GSW - gunshot wound, Y - yes, N - no, SH - small amount of hemoperitoneum, T - therapeutic laparotomy,

Five-point confidence scale for bowel injury: 1 - definitely absent, 2 - possibly present but unlikely, 3 - equivocal, 4 - likely present, 5 - definitely present

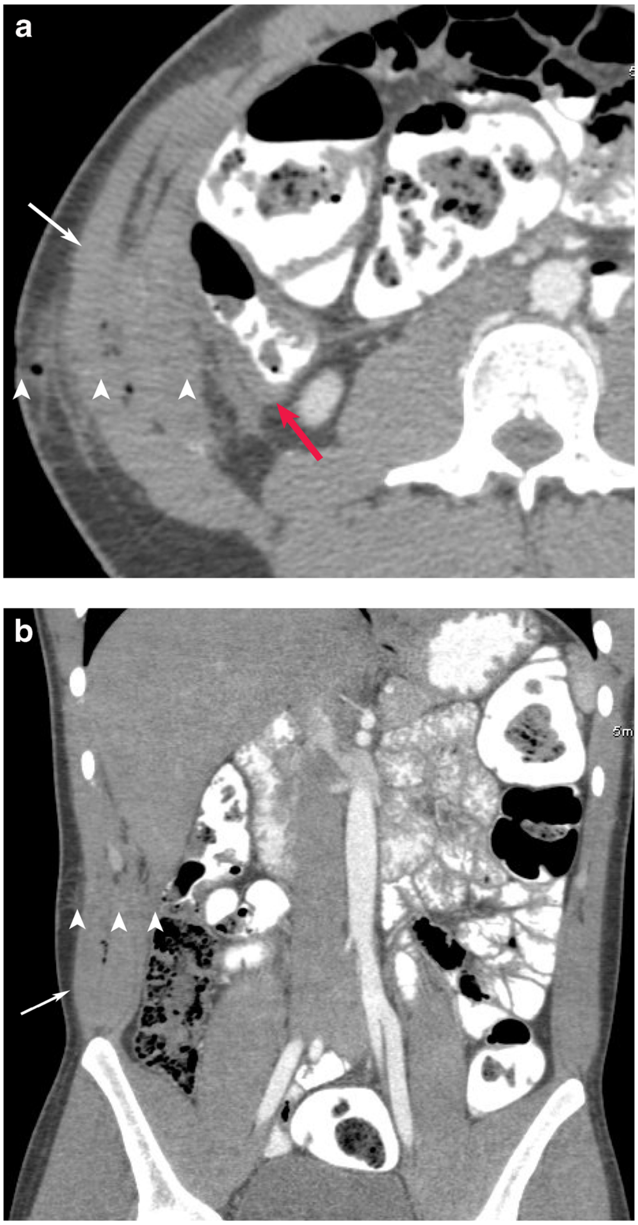

Fig. 3 Stab wound to right flank demonstrating wound tract extending up to bowel. **a.** Axial and **b.** Coronal reformat CT images demonstrate a wound tract (arrowheads) outlined by hematoma, gas bubbles extending from the skin up to proximal ascending colon. Colonic wall thickening (red arrow) and an abdominal muscle hematoma (white arrows) is also seen. At surgery a full thickness ascending colon injury was repaired

The stratum-specific likelihood ratio for each level of confidence and the overall CT diagnosis of GI injury are summarized in Table 6. The overall CT diagnosis was equivocal in 7 % (12/171) of patients. False positive cases occurred at a rate of 7 % (12/171), being rated as "equivocal" in 4.7 % (8/171,) and "GI injury likely present" in 2.3 % (4/171) of patients. The details of the outcomes, CT, and surgical findings are shown in Table 7. All patients with false-positive CT diagnosis had a wound tract extending up to the bowel wall. Only two negative and one non-therapeutic laparotomy occurred in the false positive group. Therapeutic laparotomy was performed of other injuries diagnosed by CT in the rest of the nine patients. Three patients (3/171, 1.8 %) had a false

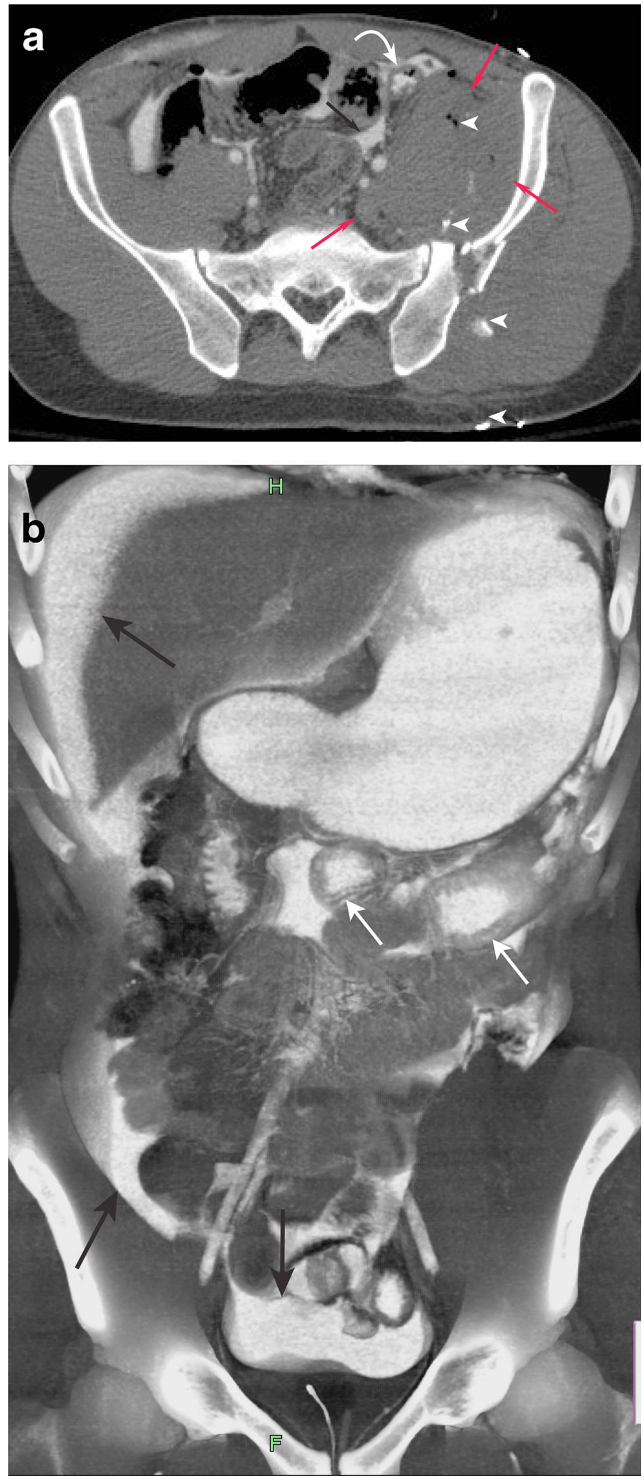

Fig. 4 Gunshot wound to left pelvis with rectal contrast material extravasation. **a.** Axial and **b.** Coronal reformat CT images demonstrate a wound tract (arrowheads) outlined by hematoma, bullet and bone fragments. There is both descending colon (curved arrow) and jejunal wall (white arrows) thickening. Rectal contrast material (black arrow) extravasation is seen throughout the peritoneum

Table 5 Areas under the receiver operating characteristic curves of the CT signs and overall CT diagnosis of penetrating GI injury[a]

CT signs	All patients		Surgical subgroup	
	AUC	95 % CI	AUC	95 % CI
Leakage of oral or rectal contrast	0.66	0.62–0.76	0.65	0.54–0.77
Leakage of GI content	0.73	0.67–0.80	0.72	0.62–0.82
Bleeding into GI lumen	0.61	0.53–0.68	0.58	0.47–0.69
Discontinuity of GI wall	0.72	0.65–0.78	0.70	0.60–0.80
Intramural air	0.61	0.53–0.68	0.57	0.47–0.68
GI wall thickening*	0.85	0.80–0.91	0.84	0.75–0.92
Wound track extending up to GI wall*	0.92	0.87–0.96	0.83	0.75–0.92
Peritoneal violation	0.77	0.71–0.84	0.59	0.48–0.70
Retroperitoneal violation	0.70	0.63–0.77	0.60	0.50–0.71
Free air at injury site	0.76	0.70–0.83	0.69	0.59–0.80
Free air away from injury site	0.73	0.67–0.80	0.70	0.60–0.81
Free intraperitoneal fluid	0.69	0.62–0.76	0.55	0.44–0.67
Mesenteric hematoma	0.80	0.74–0.86	0.78	0.69–0.87
Active mesenteric haemorrhage	0.54	0.47–0.62	0.54	0.43–0.66
Solid organ injury	0.53	0.45–0.60	0.59	0.48–0.70
Peritoneal thickening or enhancement	0.53	0.45–0.60	0.53	0.42–0.64
Overall CT diagnosis	0.97	0.95–1.00	0.94	0.88–0.99

*Wound track extending up to the GI wall and GI wall thickening had the strongest discriminatory power for GI injury

[a] Stepwise regression was used as a preliminary means of selecting the fewest and most influential covariates from among the 16 CT signs. Cross-validation was applied on the generalized regression model with the Hastie, Tibshirani, and Friedman's [13] Lasso to narrow down the key signs to be "leakage GI content," "GI wall thickening," and "wound track extending up to GI wall." The diagnostic performance of the combination of the 3 key CT signs demonstrated as an ROC area under the curve of 0.976 (95 % CI: 0.875, 0.996) on the validation set, which was not significantly different from the training set ($p = 0.44$)

Cut-off points for the five-point confidence scale were chosen from all possible cut points so the sensitivity, specificity, and correct classification rates were maximized [12]

negative diagnosis for GI injury, all of whom were rated as "possible but unlikely" to have GI injury. Six patients failed observation requiring laparotomy in five patients and laparoscopy in one. Only 1.2 % (2/171) of patients had a delayed therapeutic laparotomy for a GI injury. No complication related to laparotomy occurred among the false positive CT or the six failed observation patients.

Table 6 The overall CT diagnosis stratum-specific likelihood ratio for presence of GI injury

Overall CT diagnosis of GI injury for all patients	GI injury present	GI injury absent	Stratum specific LR with 95 % CI	
GI injury definitely present	20	0	151.43	9.37-2446
GI injury likely present	8	4	6.98	2.36-20.63
Equivocal	4	8	1.96	0.66-5.78
Possible but unlikely present	3	26	0.48	0.17-1.40
GI injury definitely absent	0	98	0.02	0.001-0.29
Total	35	136		

Table 8 shows the inter-observer variability overall and performance for the individual CT signs of the six radiologists. Leakage of oral or rectal contrast material showed nearly complete agreement and acceptable reliability. Peritoneal violation and solid organ injury showed strong agreement and reliability. Leakage of GI content, discontinuity of GI wall, GI wall thickening, wound track extending to GI wall, and free air away from the injury site showed moderate agreement and moderate to low reliability. Bleeding into the GI lumen and intramural air showed fair to poor agreement and reliability.

Discussion

Patients with penetrating injury to the torso not requiring immediate mandatory laparotomy can be managed safely with SNOM [6–8, 15–20]. Multiple techniques, including serial clinical examination, local wound exploration followed by peritoneal lavage if there is peritoneal violation, ultrasound, and laparoscopy, are useful in identifying important occult injuries prior to clinical deterioration [2–8, 15–18]. At our

Table 7 Outcome, MDCT, and surgical findings of patients with false positive and false negative interpretations

False Positive	Mechanism	5-point confidence scale	Binary scale need for surgery	Peritoneal Violation by CT	Injuries seen by CT	Injuries at Surgery	Outcome
1	SW (M)	3	N	Y	Liver injury, small bowel injury?	Liver laceration, SH	T
2	SW	3	Y	Y	LH, gastric injury	Liver laceration, bleeding abdominal wall artery, LH	T
3	SW	3	Y	Y	Ascending colon?	Retroperitoneal hematoma	NT
4	SW	3	N	Y	Liver injury, pericardial effusion	Left diaphragm, liver injury, MH, serous pericardial effusion	T
5	SW (M)	3	Y	Y	Left diaphragm, left kidney, spleen, descending colon?	Liver, spleen, left diaphragm	T
6	GSW	4	Y	Y	Bladder, small bowel ?, adenexa	Intra and extraperitoneal bladder injury, right ovarian injury, MH	T
7	SW	4	Y	Y	Descending colon injury?, retroperitoneal hematoma	Negative	Neg
8	SW	3	Y	Y	SH, ascending colon injury?	Liver laceration	T
9	SW (M)	4	N	Y	Left retroperitoneal hematoma, ascending colon injury?	Retroperitoneal hematoma, peritoneal violation	NT
10	GSW (M)	3	N	Y	Right diaphragm, liver, right kidney, descending colon?	Right diaphragm, right renal and liver laceration	T
11	GSW (M)	4	Y	N	Anorectal injury	No Surgery, clinical follow-up	NA
12	GSW (M)	3	N	Y	Liver Laceration, SH, small bowel?	No Surgery, clinical follow-up	NA
False Negative							
1	SW	2	N	Y	Left diaphragm, MH	Gastric injury, left diaphragm	T
2	SW	2	N	N	Active bleeding	Caecal injury	T
3	SW	2	N	Y	SH, gastric wall thickening	Gastric injury	T

LH - Large amount of hemoperitoneum, NT – Non-therapeutic laparotomy, M – multiple SW or GSW, MH - moderate amount of hemoperitoneum, Neg - Negative laparotomy, NA- Not applicable, SW – Stab wound, GSW – Gunshot wound, Y – Yes, N – No, SH – small amount of hemoperitoneum, T – Therapeutic laparotomy,

5 - Point confidence scale – 1- definitely absent, 2 - possibly present but unlikely, 3 - equivocal, 4 - likely present, 5 - definitely present

institution, MDCT is the technique of choice to help discriminate hemodynamically stable patients who can be safely observed from those who require surgery. Unlike previous results reported by Inaba et al. [2], in our study, the sensitivity (31 % vs. 77 %) and specificity (84 % vs. 91 %) for injuries diagnosed by CT that require surgical intervention was much higher. Though these two studies cannot be directly compared, major differences that may have contributed to these results are administration of oral and rectal contrast to opacify the bowels.

Diagnosis of penetrating GI injury is challenging because wound trajectory and depth are difficult to predict by physical examination alone. Thus, CT has an important role in establishing the trajectory of the bullet or knife and demonstrating peritoneal violation and GI injury. It is essential to neither miss nor over-diagnose GI injuries, since both may lead to increased morbidity and mortality [20, 21]. Peritoneal violation and solid organ injury do not always require laparotomy [3, 21]. Penetrating GI injury, on the other hand, has a high likelihood for potentially life-threatening complications such as peritonitis and abscess.

This study demonstrates that MDCT is highly sensitive, specific, and accurate in diagnosing penetrating GI injury and in determining the need for surgical management. Leakage of oral or rectal contrast is the most specific CT sign for a GI injury. However, the absence of this sign does not exclude a GI injury. Most of the other direct CT signs evaluated were also highly specific for GI injury but had low sensitivity, suggesting that these signs are rarely present or are difficult to detect. No single CT sign was both highly sensitive and specific. GI wall thickening had moderate sensitivity, high specificity, and showed moderate inter-observer agreement contributing to the highest accuracy among the direct signs. However, a combination of the most accurate CT signs, including GI wall thickening, leakage of GI content, and the wound tract extending up to the bowel wall increased diagnostic

Table 8 Inter-observer variability across three radiologists for all CT signs, overall CT diagnosis, and prediction for the need of surgery

CT signs					CT signs				
Direct signs		Statistic	SE	P value/95 % CI(LL-UL)	Indirect signs		Statistic	SE	P value/95 % CI(LL-UL)
Overall CT diagnosis					Peritoneal violation				
Kappa	reader 1 and reader 2	0.52	0.05	p < 0.0001	Kappa	reader 1 and reader 2	0.61	0.05	p < 0.0001
Kappa	reader 1 and reader 3	0.61	0.05	p < 0.0001	Kappa	reader 1 and reader 3	0.70	0.04	p < 0.0001
Kappa	reader 2 and reader 3	0.48	0.05	p < 0.0001	Kappa	reader 2 and reader 3	0.6	30.05	p < 0.0001
Kappa	average	0.53	0.03	p < 0.0001	Kappa	average	0.65	0.03	p < 0.0001
Kalpha*		0.82	0.03	95%CI(0.76-0.88)	Kalpha*		0.83	0.03	95%CI(0.76-0.82)
Prediction of the need of surgery					Retroperitoneal violation				
Kappa	reader 1 and reader 2	1.00	0.00	p < 0.0001	Kappa	reader 1 and reader 2	0.66	0.05	p < 0.0001
Kappa	reader 1 and reader 3	1.00	0.00	p < 0.0001	Kappa	reader 1 and reader 3	0.60	0.06	p < 0.0001
Kappa	reader 2 and reader 3	1.00	0.00	p < 0.0001	Kappa	reader 2 and reader 3	0.60	0.06	p < 0.0001
Kappa	average	1.00	0.04	p < 0.0001	Kappa	average	0.62	0.04	p < 0.0001
Kalpha*		1.00	0.00	95%CI(1.00-1.00)	Kalpha*		0.68	0.04	95%CI(0.60-0.77)
Leakage of oral or rectal contrast					Free air at injury site				
Kappa	reader 1 and reader 2	0.87	0.05	p < 0.0001	Kappa	reader 1 and reader 2	0.56	0.06	p < 0.0001
Kappa	reader 1 and reader 3	0.90	0.04	p < 0.0001	Kappa	reader 1 and reader 3	0.55	0.06	p < 0.0001
Kappa	reader 2 and reader 3	0.86	0.05	p < 0.0001	Kappa	reader 2 and reader 3	0.43	0.06	p < 0.0001
Kappa	average	0.88	0.03	p < 0.001	Kappa	average	0.51	0.04	p < 0.0001
Kalpha*		0.76	0.1	95%CI(0.52-0.91)	Kalpha*		0.59	0.05	95%CI(0.49-0.68)
Leakage of GI content					Free air away from injury site				
Kappa	reader 1 and reader 2	0.44	0.09	p < 0.0001	Kappa	reader 1 and reader 2	0.53	0.07	p < 0.0001
Kappa	reader 1 and reader 3	0.44	0.07	p < 0.0001	Kappa	reader 1 and reader3	0.58	0.07	p < 0.0001
Kappa	reader 2 and reader 3	0.40	0.08	p < 0.0001	Kappa	reader 2 and reader 3	0.47	0.07	p < 0.0001
Kappa	average	0.43	0.03	p < 0.0001	Kappa	average	0.53	0.04	p < 0.0001
Kalpha*		0.64	0.07	95%CI(0.48-0.78)	Kalpha*		0.62	0.06	95%CI(0.47-0.73)
Bleeding into GI lumen					Free intraperitoneal fluid				
Kappa	reader 1 and reader 2	0.20	0.0806	0.0176	Kappa	reader 1 and reader 2	0.63	0.06	p < 0.0001
Kappa	reader 1 and reader 3	0.13	0.0869	0.1201	Kappa	reader 1 and reader 3	0.66	0.05	p < 0.0001
Kappa	reader 1 and reader 3	0.13	0.0869	0.1201	Kappa	reader 1 and reader 3	0.66	0.05	p < 0.0001
Kappa	average	0.16	0.0311	p < 0.0001	Kappa	average	0.65	0.04	p < 0.0001
Kalpha*		0.19	0.09	95%CI(0.03-0.37)	Kalpha*		0.73	0.04	95%CI(0.64-0.81)

Table 8 (continued)

CT signs					CT signs				
Direct signs		Statistic	SE	P value/95 % CI(LL-UL)	Indirect signs		Statistic	SE	P value/95 % CI(LL-UL)
Discontinuity of GI wall					Mesenteric hematoma				
Kappa	reader 1 and reader 2	0.35	0.08	p < 0.0001	Kappa	reader 1 and reader 2	0.35	0.08	p < 0.0001
Kappa	reader 1 and reader 3	0.33	0.08	0.0001	Kappa	reader 1 and reader 3	0.38	0.08	p < 0.0001
Kappa	reader 2 and reader 3	0.25	0.08	0.0048	Kappa	reader 2 and reader 3	0.33	0.08	p < 0.0001
Kappa	average	0.31	0.03	p < 0.0001	Kappa	average	0.35	0.03	p < 0.0001
Kalpha*		0.46	0.08	95%CI(0.30-0.61)	Kalpha*		0.39	0.15	95%CI(0.31-0.59)
Intramural air					Active mesenteric hemorrhage				
Kappa	reader 1 and reader 2	0.05	0.05	0.23	Kappa	reader 1 and reader 2	0.40	0.16	0.0193
Kappa	reader 1 and reader 3	0.16	0.08	0.04	Kappa	reader 1 and reader 3	0.26	0.16	0.0994
Kappa	reader 2 and reader 3	0.25	0.09	0.01	Kappa	reader 2 and reader 3	0.45	0.14	0.0030
Kappa	average	0.15	0.03	p < 0.0001	Kappa	average	0.38	0.03	0.0000
Kalpha*		0.26	0.08	95%CI(0.09-0.43)	Kalpha*		0.39	0.15	95%CI(0.07-0.67)
GI wall thickening					Peritoneal thickening or enhancement				
Kappa	reader 1 and reader 2	0.38	0.07	p < 0.0001	Kappa	reader 1 and reader 2	-0.01	0.00	0.0533
Kappa	reader 1 and reader 3	0.42	0.07	p < 0.0001	Kappa	reader 1 and reader 3	-0.01	0.00	0.1624
Kappa	reader 2 and reader 3	0.36	0.07	p < 0.0001	Kappa	reader 2 and reader 3	-0.01	0.00	0.1624
Kappa	average	0.39	0.03	p < 0.0001	Kappa	average	-0.01	0.04	0.3901
Kalpha*		0.55	0.06	95%CI(0.40-0.66)	Kalpha*		-0.01	0.07	95%CI(-0.02-0.00)
Wound track extending up to GI wall					Solid organ injury				
Kappa	reader 1 and reader 2	0.52	0.05	p < 0.0001	Kappa	reader 1 and reader 2	0.72	0.053	p < 0.0001
Kappa	reader 1 and reader 3	0.52	0.05	p < 0.0001	Kappa	reader 1 and reader 3	0.76	0.05	p < 0.0001
Kappa	reader 2 and reader 3	0.42	0.06	p < 0.0001	Kappa	reader 2 and reader 3	0.80	0.0453	p < 0.0001
Kappa	average	0.49	0.03	p < 0.0001	Kappa	average	0.76	0.0389	p < 0.0001
Kalpha*		0.66	0.05	95%CI(0.56-0.75)	Kalpha*		0.84	0.04	95%CI(0.77-0.90)

Note: Average is the weighted average kappa computed from equation (18.48, p. 614) of JL Fleiss, B Levin, and MC Paik (2003), Statistical methods for Rates and Proportions, 3rd Wiley:New York, Chapter 18

* Krippendorff Alpha (Kalpha) reported 95 % Confidence Intervals instead of p-values. P-values did not apply because the sampling distribution of Kalpha had to be determined by bootstrapping. The Lower (LL) and Upper (UL) Limits are ranges where the true Kalpha reliability values should fall

Details for determining the sampling distribution of Kalpha can be found in Hayes and Krippendorff [14] accuracy for the presence of penetrating GI injury compared to any single sign. Analysis of the surgically proven subgroup to evaluate the accuracy of CT for patients with higher risk for GI injury based on their clinical presentation that ultimately indicated the need for operation showed a higher percentage of subjects with ballistic injury as well as a higher percentage of subjects with peritoneal and retroperitoneal violation. The major benefit of this subgroup analysis is the direct comparison of CT findings with the surgical reference standard, which is more reliable than clinical observation and follow-up. The diagnostic performance of CT in the surgically managed subgroup suggests that in patients with generally higher clinical risks, MDCT was sensitive for the diagnosis of penetrating GI injury, thus remaining a good screening tool to select patients for surgical management or close observation; however, because specificity is reduced, the risk of non-therapeutic laparotomy based on a CT is considerable. Nevertheless, certain CT signs still demonstrated very high specificity among the surgically managed subgroup, including leakage of contrast, leakage of GI content, disruption of GI wall, and bleeding into the GI lumen, and probably warrant the need for surgical treatment.

Our study demonstrates that CT can be a reliable technique to discriminate between patients requiring surgery versus observation following both gunshot and stab wounds with entry sites in the torso. It is important to take into consideration the injury mechanism, kinetic energy, and exact entry site location in the torso to determine the likelihood of a GI injury. The radiologists reviewing the studies had varying experience from 2 to 21 years in evaluating trauma cases but there was good inter-observer agreement for the various CT signs and predicting the need for surgery. The low false negative and false positive rates for a GI injury of 1.8 % and 7 %, respectively, are well below the rates reported for other techniques routinely used at other trauma centres for SNOM of penetrating torso injury.

Limitations

Our study has some limitations. This is a prospective but entirely observational single-institutional study. All patients were managed according to the institutional protocol. As 31 % (76/247) of patients selected for observation did not return to the follow-up clinic and were excluded from the study group, it is possible that patients with missed significant injury were not accounted for. Enteric contrast material was not administered to 11.7 % of patients in the study group, which may have influenced the diagnosis of a GI injury by CT. Though there is a potential to aspirate ingested contrast material, this was not observed in our study.

Conclusion

The most accurate CT sign to indicate the need for surgery for GI injury after penetrating torso trauma is GI wall thickening. The combination of GI wall thickening, leakage of GI content, and wound tract extending up to the bowel wall increased diagnostic accuracy. A low false negative rate and the small number of GI injuries among patients failing observation in our study demonstrate that CT is a useful technique to triage patients with GI injury to surgery or observation.

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