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Can multidetector CT detect the site of gastrointestinal tract injury in trauma? – A retrospective study

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PURPOSE
We aimed to assess the performance of computed tomography (CT) in localizing site of traumatic gastrointestinal tract (GIT) injury and determine the diagnostic value of CT signs in site localization.

METHODS
CT scans of 97 patients with surgically proven GIT or mesenteric injuries were retrospectively reviewed by radiologists blinded to surgical findings. Diagnosis of either GIT or mesenteric injuries was made. In patients with GIT injuries, site of injury and presence of CT signs such as focal bowel wall hyperenhancement, hypoenhancement, wall discontinuity, wall thickening, extramural air, intramural air, perivisceral infiltration, and active vascular contrast leak were evaluated.

RESULTS
Out of 97 patients, 90 had GIT injuries (70 single site injuries and 20 multiple site injuries) and seven had isolated mesenteric injury. The overall concordance between CT and operative findings for exact site localization was 67.8% (61/90), partial concordance rate was 11.1% (10/90), and discordance rate was 21.1% (19/90). For single site localization, concordance rate was 77.1% (54/70), discordance rate was 21.4% (15/70), and partial concordance rate was 1.4% (1/70). In multiple site injury, concordance rate for all sites of injury was 35% (7/20), partial concordance rate was 45% (9/20), and discordance rate was 20% (4/20). For upper GIT injuries, wall discontinuity was the most accurate sign for localization. For small bowel injury, intramural air and hyperenhancement were the most specific signs for site localization, while for large bowel injury, wall discontinuity and hypoenhancement were the most specific signs.

CONCLUSION
CT performs better in diagnosing small bowel injury compared with large bowel injury. CT can well predict the presence of multiple site injury but has limited performance in exact localization of all injury sites.

Traumatic gastrointestinal tract (GIT) injuries are uncommon, representing less than 10% of all injuries in trauma patients (1), with a higher incidence in penetrating rather than blunt trauma (2). Small bowel is the most common site of alimentary tract injury in trauma followed by colorectal injuries, while gastroduodenal injuries comprise less than 2% of all injuries in trauma (3). In the current scenario of preferential nonoperative management in trauma, detection of GIT injury remains an important indication for urgent laparotomy as delayed diagnosis and surgery are associated with high morbidity and mortality (4). Also the type of operative management, prognosis, and outcome vary according to the number and site of GIT injuries (5).

Multidetector computed tomography (MDCT) is a proven diagnostic modality for detection of traumatic GIT injuries with a reported sensitivity of 70%–95% and specificity of 92%–100% (6–11). Various CT signs of GIT and mesenteric injuries have been described such as bowel wall discontinuity, extraluminal air (either free or perivisceral), bowel wall thickening, abnormal bowel wall enhancement and intramural air, while mesenteric signs include mesenteric infiltration, active vascular contrast extravasation, beading, and abrupt termination of mesenteric vessels. These signs have reportedly variable incidences, sensitivities, and specificities; but if present, can lead prompt laparotomy and surgical exploration of the GIT to look for direct evidence of injury (12–16).

MDCT with its capabilities of fast scanning, thin-section acquisition, and multiplanar reformatting has greatly enhanced the potential for detecting direct evidence of bowel in-

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juries (17). Previous studies, conducted predominantly in nontraumatic populations, have documented that CT can accurately predict the site of GIT perforation (18–28). However, nearly all literature is focused on nontraumatic GIT perforation secondary to ischemia, malignancy, and inflammatory conditions (18–21, 23–25, 28–31). Only two studies were found to specifically evaluate the predictive value of CT in traumatic GIT perforation, both using older CT scanners such as helical scanner by Kim et al. (21) and two-detector scanner by Cadenas Rodriguez et al. (28). The results of predictive value of CT in detecting site of GIT injuries in nontraumatic cases cannot be directly extrapolated to traumatic GIT perforation, as appendiceal and gastroduodenal perforations secondary to peptic ulcer disease are common in nontraumatic cases, while small bowel injury is the most common site of injury in trauma (19, 20, 22, 24). Secondly, polytrauma patients have multiple sites of GIT injuries and other injuries which can affect diagnostic performance of MDCT in detecting sites of traumatic GIT perforation (13, 23, 32).

Since the diagnostic performance of MDCT and the diagnostic values of various CT signs in localizing site of GIT injury in polytrauma patients have not been evaluated before, the objective of this study was to determine the diagnostic performance of MDCT and the diagnostic value of various CT signs for site localization in traumatic GIT injury.

Main points

- Gastrointestinal tract (GIT) injury is an indication for exploratory laparotomy in trauma. Hence preoperative detection and localization of the site of GIT injury is important.
- MDCT performs better at localizing the site of injury in patients with single site GIT injury compared with patients with multiple site GIT injury.
- MDCT also performs better at localizing small bowel injuries than large bowel injuries.
- For gastroduodenal injuries, presence of wall discontinuity was the single best CT sign for site localization.
- Presence of intramural air (air within the bowel wall) and hyperenhancement helped localize sites of small bowel injuries while hypoenhancement and wall discontinuity were more specific in localizing sites of large bowel injuries.
- Thus, using a combination of CT signs and multiplanar evaluation of the entire GIT, MDCT can well localize sites of traumatic GIT injuries.

Methods

This was a retrospective study conducted at our level 1 trauma center after obtaining prior institutional ethics committee approval. As it was a retrospective study, informed consents of patients were not required. The hospital records from 2012 to 2014 were searched for patients with surgically confirmed GIT or mesenteric injuries who underwent a preoperative contrast-enhanced computed tomography (CECT) in our hospital. Patients with history of surgery prior to referral to our hospital or patients with CECT scans done outside our hospital were excluded from the study. A total of 97 patients fulfilling these criteria were identified. All patients underwent CECT in portal venous phase on either a 40-detector scanner (Somatom, Siemens) or a 64-detector scanner (Definition AS, Siemens). Oral contrast was given in only one patient.

For all patients, 1.5 mm thin section contrast-enhanced CT images were available from PACS and axial and multiplanar reformats were retrospectively evaluated on a three-dimensional workstation (Syngo.via, Siemens) by three radiologists (AP, AK, and SG with 3, 14, 14 years of experience, respectively) who were blinded to the original CT reports and surgical and pathologic findings. The CT images were viewed in both soft tissue window and wide window (W: 1500, C: -500) settings and were evaluated for previously described signs of GIT or mesenteric injuries (Table 1) (Figs. 1–3) (17–19, 21, 37, 39, 40). The individual CT signs were noted as present or absent and CT diagnosis of either a) "GIT injury" or b)

Figure 1. CT coronal reformatted image in a patient with ileal injury shows focal discontinuity *(arrow)* with wall thickening *(arrowhead)* in distal ileal loop.

Table 1. CT signs evaluated for GIT or mesenteric injuries*

No	CT signs	Comments
General signs for presence of GIT injury		
1.	Free air in the abdomen	Pneumoperitoneum/ pneumoretroperitoneum
2.	Blood in the abdomen	Hemoperitoneum/ hemoretroperitoneum
GIT signs		
3.	Focal wall discontinuity (Fig. 1)	Obvious discontinuity seen in mucosal lining or full thickness disruption of bowel
4.	Segmental wall thickening (Fig. 2)	Taken as >5 mm in stomach and >3 mm in noncollapsed bowel
5.	Focal extraluminal air adjacent to stomach/ bowel loop (Fig. 2b)	Seen as mottled air lucencies just outside the hollow viscera
6.	Focal intramural air (Fig. 2 a, b)	Seen as air lucencies within the walls of stomach/ bowel
7.	Focal hypoenhancement (Fig. 2c)	Enhancement less than adjacent loops
8.	Focal hyperenhancement (Fig. 2c)	Enhancement more than psoas major muscle
Perivisceral signs		
9.	Active contrast leak (Fig. 3)	Seen as focal collection of contrast isodense to aorta in initial scans and hyperdense to aorta on delayed scans
10.	Focal infiltration with blood/ fluid in omentum/ mesentery/ mesocolon	

*Modified from Brody et al. (13), Brofman et al. (14), Hanks et al. (16), and Kim et al. (31).
GIT, gastrointestinal tract; CT, computed tomography.

Table 2. Incidence of signs in isolated mesentery injury (n=7) vs. GIT injury (n=90)		
Sign	Incidence in isolated mesentery injury n/N (%)	Incidence in GIT injury n/N (%)
Intramural air	0/7 (0)	62/90 (68.9)
Extraluminal air	0/7 (0)	58/90 (64.4)
Hyperenhancement	0/7 (0)	43/90 (47.8)
Wall discontinuity	0/7 (0)	35/90 (38.9)
Hypoenhancement	1/7 (14.3)	22/90 (24.4)
Wall thickening	2/7 (28.6)	49/90 (54.4)
Pneumoperitoneum/ pneumoretroperitoneum	0/7 (0)	70/90 (77.8)
Hemoperitoneum/ hemoretroperitoneum	7/7 (100)	88/90 (97.8)
Active contrast leak	2/7 (28.6)	6/90 (6.7)
Mesenteric infiltration	7/7 (100)	51/90 (56.7)

GIT, gastrointestinal tract.

"isolated mesentery injury" were given. "GIT injury" referred to patients who had injury to GIT and may or may not have injury to mesentery while "isolated mesentery injury" referred to patients who had only injury to mesentery without any GIT injury.

For patients diagnosed to have GIT injury, the site of injury was noted as stomach, duodenum, jejunum, ileum, cecum, ascending colon, transverse colon, descending colon, sigmoid colon, rectum, multiple (if more than one site of injury could be identified on CT), and unknown (if site of injury could not be localized). For perivisceral changes (omental, mesenteric, or mesocolonic infiltration); the site of infiltration and concordance between site of infiltration and final operative site of GIT injury was also noted separately. Final CT diagnoses were determined by consensus.

Statistical analysis

Final surgical diagnosis was taken as the reference standard and surgical findings were also noted as GIT injury and isolated mesentery injury. The number of GIT injuries (i.e., single or multiple), individual sites of GIT injuries, as well as the type of injury (i.e., gangrene, full thickness tear or serosal tears on surgery) were noted. The overall incidence of GIT injury and isolated mesentery injury on CT was compared with surgical incidences of these injuries to calculate the sensitivity of CT for detecting GIT injury.

For patients with GIT injury, findings were labeled as concordant, discordant, and partially concordant with respect to surgical findings regarding the site of injury. For multiple site perforations, final diagnosis was total concordance only when CT correctly predicted all sites of multiple injuries observed on surgery. When CT correctly predicted some but not all sites of injury, it was labeled as partial concordance. For multiple injuries showing partial concordance, note was made of GIT segment for which CT-surgical concordance was present. The concordance rate for patients with single site and multiple site perforations were calculated separately.

For both single site and multiple site injuries, the number of sites correctly identified on CT versus surgery was used to calculate site-specific CT accuracy. For single site injury, CT accuracy for gastroduodenal, small bowel and large bowel injuries were also calculated separately and the difference in CT accuracy for upper GIT (gastroduodenal) and lower GIT (jejunoileal and large bowel) injury, small and large bowel injury and right-sided colon (cecum, ascending colon, and transverse colon) versus left-sided colon (descending colon to rectum) injury were calculated using Fisher's exact test of probability with $P < 0.05$ considered as significant.

To obtain diagnostic values of these signs for site localization, the sensitivities and specificities of individual signs were calculated directly for single site injury patients; for multiple site injuries only the incidences of these signs in patients with total concordance and partial concordance could be calculated. Thus for single site injury, presence of a particular sign with final diagnosis being totally concordant was taken as true positive (injury present and sign present) and absence of particular sign with final diagnosis being totally concordant was taken as false negative (injury present and sign absent). Presence of a sign with final diagnosis being discordant or partially concordant (injury absent and sign present at discordant site) was taken as false positive and absence of sign with final diagnosis being discordant (injury absent and sign absent) was taken as true negative.

Results

Out of 97 patients analyzed, 87 (89.7%) were men and 10 (10.3%) were women with a median age of 28 years (range, 2–60 years). Eighty-two had blunt trauma (road traffic accident or fall from height) while 15 had penetrating trauma (stab or gunshot wounds). On laparotomy, 90 patients had GIT injury, while seven patients had isolated mesentery injury. Out of 90 patients with GIT injury, 70 had single site injury, while 20 had multiple site injuries. CT identified GIT injuries in 87 out of surgically proven 90 patients, while three patients were misdiagnosed as isolated mesentery injury (false negative for GIT injury). A total of 10 patients were identified to have mesenteric injuries on CT; seven patients were true positive for mesentery injury, while three patients were false negative for GIT injury. Thus the sensitivity of CT for detection of GIT injury was 96.7% (87/90). The incidence of signs in isolated mesentery injury (n=7) and GIT injury (n=90) are depicted in Table 2.

Out of 87 patients detected to have GIT injury on CT, 64 were detected to have single site injury, 12 had multiple site injury, while the site of injury remained unknown in 11 patients. The overall concordance between CT and operative findings for exact site localization was 67.8% (61/90), partial concordance was 11.1% (10/90), and discordance rate was 21.1% (19/90). The concordance rate for single site localization was 54/70 (77.1%), discordance rate was 15/70 (21.4%), while partial concordance was seen in 1/70 (1.4%). Partial concordance was labeled in one patient in whom, a diagnosis of multiple site injury was given on CT (jejunum and ileum), while operative notes showed only ileal injury and CT was thus concordant only for ileum. In multiple site injury (n=20), CT was concordant for all sites of perforation in 35% (7/20), partially concordant (identifying one intraoperative site) in 45% (9/20), and totally discordant in 20% (4/20).

Out of 70 patients with single site injury on surgery, CT correctly localized 54 sites; 11 sites (nine unknown, two only mesentery) were not identified on CT (false negative for site localization) and five lesions were identified as wrong (false positive for site localization). Thus accuracy of CT for single site localization was 77.1% (54/70) and positive predictive value was 91.5%. CT performed better in detecting small bowel than large bowel injuries ($P = 0.011$; Table 3). However, there was no significant difference in CT performance in localizing site in upper GIT (gastroduodenal injuries) versus lower GIT (small and large bowel) injuries and in right-sided colon versus left-sided colon injuries (Table 3).

The overall diagnostic values of individual GIT and perivisceral signs for site localization in single site injuries are given in Table 4, and diagnostic values of signs in gastroduodenal, small bowel and large bowel injury are given in Table 5. For single site injuries, extraluminal air was the most sensitive sign, while intramural air, hypoenhancement, and wall discontinuity were the most specific GIT signs for localization (Table 4). Active contrast leak, a perivisceral sign, was the overall most specific sign for single site localization, but it had a very low sensitivity. For gastroduodenal injury, wall discontinuity was the best sign with highest sensitivity, specificity, positive predictive value, and accuracy. For small bowel injury, intramural air and hyperenhancement were the most specific GIT signs for site localization followed by wall thickening, wall discontinuity, and hypoenhancement. For large bowel injury, wall discontinuity, and hypoenhancement were the most specific GIT signs followed by intramural air (Table 5).

Twenty patients with multiple site injury had a total of 47 sites of GIT injury on surgery. CT correctly identified 28 of 47 sites of GIT injury with 59.6% CT accuracy for multiple site-localization. Overall concordance in multiple site injury (total + partial) was 80%, while discordance was 20% (4/20).

Regarding diagnostic values of signs in multiple site injury, while sensitivity and specificity could not be directly calculated, the incidence of signs in patients with complete and partial concordance were noted. In seven patients with complete concordance, extraluminal air and focal mesenteric infiltration were the most useful signs seen in all seven patients followed by hyperenhancement (5/7) and intramural air (4/7). In nine patients with partial concordance, both extraluminal air and intramural air were seen in seven, followed by hyperenhancement and wall discontinuity seen in six.

Among 90 patients with bowel injury, active contrast leak was seen in six patients (incidence 6.7%), all of which were concordant with final intraoperative site (positive predictive value, 100%). Mesenteric infiltration was seen in 51 patients: 47 patients had operative-CT site concordance (true positive) and four patients had operative-CT site discordance (false positive). Thus PPV of this sign for site localization was 92.16%.

Discussion

Traumatic gastrointestinal tract injuries, though seen in less than 10% of polytrauma patients, cause increased morbidity and mortality if the diagnosis is missed or delayed. Among traumatic gastrointestinal tract injuries, small bowel and mesenteric injuries are the most common (2). MDCT is considered to be accurate in detecting gastrointestinal, chiefly bowel and mesenteric injuries with a reported sensitivity of 70%–95% and a specificity of 92%–100% (6–11). In our study, the sensitivity of MDCT in overall detection of GIT injury was 97.8%. Three patients with bowel injury were misdiagnosed as isolated mesentery injury due to absence of free or localized air in the abdomen. While two of these three patients had abnormal bowel enhancement, the enhancement was either diffuse or false localizing. Another patient had only serosal

Table 3. Diagnostic performance of CT with respect to grouped GIT segments

Site	Upper GIT	Lower GIT	P*
Correct	12	42	0.497
Incorrect	2	14	
Total	14	56	
	Small bowel	Large bowel	P*
Correct	36	6	0.011
Incorrect	7	7	
Total	43	13	
	Right-sided colon	Left-sided colon	P*
Correct	0	6	0.462
Incorrect	2	5	
Total	2	11	

GIT, gastrointestinal tract; Right-sided colon, cecum to splenic flexure; Left-sided colon, descending colon to rectum.
*P value is calculated by Fisher's exact probability test; $P < 0.05$ is considered statistically significant.

Figure 2. a–c. Axial CT section **(a)** at wide window setting shows focal intramural air or pneumatosis intestinalis in ileum *(arrow)*. Surgery revealed gangrene of mid ileal segment. Axial CT section **(b)** in another patient with ileal injury shows both intramural air *(block arrow)* and focal extraluminal air *(white arrow)* near mid to distal ileum. Axial CT section **(c)** shows focal hypoenhancement *(white arrow)* with adjacent hyperenhancement *(black arrow)* and intramural air in jejunum, which was confirmed intraoperatively as gangrene and injury of jejunum.

tear of bowel, which in isolation is difficult to pick up on CT and is considered to be a finding of nonsurgical relevance (Fig. 4) (6). The three signs associated with abnormal or ectopic location of air in the abdomen, namely pneumoperitoneum, intramural air, and extraluminal air were absent in all patients with isolated mesentery injury and were variably present in patients with GIT injury. Thus, GIT injury may be excluded if all three signs are absent on CT. However, pneumoperitoneum was also seen in only 78% of patents with GIT injury and suggests that pneumoperitoneum by itself is not a very sensitive indicator of GIT injury. In a previous study by Roszler et al. (34), pneumoperitoneum had a variable detection rate and was missed in 17% of proven bowel injury cases.

The concordance between CT and surgical findings for overall site localization of GIT injury in our study was 68%; concordance was higher in single site injury (77%) than multiple site injury (35%). While our overall accuracy in site localization (68%) was less than that of previous studies (72.4% to 91.7%), our accuracy in single site perforation (77%) was comparable to these studies (19–25, 28). Our study population had a significant number of patients with multiple site GIT injury, which have not been analyzed by any of the authors previously. However, multiplicity is an important concern in the setting of trauma as more than one site of bowel injury can be seen in 25% of trauma patients undergoing surgery (16). Multiple site injuries are thought to be even higher in penetrating trauma due to multidirectional wound tracks in gunshots and stab wounds (2). Only Kim et al. (21) and Rodriguez et al. (28) studied GIT perforations exclusively in trauma patients, but they did not evaluate multiple site GIT trauma. Unlike nontraumatic gastrointestinal perforations, which usually occur in a single location and are associated with etiologic clues to localize the site of pathology (i.e., appendicolith, inflammatory phlegmon, abdominal mass), gastrointestinal tract injuries in trauma can be masked or missed due to presence of other organ injuries (17, 26, 31, 33). Second, oral contrast is not routinely administered in acute trauma compared with evaluation in nontraumatic cases. Third, nontraumatic perforations are more commonly due to appendicitis and peptic ulcer disease, while traumatic GIT perforations are most com-

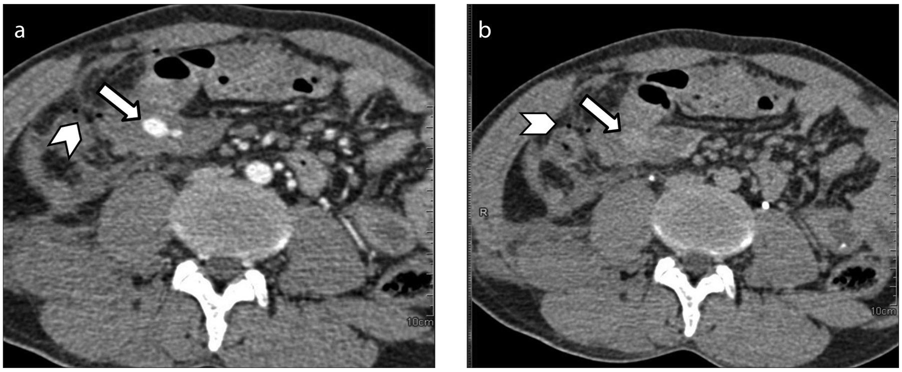

Figure 3. a, b. Axial CT sections at portal venous phase **(a)** and delayed phase **(b)** show mesenteric hematoma with a blob of contrast, which increases in size on delayed phase *(white block arrow)* suggestive of active extravasation. Few foci of extraluminal air were also seen *(white arrowhead)* and diagnosis of active mesenteric contrast leak with ileal injury was made. Intraoperatively, there was an ileal perforation 6 cm proximal to ileocecal junction with active bleeding in the ileal mesentery.

Table 4. Diagnostic value of CT signs for site localization in single site injury (n=70)

Sign	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)	Accuracy (%)
Extraluminal air	66.7 (36/54)	62.5 (10/16)	85.7 (36/42)	35.7 (10/28)	65.7
Intramural air	40.7 (22/54)	87.5 (14/16)	91.7 (22/24)	30.4 (14/46)	51.4
Hyperenhancement	53.7 (29/54)	75 (12/16)	87.9 (29/33)	32.4 (12/37)	58.6
Hypoenhancement	22.2 (12/54)	87.5 (14/16)	85.7 (12/14)	25 (14/56)	37.1
Wall discontinuity	46.3 (25/54)	87.5 (14/16)	92.6 (25/27)	32.6 (14/43)	55.7
Wall thickening	53.7 (29/54)	68.8 (11/16)	85.3 (29/34)	30.6 (11/36)	57.1
Active contrast leak	7.4 (4/54)	93.8 (15/16)	80 (4/5)	23.1 (15/65)	27.1
Mesenteric infiltration	59.3 (32/54)	56.3 (9/16)	82.1 (32/39)	29.0 (9/31)	58.6

PPV, positive predictive value; NPV, negative predictive value.

Table 5. Diagnostic value of signs for localization according to site of injury

	Gastroduodenal (n=14)					Small bowel (n=43)					Large bowel (n=13)				
Sign	Sn (%)	Sp (%)	PPV (%)	NPV (%)	Acc (%)	Sn (%)	Sp (%)	PPV (%)	NPV (%)	Acc (%)	Sn (%)	Sp (%)	PPV (%)	NPV (%)	Acc (%)
Extraluminal air	66.7	100	100	33.3	71.4	63.9	57.1	88.5	23.5	62.8	83.3	57.1	62.5	80	69.2
Intramural air	16.7	100	100	16.7	28.6	47.2	85.7	94.4	24	53.5	50	85.7	75	66.7	69.2
Hyperenhancement	33.3	100	100	20	42.9	63.9	85.7	95.8	31.6	67.4	33.3	57.`	40	50	46.2
Hypoenhancement	0	100	NA	14.3	14.3	30.6	71.4	84.6	16.7	37.2	16.7	100	100	58.3	61.5
Wall discontinuity	83.3	100	100	50	87.7	33.3	71.4	85.7	17.2	39.5	50	100	100	70	76.9
Wall thickening	16.7	100	100	16.7	28.6	61.1	71.4	91.7	26.3	62.8	83.3	57.1	62.5	80	69.2
Active contrast leak	16.9	100	100	16.7	28.6	5.6	100	100	17.1	29.9	16.9	100	100	58.3	61.5
Mesenteric infiltration	50	100	100	50	66.7	69.4	57.1	89.3	26.7	83.7	83.3	57.1	62.5	80	69.2

Sn, sensitivity; Sp, specificity; PPV, positive predictive value; NPV, negative predictive value; Acc, accuracy; NA, not applicable.

Figure 4. a, b. False negative finding for bowel injury. Axial CT section **(a)** and coronal reformatted **(b)** image show stranding in mesocolon of hepatic flexure *(arrow)*. On CT, isolated mesocolonic injury was diagnosed with likely colonic hematoma. However, intraoperatively serosal tear of ascending colon was also present, which was not detected on CT.

mon in the small bowel. These factors may also potentially contribute to diagnostic difficulty in site localization in trauma patients.

Similar to other studies (21, 22, 25), the accuracy of site localization in our study was higher for gastroduodenal injuries (85.7%, 12/14) and small bowel injuries (83.7%, 36/43), and was least accurate in large bowel injury (46.2%, 6/13) (Table 5). Unlike Kim et al. (22), our study showed no significant difference between site localization in upper (stomach and duodenum) and lower (small and large bowel) GIT injuries. But similar to Kim et al. (21), CT performed poorly in localizing colonic injuries in our study. The poor performance of CT for detecting colonic injuries was likely due to the relative mobility and redundancy of colonic loops making it difficult to trace the colonic loops in continuity and their close proximity to small bowel such that mesenteric and bowel findings were mistaken for small bowel injuries.

Extraluminal air sign comprising of mottled air lucencies and clustered air bubbles in close vicinity to bowel loop either in peritoneal cavity or retroperitoneum was overall the most sensitive and accurate sign for site localization (Figs. 2b, 5). This is because the extraluminal air represents air leak from a nearby injured bowel loop even if the break in the continuity of the wall cannot be directly visualized. Since this sign is a more sensitive sign than direct visualization of wall discontinuity, it should always be sought for using wide window settings to localize the site of injury (4). Only in gastroduodenal injuries, wall discontinuity was more sensitive and specific than extramural air for site localization (Fig. 5a, b). This is because the gastroduodenal segment has a relatively short length and fixed position, so it can be easily traced and direct discontinuity in the wall can be visualized (21, 22, 25). Similar findings were reported in a prospective study by Haiunaux et al. (19) wherein extraluminal air, focal wall thickening and wall discontinuity were found to be extremely strong predictors of site of GIT injury; though their study cohort mostly included gastroduodenal and colonic perforations secondary to inflammation, tumors, and postoperative leaks.

Intramural air was also found to be very specific for site localization in all GIT segments and represents air within the wall of the bowel due to a full or partial thickness injury (Figs. 2b, 5c, 5d) (13, 16). The diagnostic performance of this sign for site localization has never been reported previously, though it has been described as a sign of bowel injury necessitating urgent laparotomy to prevent peritonitis secondary to the full-thickness injury (16). Abnormal wall enhancement, notably hypoenhancement was more specific for site localization than hyperenhancement in our study. Hyperenhancement was found to be specific for site localization only in small bowel even though its overall sensitivity was higher (Figs. 2d, 5c). Hyperenhancement indicates diffusely increased permeability and interstitial leakage of fluid due to hypoperfusion, while hypoenhancement is a more delayed phenomenon representing gangrene or total infarct of the bowel. This could explain why incidence of hyperenhancement was higher than hypoenhancement but at the cost of decreased specificity for site localization. Brofman et al. (14) also reported hypoenhancement to have a low incidence but high specificity for presence of bowel injury, while hyperenhancement indicates a more diffuse, nonspecific, and reactive process. Presence of active vascular contrast extravasation is uncommon but if present, is extremely helpful in localizing the site of GIT injury as noted by the 100% positive predictive value of this sign in localizing injury (Fig. 3).

In the 20 patients with multiple site injuries, we could predict that injuries were multiple in 12 patients and CT accuracy for detection of all sites of injury was 59.6% (28/47). The diagnosis of multiple site injuries was given in patients in whom we saw a combination of signs in more than one location. Using these signs, complete site concordance for all sites of injuries was seen in 35% and partial concordance (CT could identify at least one site of perforation) in 45%. While CT could overall diagnose all sites of injury in only about one-third of patients with multiple site injury, it performed well in predicting presence of underlying multiple site GIT injury and localizing at least one site of injury in these patients. Wall discontinuity was a direct evidence of injury in these patients as it was seen in 8 of 17 patients with concordance and not seen in any of the four patients with discordance. Extraluminal air was incidentally the most common GIT sign seen in 13 of 17 patients with total or partial concordance, followed by intramural air and hyperenhancement. Thus, multiple site injury may be suspected if multifocal areas of extraluminal or intramural air are seen on CT and bowel loops adjacent to these ectopic air foci show abnormal enhancement.

The main limitation of this study was its retrospective nature and the prior knowledge that all patients had either GIT or mesentery injury. This is different from a clinical scenario when the injuries are unknown in polytrauma patients undergoing CT scans. Thus, the diagnostic performances of these signs for site localization need to be prospectively confirmed in a more global population comprising of both GIT and non-GIT injury patients. Also the final diagnosis regarding the site of involvement was made by considering the presence of signs together at a particular site and not by assessing the individual contributions and confidence level provided by each sign. This may have been fallacious in multiple site injury as we did not note down the presence or the absence of every sign at each individual site of injury but simply diagnosed that a segment was likely to be involved if any one of these signs was present at a particular site. Also, we did not differentiate between

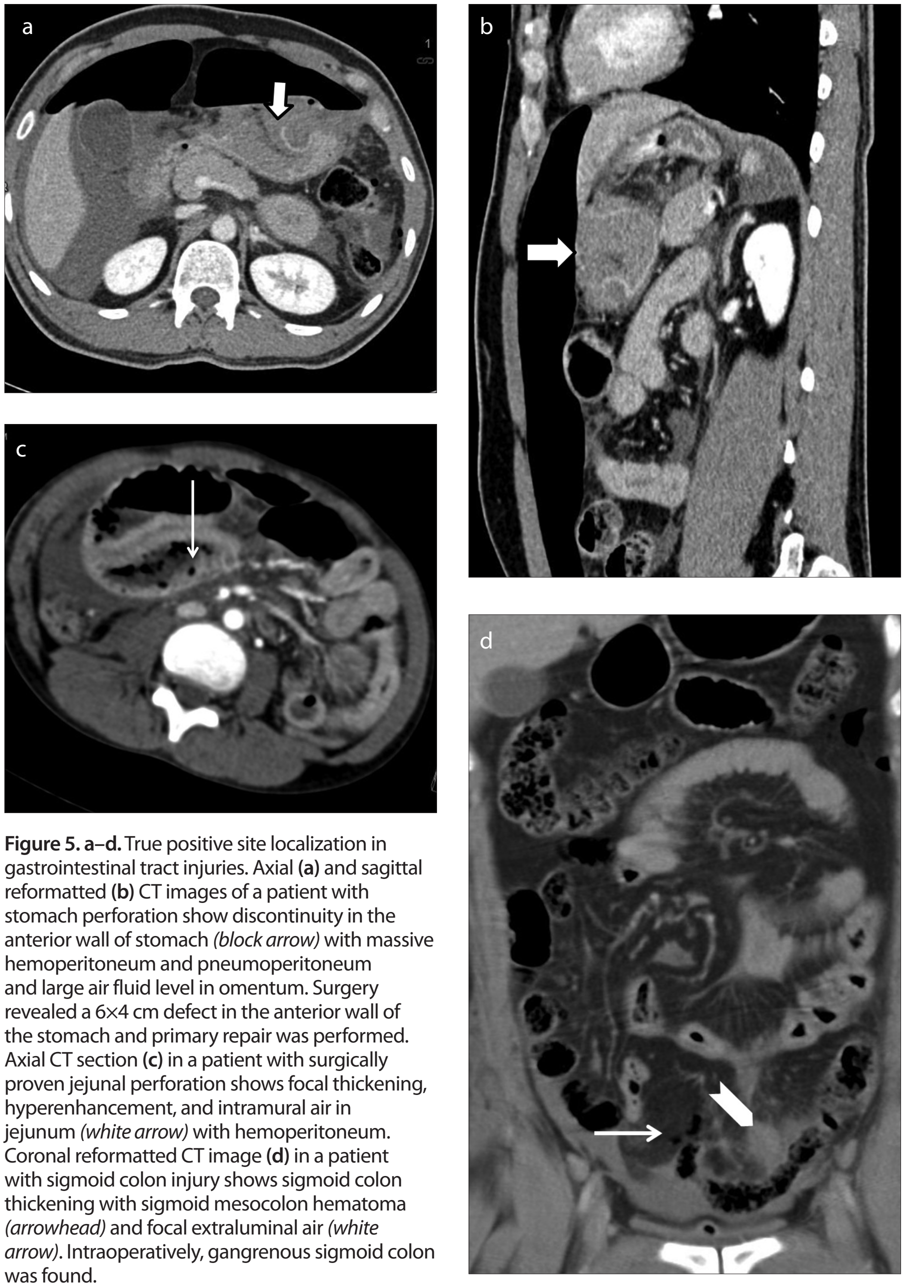

Figure 5. a–d. True positive site localization in gastrointestinal tract injuries. Axial **(a)** and sagittal reformatted **(b)** CT images of a patient with stomach perforation show discontinuity in the anterior wall of stomach *(block arrow)* with massive hemoperitoneum and pneumoperitoneum and large air fluid level in omentum. Surgery revealed a 6×4 cm defect in the anterior wall of the stomach and primary repair was performed. Axial CT section **(c)** in a patient with surgically proven jejunal perforation shows focal thickening, hyperenhancement, and intramural air in jejunum *(white arrow)* with hemoperitoneum. Coronal reformatted CT image **(d)** in a patient with sigmoid colon injury shows sigmoid colon thickening with sigmoid mesocolon hematoma *(arrowhead)* and focal extraluminal air *(white arrow)*. Intraoperatively, gangrenous sigmoid colon was found.

the various surgical types of GIT injuries, namely partial-thickness tear, full-thickness tear, transection, and gangrene; rather, we grouped them together as GIT injuries for the purpose of analysis. This is because detection of any type of GIT injury is enough to indicate laparotomy unless injury is purely serosal which, as such, is difficult to pick up on CT. Lastly, while few authors (24, 29) have differentiated extramural air as air in falciform ligament, periportal, supramesocolic, inframesocolic and retroperitoneal air, we simply defined extramural air as air outside a GIT segment in close proximity to it. While stomach and duodenal injuries were associated with periportal and supramesocolic air and retroperitoneal bowel injuries were associated with air foci in retroperitoneum in our study, we did not precisely compartmentalize the locations of extramural air. But this may not be a significant limitation as the association between the exact compartments of air and GIT site is highly variable and is not superior to the other GIT signs evaluated in this study (18).

In conclusion, CT performs well in detection of GIT and mesenteric injuries. CT performs better in diagnosing small bowel injury compared with large bowel injuries. Careful evaluation of colon is needed, as colon remains the most missed site of injury. For upper GIT trauma, focal wall discontinuity is the single most accurate sign to detect site, while for lower GIT trauma, combined analysis of various signs such as focal extraluminal and intramural air and wall discontinuity can help in site localization. Additionally, multiple foci of extraluminal or intramural air with associated wall thickening or enhancement should suggest multiple site injury.

Conflict of interest disclosure

The authors declared no conflicts of interest.

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