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Review

Effectiveness of computed tomography scanning to detect blunt bowel and mesenteric injuries requiring surgical intervention: A systematic literature review

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ABSTRACT

Background: Computed tomography (CT) diagnostic accuracy for blunt bowel and mesenteric injuries (BBMI) is controversial.
Data sources: A literature review to compute aggregate CT performance and individual CT sign sensitivity, specificity, and positive predictive value (PPV) for operative BBMI.
Conclusions: Sensitivity, specificity, and PPV were: overall CT performance 85.3%, 96.1%, 51.4%; abnormal wall enhancement 30.1%, 95.7%, 64.0%; bowel wall discontinuity 22.3%, 99.0%, 87.9%; bowel wall hematoma 22.5%, 100%, 19.5%; bowel wall thickening 35.2%, 96.5%, 32.1%; free air 32.0%, 98.7%, 57.1%; free fluid 65.6%, 85.0%, 25.5%; mesenteric air 27.6%, 99.1%, 85.3%; mesenteric extravasation 22.9%, 99.6%, 73.9%; mesenteric hematoma/fluid 33.9%, 98.7%, 52.8%; mesenteric stranding/streaking 34.3%, 91.8%, 31.6%; mesenteric vessel beading 32.1%, 97.2%, 60.4%; mesenteric vessel termination 31.6%, 97.2%, 63.5%; oral contrast extravasation 10.0%, 100%, 100%; retroperitoneal air 9.4%, 94.9%, 55.6%; and retroperitoneal fluid 44.2%, 49.4%, 38.5%. Sensitivity, specificity, and PPV vary substantially among known signs. Other clinical factors are necessary for comprehensive BBMI identification.

Introduction

Bowel and mesenteric injuries are found in approximately 5% of blunt abdominal trauma patients.[1] Blunt bowel and mesenteric injuries (BBMI) can present diagnostic difficulties and are occasionally recognized in a delayed fashion.[2] Although bowel injuries are uncommonly associated with traumatic abdominal injuries, they are associated with significant morbidity and mortality and require operative intervention unlike solid organ injuries.[3] Fakhry et al. demonstrated that relatively brief delays in diagnosing small bowel injury were directly responsible for almost half of the deaths in their study.[4]

The appearance of individual CT signs suggestive of BBMI necessitating an operative procedure are well described in the literature and widely recognized among radiologists and trauma surgeons.[1–54] Yet, the role of computed tomography (CT) in diagnosing operative hollow viscus injury after blunt abdominal trauma remains controversial with previous studies reporting both high accuracy and poor results.[26] Further, different imaging features of BBMI have varying predictability for the presence of a bowel injury requiring surgical correction.[44] Individual imaging signs and descriptions are listed in Supplementary File 1. The primary aim of this systematic review was to determine the overall sensitivity, specificity and positive predictive value (PPV) of CT scanning in the detection of BBMI requiring surgical intervention. The secondary aim was to evaluate the sensitivity, specificity, and PPV of the individual CT signs in BBMI requiring surgical intervention.

Materials and methods

This study was exempt from Institutional Review Board review because it is research involving the collection or study of existing published data. To address the review aims, the authors followed methods for the synthesis of studies without control groups.[55]

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The principal literature search objective was to obtain manuscripts that described BBMI patients requiring surgical intervention, when preoperative CT signs were presented in a format such that a sensitivity, specificity, or positive predictive value could be computed. The search, performed independently by both authors in PubMed included the following criteria: years 1990–2015, published in the English language, of any study design, and adult cohorts. The first author performed a PubMed literature search using Medical Subject Heading (MeSH) terms "blunt" and "abdominal trauma" as the two primary MeSH categories. Each primary MeSH term was combined with each of the following secondary MeSH terms: "bowel injury; " "hollow viscus injury; " and "mesenteric injury." The second author subsequently performed a PubMed text word search applying the text words "blunt" AND "bowel" AND "computed tomography." Because text word searches in PubMed include Medical Subject Heading (MESH) terms and the presence of the text in a title, abstract, or manuscript, this approach is comparable to an Ovid® search.[56] Once the records were identified by the search engine, all titles and abstracts were reviewed. Manuscripts were obtained for all review articles and all other articles when the title or abstract suggested that relevant data might be contained within the publication. After obtaining the manuscripts, the bibliographies of review articles were surveyed for additional manuscripts that might contain relevant data. The other manuscripts were carefully read to obtain data regarding preoperative CT findings in patients with a BBMI that required surgical intervention. After identifying manuscripts with relevant data, the bibliographies of those publications were assessed for additional manuscripts that might have germane data. When a bibliographical citation and manuscript statement suggested that relevant data might be contained within the article, the manuscript was obtained and reviewed for additional statistical information. Both authors reviewed and agreed upon the selected articles and extracted data points.

Aggregated CT and individual CT sign data were included in the review when the CT data was presented in a format such that a sensitivity, specificity, or PPV could be computed. The review only includes CT data for BBMI patients who required surgical intervention; with the exception of bowel wall hematoma. For the review, BBMI injuries were categorized as 1) bowel injury (stomach, small bowel, or colon); 2) bowel rupture; 3) bowel or mesenteric injury; 4) colon or small bowel injury; 5) colon, small bowel, or mesenteric injury; and 6) mesenteric injury. The first author assessed each article's quality using the quality assessment of studies of diagnostic accuracy included in systematic reviews (QUADAS-2) tool.[57]

Traits of the BBMI patients undergoing CT scanning were 1) underwent laparotomy; 2) had a diagnosis of bowel or mesenteric injury; 3) had blunt trauma; 4) had bowel rupture; 5) mesenteric injury identified at laparotomy; 6) bowel injury identified at laparotomy; 7) bowel or mesenteric injury identified at laparotomy; 8) CT positive mesenteric injury; and 9) mesenteric injury requiring surgical intervention.

Data were entered in a Microsoft Excel 2010 (Redmond, WA, USA) worksheet and imported into the SAS System for Windows, release 9.2 (SAS Institute Inc., Cary, NC, USA) to perform statistical analysis. Inter-study testing of heterogeneity for sensitivity, specificity, and PPV proportions were performed, using the Chi-Square statistic. If the p-value was greater or equal to 0.05, the cohorts were homogenous. When sensitivity, specificity, and PPV proportions from individual studies were combined, an overall weighted mean proportion was computed. The weighted mean proportion was based on the size of each individual cohort. A 95% confidence interval (CI) was reported when the combined cohorts contained less than 100 patients.

Results

Fig. 1 depicts the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram of publications identified, included, and excluded, and the reasons for exclusions. The search generated 45 publications reporting on BBMI patients requiring surgical intervention. Forty publications contained true-positive and false-negative results for individual CT signs, and 18 publications contained true-positive and false-negative for overall CT performance. The QUADAS-2 assessment is listed in Table 1.

The overall CT performance for BBMI had an 85.3% (713/836; Chi-Sq $p = 0.0965$) sensitivity, 96.1% (11,459/11,924; Chi-Sq $p = 0.1804$) specificity, and 51.4% (492/957; Chi-Sq $p = 0.3078$) PPV. Table 2 displays aggregate CT sign outcomes. A summary of the aggregate and individual signs' sensitivity, specificity, and PPV can be found in Table 3. Analysis of the individual CT signs was as follows:

Abnormal wall enhancement

Eight studies with 10 cohorts explored the significance of abnormal bowel wall enhancement (Table 4). The sensitivity, specificity, and PPV for this sign was 30.1% (91/302; Chi-Sq $p = 0.1894$), 95.7% (687/718; Chi-Sq $p = 0.8964$), 64.0% (55/86; Chi-Sq $p = 0.8187$; CI 53.4%–73.3%), respectively.

Bowel wall discontinuity

Fourteen cohorts from 12 studies investigated bowel wall discontinuity (Table 5). For this CT sign, the sensitivity was 22.3% (85/381; Chi-Sq $p = 0.0618$), specificity 99.0% (829/837; Chi-Sq $p = 0.6834$), and PPV 87.9% (58/66; Chi-Sq $p = 0.3679$; CI 77.9%–93.7%).

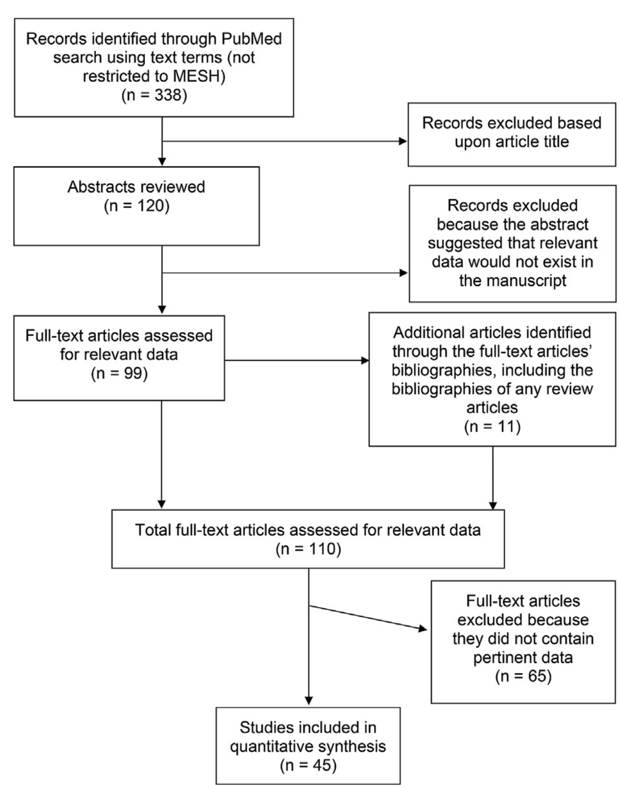

Fig. 1. PRISMA flow diagram.

Table 1
QUADAS-2 assessment.

Study	Risk of Bias				Applicability Concerns		
	Patient Selection	Index Test	Reference Standard	Flow and Timing	Patient Selection	Index Test	Reference
Allen[5]	low	low	low	low	low	low	low
Atri[6]	low	unclear	low	low	low	low	low
Bege[7]	low	low	low	low	low	low	low
Bradley[8]	low	low	unclear	low	low	low	low
Brasel[9]	low	unclear	unclear	low	low	low	unclear
Breen[10]	low	low	low	low	low	low	low
Brofman[11]	low	low	low	low	low	low	low
Butela[12]	low	low	low	low	low	low	low
Cho[13]	low	low	unclear	low	low	low	low
de Araujo[14]	low	low	low	low	low	low	low
Donohue[15]	unclear	low	low	low	low	low	low
Dowe[16]	low	unclear	low	low	low	low	low
Ekeh[2]	unclear	unclear	low	low	low	low	low
Elton[17]	low	unclear	low	low	low	low	low
Faget[18]	low	unclear	low	low	low	low	low
Fakhry[19]	unclear	unclear	unclear	unclear	unclear	low	low
Hagiwara[20]	low	low	low	low	low	low	low
Hefny[23]	low	low	low	low	low	low	low
Hughes[24]	low	low	low	low	low	low	low
Janzen[25]	low	low	low	low	low	low	low
Killeen[26]	low	low	unclear	low	low	low	low
Kim[27]	low	low	low	low	low	low	low
Kong[29]	unclear	low	low	low	low	low	low
Magu[3]	low	unclear	low	low	low	unclear	low
Mahmood[32]	low	low	low	low	low	low	low
Malhotra[33]	low	unclear	low	low	low	low	low
Matsushima[34]	low	low	unclear	unclear	unclear	low	low
McNutt[35]	low	low	low	low	low	low	low
Mirvis[36]	low	unclear	unclear	low	low	low	low
Murakami[37]	low	low	low	low	low	low	low
Park[38]	unclear	unclear	unclear	low	low	low	low
Petrosoniak[39]	low	unclear	low	low	low	unclear	low
Polat[40]	low	low	low	low	low	low	low
Saku[41]	unclear	low	low	low	low	low	low
Scaglione[42]	low	unclear	unclear	unclear	low	low	low
Sharma[43]	low	low	low	low	low	low	low
Steenburg[44]	low	low	low	high	low	low	unclear
Stuhlfaut[45]	low	unclear	unclear	unclear	low	low	low
Tan[46]	low	low	low	low	low	low	low
Tsang[47]	low	low	low	low	low	low	low
Walker[49]	low	low	low	low	unclear	low	low
Wisner[50]	low	high	unclear	high	low	high	unclear
Wu[51]	low	low	low	low	low	low	low
Yu[52]	low	unclear	unclear	low	low	unclear	low
Zarour[53]	low	unclear	unclear	low	low	low	low

Low, low risk; high, high risk; unclear, unclear risk; QUADAS, quality assessment of studies of diagnostic accuracy included in systematic reviews.

Bowel wall hematoma

Bowel wall hematoma was investigated in 6 studies with 8 cohorts (Table 6). In most of the cohorts, only select patients underwent surgery. The sensitivity was 22.5% (25/111; Chi-Sq p = 0.2794), specificity was 100% (1468/1468; Chi-Sq p = 1.0), and PPV was 19.5% (16/82; Chi-Sq p = 0.1353; CI 12.4%–29.4%) for this CT sign.

Bowel wall thickening

A total of 22 studies including 27 cohorts discussed bowel wall thickening (Table 7). The sensitivity, specificity, and PPV for this CT sign was 35.2% (394/1119; Chi-Sq p = 0.4776), 96.5% (11,340/11,754; Chi-Sq p = 0.2426), and 32.1% (196/610; Chi-Sq p = 0.2270), respectively.

Free air

Free air data was presented in 25 studies containing 30 cohorts (Table 8). For this CT sign, the sensitivity was 32.0% (377/1178; Chi-Sq p = 0.1463), specificity 98.7% (12,388/12,556; Chi-Sq p = 0.2544), and PPV 57.1% (224/392; Chi-Sq p = 0.2564).

Free fluid

Forty-two cohorts in 31 studies investigated the CT finding of free intraperitoneal fluid (Table 9). The sensitivity was 65.6% (1286/1960; Chi-Sq p = 0.4463), specificity was 85.0% (14,179/16,689; Chi-Sq p = 0.2417), and PPV was 25.5% (873/3422; Chi-Sq p = 0.3681) for this CT sign.

In 9 cohorts where free fluid was present without solid organ injury, the sensitivity specificity, and PPV was 52.9% (342/646; Chi-Sq p = 0.2892), 81.7% (2371/2901; Chi-Sq p = 0.3137), and 30.3% (233/770; Chi-Sq p = 0.1991) respectively.

Mesenteric air

Three studies with 5 cohorts reported on mesenteric air in surgical BBMI patients (Table 10). The sensitivity, specificity, and

Table 2
Aggregate CT signs.

Study	Injury	TP	FN	FP	TN	Patient Traits
Atri, 2008[6]	CS	30	7	20	39	had laparotomy
Atri, 2008[6]	CSM	36	2	30	28	had laparotomy
Atri, 2008[6]	M	23	2	36	35	had laparotomy
Ekeh, 2008[2]	CSM	49	8	–	–	had BMI
Elton, 2005[17]	BM	91	7	180	441	blunt trauma
Faget, 2015[18]	BM	54	2	42	458	blunt trauma
Hughes, 2002[24]	B	24	1	–	–	had laparotomy
Janzen, 1998[25]	B	6	3	3	19	had laparotomy
Janzen, 1998[25]	M	5	0	5	21	had laparotomy
Killeen, 2001[26]	B	23	2	–	–	had BMI
Killeen, 2001[26]	M	10	17	–	–	had BMI
Malhotra, 2000[33]	BM	46	7	47	8012	blunt trauma
Matsushima, 2013[34]	BM	22	4	–	–	had laparotomy
McNutt, 2015[35]	B‡	36	7	18	49	had BMI
McNutt, 2015[35]	CSM‡	47	13	7	43	had BMI
Mirvis, 1992[36]	BR	10	6	–	–	bowel rupture
Murakami, 2004[37]	M	15	0	–	–	laparotomy: MI +
Park, 2013[38]	BR	62	16	1	27	laparotomy: BMI +
Petrosoniak, 2013[39]	CSM	68	0	–	–	laparotomy: BMI +
Polat, 2014[40]	CSM	23	4	0	21	had laparotomy
Steenburg, 2015[44]	B	12	3	30	81	CT positive MI
Stuhlfaut, 2004[45]	BM	9	2	5	1066	blunt trauma
Stuhlfaut, 2004[45]	BM	9	2	39‡	1032	blunt trauma
Walker, 2012[49]	BR	3	8	2	87	blunt trauma

B, bowel: stomach, small bowel, or colon; BR, bowel rupture; BM, bowel or mesentery; CS, colon or small bowel; CSM, colon, small bowel, or mesentery; M, mesentery; TP, true-positive; FN, false-negative; FP, false-positive; TN, true-negative; +, positive; BMI, bowel or mesenteric injury; MI, mesenteric injury; CT, computed tomography; ‡with need for surgical intervention; ‡free fluid was considered as false-positive.

PPV for this CT sign was 27.6% (42/152; Chi-Sq p = 0.8187), 99.1% (574/579; Chi-Sq p = 0.05637), and 85.3% (29/34; Chi-Sq p = 0.5637; CI 69.9%–93.6%), respectively.

Table 3
Sensitivity, specificity, and positive predictive value summary for aggregate and individual CT signs.

	Sensitivity	Specificity	PPV
Overall CT Signs	85.3%	96.1%	51.4%
	713/836	11,459/11,924	492/957
Abnormal Bowel Wall Enhancement	30.1%	95.7%	64.0%
	91/302	687/718	55/86
Bowel Wall Discontinuity	22.3%	99.0%	87.9%
	85/381	829/837	58/66
Bowel Wall Hematoma	22.5%	100%	19.5%
	25/111	1468/1468	16/82
Bowel Wall Thickening	35.2%	96.5%	32.1%
	394/1119	11,340/11,754	196/610
Free Air	32.0%	98.7%	57.1%
	377/1178	12,388/12,556	224/392
Free Fluid	65.6%	85.0%	25.5%
	1286/1960	14,179/16,689	873/3422
Mesenteric Air	27.6%	99.1%	85.3%
	42/152	574/579	29/34
Mesenteric Extravasation	22.9%	99.6%	73.9%
	182/796	9005/9039	96/130
Mesenteric Hematoma/Fluid	33.9%	98.7%	52.8%
	261/769	8693/8811	132/250
Mesenteric Stranding/Streaking	34.3%	91.8%	31.6%
	272/793	3620/3943	149/472
Mesenteric Vessel Beading	32.1%	97.2%	60.4%
	45/140	650/669	29/48
Mesenteric Vessel Termination	31.6%	97.2%	63.5%
	37/117	650/669	33/52
Oral Contrast Extravasation	10.0%	100%	100%
	28/279	8277/8277	7/7
Retroperitoneal Air	9.4%	94.9%	55.6%
	9/96	75/79	5/9
Retroperitoneal Fluid	44.2%	49.4%	38.5%
	46/104	39/79	25/65

PPV, positive predictive value.

Table 4
Abnormal bowel wall enhancement.

Study	Injury	TP	FN	FP	TN	Patient Traits
Atri, 2008[6]	CSM	3	35	6	52	had laparotomy
Bege, 2014[7]	BM	10	13	–	–	laparotomy: MI +
Cho, 2013[13]	BR	6	2	–	–	bowel rupture
Faget, 2015[18]	BM	22	34	11	489	blunt trauma
Matsushima, 2013[34]	BM	5	21	–	–	had laparotomy
Park, 2013[38]	BR	11	67	3	25	laparotomy: BMI +
Polat, 2014[40]	CSM	14	13	0	21	had laparotomy
Polat, 2014[40]	CS	14	10	–	–	had laparotomy
Polat, 2014[40]	M	1	6	–	–	had laparotomy
Steenburg, 2013[44]	B	5	10	11	100	CT positive MI

B, bowel: stomach, small bowel, or colon; BR, bowel rupture; BM, bowel or mesentery; CS, colon or small bowel; CSM, colon, small bowel, or mesentery; CT, computed tomography; M, mesentery; MI, mesenteric injury; TP, true-positive; FN, false-negative; FP, false-positive; TN, true-negative; +, positive; BMI, bowel or mesenteric injury.

Table 5
Bowel wall discontinuity.

Study	Injury	TP	FN	FP	TN	Patient Traits
Atri, 2008[6]	CSM	4	34	0	58	had laparotomy
Bege, 2014[7]	BM	3	20	–	–	laparotomy: MI +
Breen, 1997[10]	B	6	3	2	20	had laparotomy
Cho, 2013[13]	BR	8	0	–	–	bowel rupture
Faget, 2015[18]	BM	19	37	1	499	blunt trauma
Kim, 2004[27]	BR	3	54	–	–	bowel rupture
Mirvis, 1992[36]	BR	3	14	–	–	bowel rupture
Park, 2013[38]	BR	15	63	0	28	laparotomy: BMI +
Polat, 2014[40]	CSM	7	20	0	21	had laparotomy
Polat, 2014[40]	CS	7	17	–	–	had laparotomy
Polat, 2014[40]	M	2	5	–	–	had laparotomy
Scaglione, 2004[42]	BR	1	12	–	–	bowel rupture
Steenburg, 2013[44]	B	1	14	3	108	CT positive MI
Wu, 2011[51]	B	6	3	2	95	blunt trauma

B, bowel: stomach, small bowel, or colon; BM, bowel or mesentery; BMI, bowel or mesenteric injury; BR, bowel rupture; CS, colon or small bowel; CSM, colon, small bowel, or mesentery; CT, computed tomography; M, mesentery; MI, mesenteric injury; TP, true-positive; FN, false-negative; FP, false-positive; TN, true-negative; +, positive.

Table 6
Bowel wall hematoma.

Study	Injury	TP	FN	FP	TN	Patient Traits
Allen, 2004‡[5]	BM	3	11	0	486	blunt trauma
Allen, 2004‡[5]	B	3	6	0	491	blunt trauma
Allen, 2004‡[5]	M	2	7	0	491	blunt trauma
Bradley, 2016[8]	B	8	–	66	–	blunt trauma
Hughes, 2002[24]	B	2	24	–	–	had laparotomy
Magu, 2012‡[3]	B	7	25	–	–	laparotomy: BI +
Scaglione, 2004†[42]	BR	3	5	–	–	bowel rupture
Sharma, 2004[43]	BR	5	8	–	–	bowel rupture

B, bowel: stomach, small bowel, or colon; BR, bowel rupture; BM, bowel or mesentery; M, mesentery; TP, true-positive; FN, false-negative; FP, false-positive; TN, true-negative; BI, bowel injury; +, positive; ‡some patients did not require surgery; †all patients required surgery.

Mesenteric extravasation

Twenty-one studies including 24 cohorts focused on the above finding (Table 11). For this CT sign, the sensitivity was 22.9% (182/796; Chi-Sq $p = 0.2495$), specificity 99.6% (9005/9039; Chi-Sq $p = 0.0396$), and PPV 73.9% (96/130; Chi-Sq $p = 0.0970$).

Mesenteric hematoma/fluid

Among 26 cohorts in 17 studies that focused on mesenteric hematoma/fluid, most included patients with mesenteric injuries (Table 12). The sensitivity was 33.9% (261/769; Chi-Sq $p = 0.1957$), specificity was 98.7% (8693/8811; Chi-Sq $p = 0.9977$), and PPV was 52.8% (132/250; Chi-Sq $p = 0.9536$) for this CT sign.

Mesenteric stranding/streaking

The CT finding of mesenteric streaking/stranding was discussed in a total of 16 studies containing 18 cohorts (Table 13). The sensitivity, specificity, and PPV for this CT sign was 34.3% (272/793; Chi-Sq $p = 0.5429$), 91.8% (3620/3943; Chi-Sq $p = 0.2243$), and 31.6% (149/472; Chi-Sq $p = 0.2243$), respectively.

Table 7
Bowel wall thickening.

Study	Injury	TP	FN	FP	TN	Patient Traits
Atri, 2008[6]	CSM‡	7	31	2	56	had laparotomy
Atri, 2008[6]	CSM†	17	21	14	44	had laparotomy
Bege, 2014[7]	BM	14	9	–	–	laparotomy: MI +
Cho, 2013[13]	BR	7	1	–	–	bowel rupture
de Araujo, 2014[14]	B	6	5	–	–	had laparotomy
Donohue, 1987[15]	BM	8	1	–	–	laparotomy: BMI +
Dowe, 1997[16]	M	5	16	–	–	MI needing surgery
Ekeh, 2008[2]	CSM	3	54	–	–	had BMI
Faget, 2015[18]	BM	38	18	44	456	blunt trauma
Fakhry, 2003[19]	BR	87	321	246	2604	blunt trauma
Kim, 2004[27]	BR	44	13	–	–	bowel rupture
Malhotra, 2000[33]	BM	16	37	4	8055	blunt trauma
Malhotra, 2000[33]	B	10	18	–	–	blunt trauma
Malhotra, 2000[33]	M	6	26	–	–	blunt trauma
Matsushima, 2013[34]	BM	5	21	–	–	had laparotomy
Mirvis, 1992[36]	BR	4	13	–	–	bowel rupture
Murakami, 2004[37]	M	2	13	–	–	laparotomy: MI +
Petrosoniak, 2013[39]	CSM	39	29	–	–	laparotomy: BMI +
Polat, 2014[40]	CSM	14	13	2	19	had laparotomy
Polat, 2014[40]	CS	14	10	–	–	had laparotomy
Polat, 2014[40]	M	1	6	–	–	had laparotomy
Saku, 2006[41]	BR	4	8	–	–	bowel rupture
Scaglione, 2004[42]	BR	5	3	–	–	bowel rupture
Steenburg, 2013[44]	B	14	1	97	14	CT positive MI
Tan, 2010[46]	BM	9	22	–	–	laparotomy: BMI +
Wu, 2011[51]	B	3	6	5	92	blunt trauma
Yu, 2011[52]	B	12	9	–	–	had laparotomy

B, bowel: stomach, small bowel, or colon; BR, bowel rupture; BM, bowel or mesentery; BMI, bowel or mesenteric injury; CS, colon or small bowel; CSM, colon, small bowel, or mesentery; CT, computed tomography; M, mesentery; MI, mesenteric injury; TP, true-positive; FN, false-negative; FP, false-positive; TN, true-negative; +, positive; ‡thick large bowel; †thick small bowel.

Table 8
Free air.

Study	Injury	TP	FN	FP	TN	Patient Traits
Atri, 2008[6]	CSM	9	29	3	55	had laparotomy
Bege, 2014[7]	BM	6	17	–	–	laparotomy: MI +
Cho, 2013[13]	BR‡	5	3	–	–	bowel rupture
Cho, 2013[13]	BR†	7	1	–	–	bowel rupture
de Araujo, 2014[14]	B	9	7	–	–	had laparotomy
Donohue, 1987[15]	BM	3	6	–	–	laparotomy: BMI +
Ekeh, 2008[2]	CSM	6	51	–	–	had BMI
Faget, 2015[18]	BM	17	39	4	496	blunt trauma
Fakhry, 2003[19]	BR	103	305	132	2718	blunt trauma
Hagiwara, 1995[20]	BR	6	7	6	411	blunt trauma
Hefny, 2015[23]	BR	2	2	19	396	blunt trauma
Kim, 2004[27]	BR	32	25	–	–	bowel rupture
Malhotra, 2000[33]	BM	15	38	1	8058	blunt trauma
Malhotra, 2000[33]	B	12	16	–	–	blunt trauma
Malhotra, 2000[33]	M	3	29	–	–	blunt trauma
Matsushima, 2013[34]	BM	2	24	–	–	had laparotomy
Mirvis, 1992[36]	BR	6	11	–	–	bowel rupture
Park, 2013[38]	BR	58	20	1	27	laparotomy: BMI +
Petrosoniak, 2013[39]	CSM	18	50	–	–	laparotomy: BMI +
Polat, 2014[40]	CSM	9	18	0	21	had laparotomy
Polat, 2014[40]	CS	9	15	–	–	had laparotomy
Polat, 2014[40]	M	1	6	–	–	had laparotomy
Saku, 2006[41]	BR	7	5	–	–	bowel rupture
Scaglione, 2004[42]	BR	6	2	–	–	bowel rupture
Sharma, 2004[43]	BR	4	9	–	–	bowel rupture
Steenburg, 2013[44]	B	0	15	0	111	CT positive MI
Tan, 2010[46]	BM	11	20	–	–	laparotomy: BMI +
Tsang, 1997[47]	BR	0	7	–	–	bowel rupture
Wu, 2011[51]	B	5	4	2	95	blunt trauma
Yu, 2011[52]	BM	6	20	–	–	had laparotomy

B, bowel: stomach, small bowel, or colon; BR, bowel rupture; BM, bowel or mesentery; CS, colon or small bowel; CSM, colon, small bowel, or mesentery; M, mesentery; MI, mesenteric injury; TP, true-positive; FN, false-negative; FP, false-positive; TN, true-negative; +, positive; BMI, bowel or mesenteric injury; CT, computed tomography; ‡bowel rupture on CT; †bowel rupture or intramural air on CT.

Mesenteric vessel beading

Mesenteric vessel beading data was presented in 5 studies (Table 14). For this CT sign, the sensitivity was 32.1% (45/140; Chi-Sq $p = 0.2414$), specificity 97.2% (650/669; Chi-Sq $p = 1.0$), and PPV 60.4% (29/48; Chi-Sq $p = 1.0$; CI 46.3%–73.0%).

Mesenteric vessel termination

Data was presented for mesenteric vessel termination in four studies (Table 15). The sensitivity was 31.6% (37/117; Chi-Sq $p = 0.7788$), specificity was 97.2% (650/669; Chi-Sq $p = 1.0$), and PPV was 63.5% (33/52; Chi-Sq $p = 1.0$; CI 49.9%–75.2%) for this CT sign.

Oral contrast extravasation

A total of 9 cohorts in 7 studies focused on the CT finding of oral contrast extravasation (Table 16). The sensitivity, specificity, and PPV for this CT sign were 10.0% (28/279; Chi-Sq $p = 0.0956$), 100% (8277/8277; Chi-Sq $p = 1.0$), and 100% (7/7; Chi-Sq $p = 0.3173$; CI 64.6%–100%), respectively.

Retroperitoneal air

Data regarding retroperitoneal air was presented in 2 studies

Table 9
Free fluid.

Study	Injury	TP	FN	FP	TN	Patient Traits
Atri, 2008[6]	CSM	38	0	43	15	had laparotomy
Bege, 2014[7]	BM	21	2	–	–	laparotomy: MI +; FF
Bege, 2014[7]	BM	17	6	–	–	laparotomy: MI +; FFǂ
Brasel, 1998[9]	CSM	7	0	27	994	bunt trauma
Cho, 2013[13]	BR	8	0	–	–	bowel rupture
de Araujo, 2014[14]	B	12	4	–	–	had laparotomy
Donohue, 1987[15]	BM	9	0	–	–	laparotomy: BMI +
Dowe, 1996[16]	M	9	12			MI needing surgery
Ekeh, 2008[2]	CSM	29	28	–	–	had BMI
Faget, 2015[18]	BM	39	17	127	373	blunt trauma; large HP
Faget, 2015[18]	BM	53	3	346	154	blunt trauma; any HP
Fakhry, 2003[19]	BR	292	116	1091	1759	blunt trauma
Fakhry, 2003[19]	BR	228	180	519	2331	ǂblunt trauma
Hagiwara, 1995[20]	BR	8	5	112	305	blunt trauma
Hefny, 2015[23]	BR	3	1	–	–	ǂbowel rupture
Hughes, 2002[24]	B	15	11	–	–	ǂhad laparotomy
Killeen, 2001[26]	B	19	6	30	19	had BMI
Killeen, 2001[26]	M	19	8	19	30	had BMI
Kim, 2004[27]	BR	43	14	–	–	bowel rupture
Kong, 2015[29]	BR	5	0	31	–	blunt trauma
Kong, 2015[29]	BR	0	0	7	–	ǂblunt trauma
Mahmood, 2014[32]	BM	29	93	–	–	ǂblunt trauma
Malhotra, 2000[33]	BM	39	14	37	8022	blunt trauma
Malhotra, 2000[33]	B	18	10	–	–	blunt trauma
Malhotra, 2000[33]	M	21	11	–	–	blunt trauma
Matsushima, 2013[34]	BM	16	10	–	–	ǂhad laparotomy
Mirvis, 1992[36]	B	4	13	–	–	bowel rupture
Murakami, 2004[37]	M	15	0	–	–	laparotomy: MI +
Park, 2013[38]	BR	19	59	1	27	laparotomy: BMI +; FF
Park, 2013[38]	BR	58	20	27	1	laparotomy: BMI +; HP
Petrosoniak, 2013[39]	CSM	68	0	–	–	laparotomy: BMI +
Polat, 2014[40]	CSM	22	5	14	7	had laparotomy
Polat, 2014[40]	CS	19	5	–	–	had laparotomy
Polat, 2014[40]	M	5	2	–	–	had laparotomy
Saku, 2006[41]	BR	9	3	–	–	bowel rupture
Scaglione, 2004[42]	BR	3	5	–	–	bowel rupture
Sharma, 2004[43]	BR	10	3	–	–	bowel rupture
Steenburg, 2015[44]	B	14	1	55	56	CT positive MI
Tan, 2010[46]	BM	29	2	–	–	ǂlaparotomy: BMI +
Wisner, 1990[50]	BR	1	3	–	–	bowel rupture
Wu, 2011[51]	B	8	1	52	45	blunt trauma
Wu, 2011[51]	B	5	1	11	40	ǂblunt trauma

B, bowel: stomach, small bowel, or colon; BR, bowel rupture; BM, bowel or mesentery; CS, colon or small bowel; CSM, colon, small bowel, or mesentery; CT, computed tomography; M, mesentery; MI, mesenteric injury; TP, true-positive; FN, false-negative; FP, false-positive; TN, true-negative; BMI, bowel or mesenteric injury; HP, hemoperitoneum; FF, free fluid; +, positive; ǂno solid organ injury.

with 4 cohorts (Table 17). The synthesized sensitivity was 9.4% (9/96; Chi-Sq $p = 1.0$; CI 5.0%–16.9%), specificity 94.9% (75/79; Chi-Sq $p = 1.0$; CI 87.7%–98.0%), and PPV 55.6% (5/9; Chi-Sq $p = 1.0$; CI 26.7%–81.1%).

Retroperitoneal fluid

Data for retroperitoneal fluid was presented for 5 cohorts in 3 studies (Table 18). The sensitivity, specificity and PPV of retroperitoneal fluid were 44.2% (46/104; Chi-Sq $p = 0.8964$), 49.4% (39/79; Chi-Sq $p = 1.0$; CI 38.6%–60.2%) and 38.5% (25/65; Chi-Sq $p = 1.0$; CI 27.6–50.6%), respectively.

Table 10
Mesenteric air.

Study	Injury	TP	FN	FP	TN	Patient Traits
Atri, 2008[6]	CSM	8	30	3	55	had laparotomy
Faget, 2015[18]	BM	10	46	2	498	blunt trauma
Polat, 2014[40]	CSM	11	16	0	21	had laparotomy
Polat, 2014[40]	CS	11	13	–	–	had laparotomy
Polat, 2014[40]	M	2	5	–	–	had laparotomy

BM, bowel or mesentery; CS, colon or small bowel; CSM, colon, small bowel, or mesentery; M, mesentery; TP, true-positive; FN, false-negative; FP, false-positive; TN, true-negative.

Discussion

Methodology for combining study proportions

The following literature lends support to the methodology used in the current investigation for combining study proportions. After an assessment of 11 systematic reviews, Fitzpatrick-Lewis et al. found that good quality non-randomized studies yield results similar to randomized control trials.[55] The authors indicate that there are several methodological approaches for including data from non-randomized studies and concluded that there is no standardized model for synthesizing the results of studies that do not have control groups.

We examined an investigation that included 14 cohorts of patients who underwent esophageal endoscopy for esophageal food impaction.[58] By using the method in the current investigation, we divided the 223 that had eosinophilic esophagitis by the 433 that underwent biopsy (Table 3, page 21 of their manuscript).[58] This yielded a total proportion of 51.5%, similar to the meta-analysis

Table 11
Mesenteric extravasation.

Study	Injury	TP	FN	FP	TN	Patient Traits
Atri, 2008[6]	CSM	10	28	0	58	had laparotomy
Bege, 2014[7]	BM	3	20	–	–	laparotomy: MI +
Brofman, 2006[11]	CSM	9	45	–	–	had BMI
Butela, 2001[12]	BM	8	42	0	62	blunt trauma
Cho, 2013[13]	BR	4	4	–	–	bowel rupture
Dowe, 1996[16]	M	7	14	–	–	MI needing surgery
Ekeh, 2008[2]	CSM	6	51	–	–	had BMI
Faget, 2015[18]	BM	15	41	6	494	blunt trauma
Hagiwara, 1995[20]	BR	0	13	–	–	bowel rupture
Killeen, 2001[26]	M	5	22	0	49	had BMI
Malhotra, 2000[33]	BM	5	48	0	8059	blunt trauma
Malhotra, 2000[33]	B	1	27	–	–	blunt trauma
Malhotra, 2000[33]	M	4	28	–	–	blunt trauma
Matsushima, 2013[34]	BM	4	22	–	–	had laparotomy
Murakami, 2004[37]	M	1	14	–	–	laparotomy: MI +
Park, 2013[38]	BR	32	46	17	11	laparotomy: BMI +
Petrosoniak, 2013[39]	CSM	24	44	–	–	laparotomy: BMI +
Scaglione, 2004[42]	M	10	13	–	–	laparotomy: MI +
Steenburg, 2013[44]	B	8	7	11	100	CT positive MI
Tan, 2010[46]	BM	3	28	–	–	laparotomy: BMI +
Wu, 2011[51]	M	7	1	0	98	blunt trauma
Yu, 2011[52]	BM	5	21	–	–	had laparotomy
Yu, 2011[52]	M	5	10	–	–	had laparotomy
Zarour, 2014[53]	CSM	6	25	0	74	abdominal injury

B, bowel: stomach, small bowel, or colon; BR, bowel rupture; BM, bowel or mesentery; CSM, colon, small bowel, or mesentery; CT, computed tomography; M, mesentery; TP, true-positive; FN, false-negative; FP, false-positive; TN, true-negative; BMI, bowel or mesenteric injury; MI, mesenteric injury; +, positive.

proportion of 54% provided in the manuscript.[58] Further, dividing the 148 with eosinophilic esophagitis by the 298 who underwent biopsy (Table 3, page 21 of their manuscript) produced a total proportion of 49.7%, similar to the meta-analysis proportion of 52% (Supplementary Graph 5, page 8 of their manuscript).[58] We also evaluated a study that included 38 cohorts of patients who had a diagnosis of primary cardiac tumor.[59] The total number of primary cardiac tumor patients was 5586 (Table 1 of their manuscript) and the sum of the primary malignant cardiac tumor patients was 565.[59] Dividing the 565 with a primary malignant cardiac tumor by the 5586 diagnosed with primary cardiac tumor yielded a total proportion of 10.1%, similar to the meta-analysis proportion of 9.9% (page 43,289 of their manuscript).[59] The computations from these 2 studies demonstrate the comparability of the results using the current study method, when compared to meta-analysis proportion techniques.

Finally, another study included 11 cohorts of patients who had a diagnosis of Oculomotor Nerve Palsy (OMNP) due to Posterior Communicating Artery Aneurysm.[60] Their aim was to compare the overall proportion of complete OMNP resolution according to two aneurysm control interventions – surgical clipping or endovascular coiling.[60] Of the 98 patients described in the 11 cohorts, 43 had

Table 12
Mesenteric hematoma/fluid.

Study	Injury	TP	FN	FP	TN	Patient Traits
Atri, 2008[6]	CSM	17	21	6	52	had laparotomy
Bege, 2014[7]	BM	10	13	–	–	laparotomy: MI +
Breen, 1997[10]	M	3	2	5	21	had laparotomy
Cho, 2013[13]	BR	8	0	–	–	bowel rupture
Dowe, 1996╪[16]	M	6	15	–	–	MI needing surgery
Dowe, 1996╫[16]	M	12	9	–	–	MI needing surgery
Faget, 2015[18]	BM	24	32	32	468	blunt trauma
Hagiwara, 1995[20]	BR	0	13	–	–	bowel rupture
Hughes, 2002[24]	B	3	23	–	–	had laparotomy
Killeen, 2001╟[26]	M	13	14	41	8	had BMI
Killeen, 2001╫[26]	M	14	13	6	43	had BMI
Kim, 2004[27]	BR	8	49	–	–	bowel rupture
Malhotra, 2000[33]	BM	10	43	9	8050	blunt trauma
Malhotra, 2000[33]	B	0	28	–	–	blunt trauma
Malhotra, 2000[33]	M	10	22	–	–	blunt trauma
Matsushima, 2013[34]	BM	6	20	–	–	had laparotomy
Murakami, 2004[37]	M	12	3	–	–	laparotomy: MI +
Park, 2013[38]	BR	32	46	17	11	laparotomy: BMI +
Petrosoniak, 2013[39]	CSM	33	35	–	–	laparotomy: BMI +
Polat, 2014╪[40]	CSM	14	13	1	20	had laparotomy
Polat, 2014╪[40]	CS	13	11	–	–	had laparotomy
Polat, 2014╪[40]	M	1	6	–	–	had laparotomy
Polat, 2014╫[40]	CSM	5	22	1	20	had laparotomy
Polat, 2014╫[40]	CS	3	21	–	–	had laparotomy
Polat, 2014╫[40]	M	2	5	–	–	had laparotomy
Tan, 2010[46]	BM	2	29	–	–	laparotomy: BMI +

B, bowel: stomach, small bowel, or colon; BR, bowel rupture; BM, bowel or mesentery; BMI, bowel or mesenteric injury; CS, colon or small bowel; CSM, colon, small bowel, or mesentery; M, mesentery; TP, true-positive; FN, false-negative; FP, false-positive; TN, true-negative; MI, mesenteric injury; +, positive; ╫hematoma; ╪fluid; ╟contusion.

Table 13
Mesenteric stranding/streaking.

Study	Injury	TP	FN	FP	TN	Patient Traits
Atri, 2008[6]	CSM	32	6	20	38	had laparotomy
Bege, 2014[7]	BM	19	4	–	–	laparotomy: MI +
Cho, 2013[13]	BR	8	0	–	–	bowel rupture
de Araujo, 2014[14]	B	8	3	–	–	had laparotomy
Donohue, 1987[15]	BM	7	2	–	–	laparotomy: BMI +
Faget, 2015[18]	BM	33	23	52	448	blunt trauma
Fakhry, 2003[19]	BR	45	363	235	2615	blunt trauma
Hagiwara, 1995[20]	BR	9	4	0	417	blunt trauma
Hughes, 2002[24]	B	3	23	–	–	had laparotomy
Matsushima, 2013[34]	BM	8	18	–	–	had laparotomy
Murakami, 2004[37]	M	15	0	–	–	laparotomy: MI +
Petrosoniak, 2013[39]	CSM	19	49	–	–	laparotomy: BMI +
Polat, 2014[40]	CSM	22	5	5	16	had laparotomy
Polat, 2014[40]	CS	19	5	–	–	had laparotomy
Polat, 2014[40]	M	5	2	–	–	had laparotomy
Saku, 2006[41]	BR	7	5	–	–	bowel rupture
Sharma, 2004[43]	BR	5	8	–	–	bowel rupture
Wu, 2011[51]	B	8	1	11	86	blunt trauma

B, bowel: stomach, small bowel, or colon; BR, bowel rupture; BM, bowel or mesentery; BMI, bowel or mesenteric injury; CS, colon or small bowel; CSM, colon, small bowel, or mesentery; M, mesentery; TP, true-positive; FN, false-negative; FP, false-positive; TN, true-negative; MI, mesenteric injury; +, positive.

Table 14
Mesenteric vessel beading.

Study	Injury	TP	FN	FP	TN	Patient Traits
Atri, 2008[6]	CSM	19	19	3	55	had laparotomy
Bege, 2014[7]	BM	9	14	–	–	laparotomy: MI +
Cho, 2013[13]	BR	7	1	–	–	bowel rupture
Faget, 2015[18]	BM	7	49	6	494	blunt trauma
Steenburg, 2013[44]	B	3	12	10	101	CT positive MI

B, bowel: stomach, small bowel, or colon; BR, bowel rupture; BM, bowel or mesentery; CSM, colon, small bowel, or mesentery; CT, computed tomography; TP, true-positive; FN, false-negative; FP, false-positive; TN, true-negative; MI, mesenteric injury.

Table 15
Mesenteric vessel termination.

Study	Injury	TP	FN	FP	TN	Patient Traits
Atri, 2008[6]	CSM	17	21	4	54	had laparotomy
Cho, 2013[13]	BR	4	4	–	–	bowel rupture
Faget, 2015[18]	BM	14	42	4	496	blunt trauma
Steenburg, 2015[44]	B	2	13	11	100	CT positive MI

B, bowel: stomach, small bowel, or colon; BR, bowel rupture; BM, bowel or mesentery; CSM, colon, small bowel, or mesentery; CT, computed tomography; TP, true-positive; FN, false-negative; FP, false-positive; TN, true-negative; MI, mesenteric injury.

Table 16
Oral contrast extravasation.

Study	Injury	TP	FN	FP	TN	Patient Traits
Atri, 2008[6]	CSM	3	35	0	58	had laparotomy
Killeen, 2001[26]	B	2	23	0	49	had BMI
Malhotra, 2000[33]	BM	2	51	0	8059	blunt trauma
Malhotra, 2000[33]	B	1	27	–	–	blunt trauma
Malhotra, 2000[33]	M	1	31	–	–	blunt trauma
Petrosoniak, 2013[39]	CSM	15	53	–	–	laparotomy: BMI +
Scaglione, 2004[42]	B	4	9	–	–	laparotomy positive
Steenburg, 2015[44]	B	0	15	0	111	CT positive MI
Tsang, 1997[47]	BR	0	7	–	–	bowel rupture

B, bowel: stomach, small bowel, or colon; BR, bowel rupture; BM, bowel or mesentery; CSM, colon, small bowel, or mesentery; CT, computed tomography; M, mesentery; TP, true-positive; FN, false-negative; FP, false-positive; TN, true-negative; +, positive; BMI, bowel or mesenteric injury; MI, mesenteric injury.

Table 17
Retroperitoneal air.

Study	Injury	TP	FN	FP	TN	Patient Traits
Atri, 2008[6]	CSM	2	36	1	57	had laparotomy
Polat, 2014[40]	CSM	3	24	3	18	had laparotomy
Polat, 2014[40]	CS	3	21	–	–	had laparotomy
Polat, 2014[40]	M	1	6	–	–	had laparotomy

CS, colon or small bowel; CSM, colon, small bowel, or mesentery; M, mesentery; TP, true-positive; FN, false-negative; FP, false-positive; TN, true-negative.

clipping with complete OMNP resolution in 36 (83.7%), whereas in the 55 who had coiling complete OMNP resolution was found in 29 (52.7%).[60] The authors simply took the total number of patients with complete OMNP resolution according to the clipping or coiling intervention and divided these values by the total patients who underwent clipping or coiling, a method similar to that utilized in the current investigation. We believe that our method for combining study proportions to create a weighted mean proportion has literature-based precedence and validity.

Clinical implications

CT performance in the detection of BBMI requiring surgical intervention was evaluated in all 45 studies. The aggregate CT data focused on BBMI patients who required surgical intervention, but commonly included other patients, some who were operated upon and some that were not. The 15 individual CT sign data included only studies where the BBMI patients required an operative procedure; with the exception of bowel wall hematoma (Table 5), where each study is delineated according to surgical intervention status.

The BBMI sensitivity for aggregated CT signs was nearly 90%; however, this leaves a substantial clinically important gap in detecting BBMI necessitating an operative procedure by CT. Most of the study investigators used between 6 and 8 individual CT signs to determine the presence or absence of BBMI. To compensate for CT scanning insensitivity, recommendations have included sequential abdominal examinations to detect tenderness or distention, WBC count monitoring, and vital sign assessments and repeat CT scanning.[5,18,35,39,45] The presence of an abdominal wall injury has also been advocated as a sign that should increase concern for the presence of BBMI.[18]

Individual CT sign sensitivity for BBMI requiring surgical intervention ranged from as high as 66% to as low as 9%, with all but one synthesized sensitivities containing more than 100 patients. BBMI sensitivity was less than 60% for all of the individual CT signs, except free fluid, and although the sensitivity for free fluid was 66%, the PPV had only a 1-in-4 chance for the presence of BBMI requiring surgical intervention. These findings suggest that multiple CT signs are necessary to detect BBMI necessitating an operative procedure, yet there remains a gap relative to comprehensive BBMI detection, even when multiple CT signs are included.

The aggregate CT PPV for BBMI was 50% and was computed from almost a thousand patients for which the true-positive and false-positive status had been documented. That is, for every patient where the CT scan suggests that a BBMI requiring surgical intervention is present, another patient will have no BBMI, a 1-to-1 chance of BBMI yes or BBMI no. The PPV was ≥60% for less than half of the individual BBMI CT signs (7/15 signs). This implies that the number of false-positive observations substantially exceed those with true-positive outcomes.

It is also important to consider the 95% confidence interval for small cohorts of less than 100 observations. For example, retroperitoneal air had a PPV of 55.6% but the CI range is 26.7%–81.1%. Out of the 48 computed proportions in this systematic review, 36 were based on data containing 100 or more observations, and 12 were based on data containing less than 100 total observations. In 10 of the 12 computed proportions, the lower CI was 64–92% of the computed proportion. That is, the lowest likely proportion is quite similar to the computed proportion. In 2 of the 12 computed proportions made from 100 observations or less, the lower CI was 50% of the proportion (retroperitoneal air sensitivity and PPV), that is, the actual or real point estimate may very well be substantially lower than the computed proportion estimate. The authors can conclude that only 2 of the 48 proportional computations may be imprecise from a clinical perspective.

The relative insensitivity of CT scanning to detect surgically significant BBMI is a concern for the trauma surgeon. For patients with abdominal pain or tenderness, hemodynamic instability, systemic inflammatory response syndrome, or coma and a benign appearing abdominal CT scan, the trauma surgeon should consider that this may be a false-negative BBMI image. Investigations that were included in the current review also provide evidence that repeat CT scanning can increase the sensitivity for detecting bowel perforation.[41,49] Thus, it would be reasonable to consider repeating the abdominal CT, when the initial images are unimpressive or with uncertainty regarding surgically significant BBMI yet abdominal pain or tenderness, hemodynamic instability, systemic inflammatory response syndrome, or coma are present.

Study limitations

This analysis has several limitations. First, PubMed was the only publication database searched for relevant articles. Searching Excerpta Medica Database (EMBASE) or Ovid in addition to PubMed could have increased the eligible studies and cohorts. However, an interesting study that examined seven common medical databases found that PubMed retrieved more articles than all the other six databases.[56] That study reported that Ovid and PubMed produced similar search results, with the exception that PubMed is larger

Table 18
Retroperitoneal fluid.

Study	Injury	TP	FN	FP	TN	Patient Traits
Atri, 2008[6]	CSM	14	24	28	30	had laparotomy
Cho, 2013[13]	BR	7	1	–	–	bowel rupture
Polat, 2014[40]	CSM	11	16	12	9	had laparotomy
Polat, 2014[40]	CS	9	15	–	–	had laparotomy
Polat, 2014[40]	M	5	2	–	–	had laparotomy

BR, bowel rupture; CS, colon or small bowel; CSM, colon, small bowel, or mesentery; M, mesentery; TP, true-positive; FN, false-negative; FP, false-positive; TN, true-negative.

with a broader scope than Ovid, and would retrieve a larger number of articles when a text word search was employed.[56] A different evaluation that searched MEDLINE, EMBASE, and CENTRAL concluded that those three databases were not sufficient for identifying all studies, and that searching an additional ten databases only improved the publication recall by 2%.[61] They suggested that authors consider additional resources.[61] The authors of this review searched the bibliographies of all 99 full-text articles that were assessed for eligibility including the bibliographies of all identified review articles for other apposite articles, rather than searching other databases. While searching multiple databases would have initially retrieved hundreds of more articles, it would have also resulted more duplicate articles and more irrelevant articles. It is unlikely that searching additional databases would have provided enough eligible studies to influenced the results of this review.

Secondly, to be included in this analysis, all patients in the cohort must have undergone surgical intervention for the BBMI, with the exception of bowel wall hematoma. Our study reflects the limitations inherent to all studies used in this analysis. Time from presentation to initial CT was not mentioned in all studies. In some studies, oral contrast was administered as part of the protocol prior to initial CT. CT findings for each type of injury (small bowel, large bowel and mesenteric) were grouped together in many studies as were findings specific or suggestive of an injury. A few studies were older and utilized first generation CT scanners. Therefore, a prospective study with standardized time to CT, contrast type and CT type with careful radiologic evaluation and surgical correlation for all aforementioned CT signs might provide better and more accurate interpretation for the significance of these findings.

Finally, this systematic review utilized methods for the synthesis of studies without control groups.[55] Standard meta-analytic proportion computations using a random effects or fixed effects model, where appropriate, might have produced different proportion point estimates. Based on the methodological justification with examples, it is unlikely that traditional meta-analytic methods would have produced significantly different results for aggregate and individual CT signs that would change the clinical implications of the findings.

Conclusion

Overall the sensitivity, specificity and PPV for BBMI vary substantially among the 15 widely known and accepted CT signs. Although CT scan is a valuable diagnostic modality, its sensitivity suggests that other clinical factors are necessary for comprehensive identification of surgical BBMI. The trauma surgeon should consider repeating the abdominal CT in select patients.

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Disclosures and conflict of interest

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.amjsurg.2018.08.018.

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