Academic Emergency Medicine
Official Journal of the Society for Academic Emergency Medicine

Continuing Medical Education

Continuing Medical Education Activity in *Academic Emergency Medicine*

CME Editor: Hal Thomas, MD
Authors: Mark R. Taylor, MD, and Nadim Lalani, MD, FRCPC

Article Title: Adult Small Bowel Obstruction

If you wish to receive free CME credit for this activity, please refer to the website: http://www.wileyhealthlearning.com.

Accreditation and Designation Statement:
Blackwell Futura Media Services designates this journal-based CME activity for a maximum of 1 *AMA PRA Category 1 Credit*™. Physicians should only claim credit commensurate with the extent of their participation in the activity.

Blackwell Futura Media Services is accredited by the Accreditation Council for Continuing Medical Education to provide continuing medical education for physicians.

Educational Objectives
After completing this exercise the participant will be able to explain the relative roles of the various components of the diagnostic assessment for small bowel obstructions in adults.

Activity Disclosures
No commercial support has been accepted related to the development or publication of this activity.

Faculty Disclosures:
CME editor – Hal Thomas, MD: No relevant financial relationships to disclose.

Authors – Mark R. Taylor, MD, and Nadim Lalani, MD, FRCPC

This manuscript underwent peer review in line with the standards of editorial integrity and publication ethics maintained by *Academic Emergency Medicine*. The peer reviewers have no relevant financial relationships. The peer review process for *Academic Emergency Medicine* is double-blinded. As such, the identities of the reviewers are not disclosed in line with the standard accepted practices of medical journal peer review.

Conflicts of interest have been identified and resolved in accordance with Blackwell Futura Media Services's Policy on Activity Disclosure and Conflict of Interest. No relevant financial relationships exist for any individual in control of the content and therefore there were no conflicts to resolve.

Instructions on Receiving Free CME Credit
For information on applicability and acceptance of CME credit for this activity, please consult your professional licensing board.

This activity is designed to be completed within an hour; physicians should claim only those credits that reflect the time actually spent in the activity. To successfully earn credit, participants must complete the activity during the valid credit period, which is up to two years from initial publication.

Follow these steps to earn credit:

- Log on to http://www.wileyhealthlearning.com
- Read the target audience, educational objectives, and activity disclosures.
- Read the article in print or online format.
- Reflect on the article.
- Access the CME Exam, and choose the best answer to each question.
- Complete the required evaluation component of the activity.

This activity will be available for CME credit for twelve months following its publication date. At that time, it will be reviewed and potentially updated and extended for an additional twelve months.

CME

Adult Small Bowel Obstruction

Mark R. Taylor, MD, and Nadim Lalani, MD, FRCPC

Abstract

Background: Small bowel obstruction (SBO) is a clinical condition that is often initially diagnosed and managed in the emergency department (ED). The high rates of potential complications that are associated with an SBO make it essential for the emergency physician (EP) to make a timely and accurate diagnosis.

Objectives: The primary objective was to perform a systematic review and meta-analysis of the history, physical examination, and imaging modalities associated with the diagnosis of SBO. The secondary objectives were to identify the prevalence of SBO in prospective ED-based studies of adult abdominal pain and to apply Pauker and Kassirer's threshold approach to clinical decision-making to the diagnosis and management of SBO.

Methods: MEDLINE, EMBASE, major emergency medicine (EM) textbooks, and the bibliographies of selected articles were scanned for studies that assessed one or more components of the history, physical examination, or diagnostic imaging modalities used for the diagnosis of SBO. The selected articles underwent a quality assessment by two of the authors using the Quality Assessment of Diagnostic Accuracy Studies 2 (QUADAS-2) tool. Data used to compile sensitivities and specificities were obtained from these studies and a meta-analysis was performed on those that examined the same historical component, physical examination technique, or diagnostic test. Separate information on the prevalence and management of SBO was used in conjunction with the meta-analysis findings of computed tomography (CT) to determine the test and treatment threshold.

Results: The prevalence of SBO in the ED was determined to be approximately 2% of all patients who present with abdominal pain. Having a previous history of abdominal surgery, constipation, abnormal bowel sounds, and/or abdominal distention on examination were the best history and physical examination predictors of SBO. X-ray was determined to be the least useful imaging modality for the diagnosis of SBO, with a pooled positive likelihood ratio (+LR) of 1.64 (95% confidence interval [CI] = 1.07 to 2.52). On the other hand, CT and magnetic resonance imaging (MRI) were both quite accurate in diagnosing SBO with +LRs of 3.6 (5- to 10-mm slices, 95% CI = 2.3 to 5.4) and 6.77 (95% CI = 2.13 to 21.55), respectively. Although limited to only a select number of studies, the use of ultrasound (US) was determined to be superior to all other imaging modalities, with a +LR of 14.1 (95% CI = 3.57 to 55.66) and a negative likelihood ratio (–LR) of 0.13 (95% CI = 0.08 to 0.20) for formal scans and a +LR of 9.55 (95% CI = 2.16 to 42.21) and a –LR of 0.04 (95% CI = 0.01 to 0.13) for beside scans. Using the CT results of the meta-analysis for the 5- to 10-mm slice subgroup as well as information on intravenous (IV) contrast reactions and nasogastric (NG) intubation management, the pretest probability threshold for further testing was determined to be 1.5%, and the pretest probability threshold for beginning treatment was determined to be 20.7%.

Conclusions: The potentially useful aspects of the history and physical examination were limited to a history of abdominal surgery, constipation, and the clinical examination findings of abnormal bowel sounds and abdominal distention. CT, MRI, and US are all adequate imaging modalities to make the diagnosis of SBO. Bedside US, which can be performed by EPs, had very good diagnostic accuracy and has the potential to play a larger role in the ED diagnosis of SBO. More ED-focused research into this area will be necessary to bring about this change.

ACADEMIC EMERGENCY MEDICINE 2013; 20:528–544

From the Department of Emergency Medicine, University of Saskatchewan, Saskatoon, SK, Canada.

Received July 26, 2012; revisions received October 28, 2012, and January 2, 2013; accepted January 28, 2013.

The authors have no relevant financial information or potential conflicts of interest to disclose.

Supervising Editor: Christopher R. Carpenter, MD, MS.

Address for correspondence and reprints: Mark R. Taylor, MD; e-mail: mark.taylor@ualberta.ca.

A related commentary appears on page 618.

ISSN 1069-6563
PII ISSN 1069-6563583

doi: 10.1111/acem.12150

Small bowel obstruction (SBO) is a common clinical condition that is often initially diagnosed and managed by an emergency physician (EP). It is estimated that 300,000 hospitalizations occur annually as a result of SBO in the United States,[1] with approximately 70% of these patients being admitted through an emergency department (ED).[2] The diagnosis of intestinal obstruction in the ED has been estimated to be around 2% of all patients who present with the symptom of abdominal pain,[3] and 15% of all patients who ultimately get admitted to a surgical unit from the ED.[1] Although presentations are highly variable, primary emergency medicine (EM) textbooks teach the "classical" signs and symptoms as some combination of abdominal pain, nausea, vomiting, and abdominal distention.[4,5]

The most common cause of SBO is adhesions from previous abdominal surgery, which account for approximately 75% of all cases.[6] Other common etiologies include neoplasms, hernias, and Crohn's disease.[7] The complication risks associated with SBO are very high, with strangulation occurring in 30% and bowel necrosis in 15%.[8] Both may ultimately lead to perforation, sepsis, and death.[9] Risk factors for complicated SBO included age, comorbid illness, and a delayed diagnosis of >24 hours.[8] The high rate of complications and the need for urgent management make it essential for the EP to make the diagnosis as early as possible.

There are several diagnostic tests available to assist in making the diagnosis of SBO. These include plain radiographs, ultrasonography (US), computed tomography (CT), and magnetic resonance imaging (MRI). There are currently no serum markers that are predictive of noncomplicated SBO, limiting any potential usefulness in the ED decision-making process.[10] Patients with strangulated bowel obstruction were not the focus of this meta-analysis, but often present with metabolic acidosis[11] and elevation of other potential serum markers that are not readily available to the EP, such as intestinal fatty acid–binding protein.[12]

An effective way to make the diagnosis of SBO in the ED as quickly as possible is with the use of likelihood ratios (LRs) as described by Hayden et al.[13] Diagnosis is made from determining a pretest probability based on the history and physical examination and from a LR of the specific diagnostic test used. Historically, this information could have been plotted on the Fagan nomogram to determine a posttest probability of having the condition.[14] Readily available and easy-to-use applications such as PEPID (www.pepid.com) and MedCalc (www.medcalc.org) have replaced the Fagan nomogram as quick alternatives for the EP to accomplish this task. Although this approach can be very useful, it ultimately depends on the EP's ability to determine an accurate pretest probability and to have clinically relevant LRs available for the diagnostic tests that are ordered. Unfortunately, there are few EM-specific resources that assist in this task. Core EM textbooks do not provide summarized quantitative data in regard to history, physical examination, and diagnostic test LRs for SBO and instead rely on single study findings at best.[4,5] To the best of our knowledge, no EM-specific systematic reviews for the diagnosis of SBO exist. Of the non-EM reviews that have been written regarding SBO, including those from the surgical literature, none provide a comprehensive diagnostic meta-analysis with pooled estimates for history and physical examination as well as diagnostic studies.[15–18]

The primary objective of this meta-analysis was to provide the EP with evidence-based reliability and pooled diagnostic accuracy estimates for history, physical examination, and imaging for SBO in ED settings. This information can then be used to develop pre- and posttest probability of SBO to facilitate Bayesian decision-making and hopefully improve diagnostic accuracy and efficiency. The second objective is to use the method described by Pauker and Kassirer[19] to determine a test-treatment threshold for SBO to assist the EP in deciding when to begin treatment for SBO versus getting further testing to confirm the diagnosis. Treatment in this case involves conservative management with intravenous (IV) fluids and nasogastric (NG) intubation.

METHODS

Search Strategy

One investigator (MRT) searched the medical literature using both OVID MEDLINE and EMBASE during the time periods of 1946 to November 2011 and 1947 to November 2011, respectively. The Medical Subject Headings (MeSH) term *intestinal obstruction* was combined individually using "and" with the MeSH terms *emergency medicine, history, physical examination, sensitivity and specificity, diagnostic tests,* and *diagnostic imaging*. The "explode" option was used for the OVID MEDLINE search. Results were limited to "humans" and "English language studies." An additional OVID MEDLINE search was used with the above terms along with the search limitations of "Clinical Prediction Guidelines" (best balance of sensitivity and specificity—a MEDLINE clinical query option used to retrieve the largest number of high-quality studies).[20] To identify the risk of IV contrast allergic reactions from CT for the test-treatment threshold, the MeSH terms *IV contrast* and *hypersensitivity* were used in a MEDLINE search. Conversely, the MeSH term *gastrointestinal intubation* was searched with the limit of "therapy (best balance of sensitivity and specificity)" to determine the risks and benefits of NG insertion. References from selected articles, the Cochrane database of systematic reviews, and core textbooks of EM[4,5] were searched for relevant studies. This expansive search strategy was also used to identify the studies of SBO prevalence after the above combined MeSH terms with the addition of *prevalence* failed to produce any articles stating these statistics. Abstract submissions to *Academic Emergency Medicine* (1995 to November 2011), *Annals of Emergency Medicine* (1993 to November 2011), and *Canadian Journal of Emergency Medicine* (2002 to November 2011) were also searched. The articles that provided the highest level of evidence according to the hierarchy of evidence-based medicine were selected for use in the test-treatment threshold calculations. The hierarchy of evidence-based medicine considers the relative strength of the primary types of research in the following order: systematic reviews rank above individual randomized controlled trials, which in

turn rank above cohort studies, case-control studies, and expert opinion.[21]

The inclusion criteria for the studies selected included those that focused primarily on SBO in an adult population and with sufficient data to develop a two-by-two table for sensitivity and specificity calculations. There were a few studies included that indiscriminately assessed bowel obstruction in general, but whose study populations predominantly were diagnosed with SBO.[22–26] Our exclusion criteria included case studies, studies with insufficient data to develop a two-by-two table, pediatric populations studies, those with tests not readily available to the EP, those focused on a single radiographic sign, those focused on treatment, and studies that were not primary research. Furthermore, studies that focused solely on ischemic bowel, cancer, intussusception, or Crohn's disease were not selected. Both authors independently reviewed all the titles and abstracts for selection of potential studies using the predetermined inclusion criteria. A medical librarian provided assistance when requested in the retrieval process.

Individual Evidence Quality Appraisal

The authors independently used the Quality Assessment of Diagnostic Accuracy Studies tool (QUADAS-2) to evaluate the evidence of the studies that were selected.[27] When there was disagreement regarding one of the aspects of the QUADAS-2 answers, consensus was reached via discussion. Statistical agreement was determined with kappa analysis using SPSS Statistics v17.0 (SPSS, Inc., Chicago, IL).[28]

The QUADAS-2 tool uses four key domains to assess for bias: patient selection, index test, criterion standard, and flow and timing.[27] In terms of patient selection, bias was determined to be high if a study used a case-control approach, did not have a random or consecutive sample of patients enrolled, or had inappropriate exclusions. If the majority of the patients involved were not originally assessed in the ED, then the concern that patients did not match the review question was stated as being either unclear or high. The risk of bias for the index test was determined to be high if the test was interpreted with knowledge of the criterion standard. On the other hand, bias of the use of the criterion standard was high if the criterion standard was unlikely to correctly classify the target condition. Last, bias toward study flow was stated as high if all the patients were not included in the analysis or if they were not subject to a criterion standard.

Data Analysis

The following information was independently collected from the selected studies by the two authors using a standardized collection form: type of study, setting, patient population, inclusion criteria, index test, index test properties, criterion standard, true-positives and -negatives, and false-positives and -negatives. Each of the studies had a majority of this information readily available in their methods and results sections. A "true-positive" was defined as a diagnostic test that correctly identified SBO according to previously defined criteria and was confirmed with the criterion standard. A "false-positive" was a diagnostic test that suggested SBO was present when the criterion standard did not demonstrate this. A "true-negative" was a diagnostic test that suggested the absence of SBO when the criterion standard confirmed that no SBO was present. A "false-negative" was a diagnostic test that suggested no SBO was present when the criterion standard found there to be one.

Sensitivities and specificities were determined and LRs were calculated whenever possible. If there were more than two qualitatively similar studies of the same index test, we combined the results using Meta-DiSc.[29] Interstudy heterogeneity of the pooled sensitivities and specificities was assessed with the I^2 and chi-square test using the Dersimonian-Laird random effects model.[30] Data were not combined for the history and physical examination because there were only two studies that looked at these components, and each assessed a different group of questions and physical examination maneuvers. If there was significant heterogeneity for a particular diagnostic test, single studies were sequentially removed to see if the heterogeneity could be eliminated. This was not possible for some subsets.

There was tremendous variability in the equipment and techniques used in the studies that looked at CT scan for SBO. The one variable that was most likely to affect the accuracy of the studies was the thickness of slices that were taken, also known as beam collimation.[31] The groups were divided into the studies that did not define slice thickness and those that were 50-, 5- to 10, or 0.75-mm slices. US studies were split into those that were formal US done by radiology and those that were bedside US done in the ED.

Test-Treatment Threshold

From our selected studies we abstracted the following data for inclusion into the Pauker and Kassirer model equation for test-treatment threshold: sensitivity of test, specificity of test, false-negatives of test, false-positives of test, risk of test, risk of treatment in those without SBO, and anticipated benefit of treatment in those with SBO.[19] The 5- to 10-mm subgroup of CT scans was chosen as the test of choice because 7 mm is the mean slice thickness used for abdominal pain protocols, according to the Society of Computed Body Tomography.[32] These variables are highly open to interpretation and estimates were based on the best available research.

RESULTS

A search of MEDLINE yielded 3,801 studies. An assessment of both titles and abstracts selected 207 studies for further review. A search of EMBASE yielded 3,901 studies, of which 136 were selected for further review. Twenty papers were selected that met the inclusion criteria. An additional two papers were added from a review of the bibliographies of selected articles, for a total of 22 papers (Figure 1).[22–26,33–49] Data Supplement S1 (available as supporting information in the online version of this paper) includes summaries of all the included studies.

There were 12 prospective, cross-sectional studies[22,24–26,34,36–39,41,44,46] and 10 retrospective

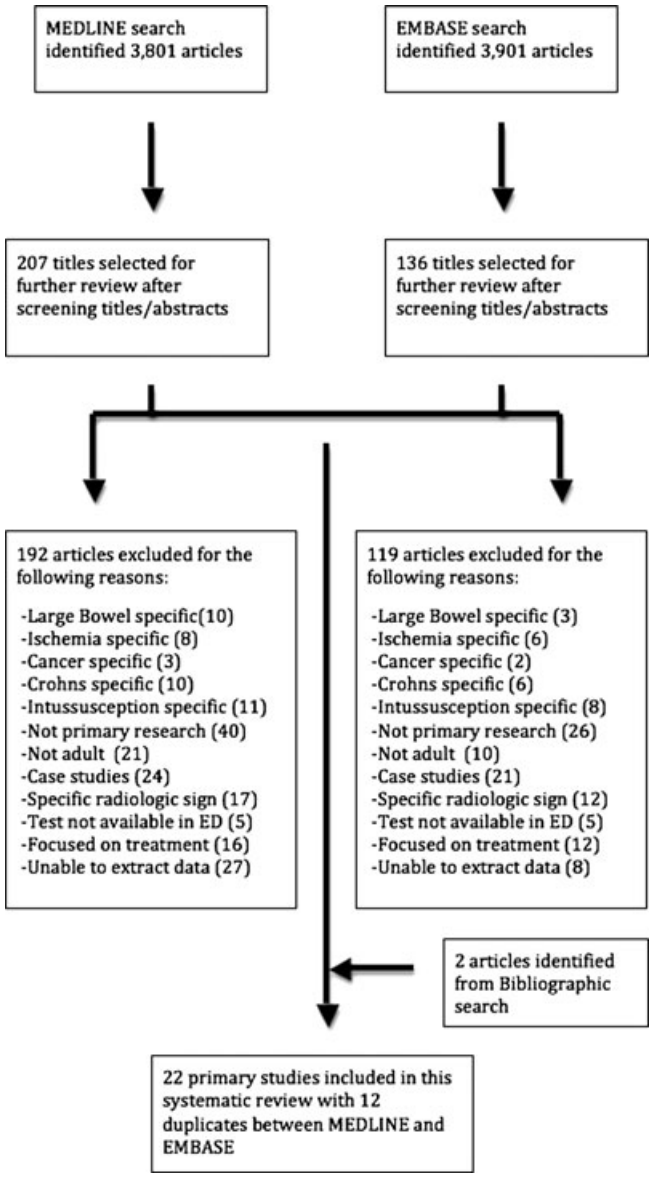

Figure 1. Article selection process.

studies.[23,33,35,40,42,43,45–49] No case-control or randomized controlled trials were identified. Two studies looked at the history and physical examination for diagnosis of SBO.[24,33] Others looked at the different imaging modalities and often compared them head to head for the diagnosis of SBO.[22,34,35] There were only two studies that were based on an emergency patient population exclusively, and both were ED-personnel US studies.[36,37] The rest often included patients who were first assessed in the ED, but were not explicitly limited to these patients.

Table 1 shows a summary of the QUADAS-2 assessments. The purpose of the tool is to help readers judge the risk of bias in the markedly heterogeneous group of studies that make up this meta-analysis. The kappa scores ranged from 0.621 to 1. The majority of the articles selected for this meta-analysis had low risks of bias in patient selection, index test usage, criterion standard choice, and flow and timing. However, some studies did not explicitly explain how the patient selection process occurred.[23,37–39] Moreover, for several studies it was unclear whether the criterion standard results were interpreted without knowledge of the index test.[22–25,40–45] Finally, some studies did not state the interval between the reference test and the criterion standard.[24,33,35,41,42,45–47]

The criterion standard for the majority of the studies was usually a combination of surgical findings, eventual clinical outcomes, or both. Unfortunately, many of the studies do not go into further detail about the specifics of the surgical diagnosis nor the timeline of the eventual clinical diagnosis.

Prevalence

There are very few studies that state the prevalence of SBO in the ED. A study completed at the University of Virginia Hospital provided an estimate of 2% for all patients presenting with abdominal pain to the ED.[3] An audit of a U.K. ED reported an intestinal obstruction prevalence-based estimate of 15% of all patients with abdominal pain who presented to the ED and were admitted to a surgical unit.[1] They did not differentiate between large or SBOs. Another large population-based study out of California had 30,000 SBO admissions annually, of which 70% originally presented to an ED.[2] Other sources state that SBO accounts for approximately 15% to 20% of all admissions to surgical services.[50,51]

History

Only two articles assessed the diagnostic accuracy of history for SBO and met the inclusion criteria.[24,33] The results are shown in Table 2. Both studies used surgical findings, x-ray findings, or diagnosis at time of discharge as their criterion standard. The first study was a prospective analysis of 1,300 patients in Finland who were admitted with acute abdominal pain.[33] Only 53 of these patients were ultimately found to have SBOs from operation or clinical follow-up. There were no components of the history that could reliably and accurately predict SBO. Having a history of previous abdominal surgery had the best combination (+LR = 3.86 and –LR = 0.19). The second study was also prospective and looked at 1,200 patients presenting with abdominal pain to several hospitals throughout Germany.[24] Forty-eight patients ultimately were diagnosed with SBO. In this study, a history of constipation had the best combination (+LR = 8.8 and –LR = 0.59).

Physical Examination

The same two articles that assessed the history for SBO also looked at the physical examination findings.[24,33] The results are shown in Table 3. Again, there were very few components of the physical examination that could be used reliably for diagnostic accuracy. Abdominal distention was the best sign with a +LR of 16.8 and –LR of 0.34 in the study by Eskelinen et al.[33] and +LR of 5.64 and –LR of 0.43 in the study by Böhner et al.[24] Eskelinen et al. also found that abnormal bowel sounds had a +LR of 6.33 and a –LR of 0.27. Having a normal urine was 100% sensitive, but not very specific, and visualizing peristalsis was 100% specific but not very sensitive.

Table 1
QUADAS-2 Results

	Risk of Bias				Applicability Concerns		
Study, year	Patient Selection	Index Test	Criterion Standard	Flow and Timing	Patient Selection	Index Test	Criterion Standard
Fukuya 1992[38]	H	L	L	L	L	L	L
Maglinte 1993[49]	L	L	L	L	L	L	L
Eskelinen 1994[33]	L	L	U	U	L	L	U
Frager 1994[46]	L	L	L	U	L	L	L
Maglinte 1996[35]	L	L	L	H	L	L	L
Ogata 1996[26]	L	L	L	L	L	L	L
Schmutz 1997[39]	L	L	L	L	H	L	L
Böhner 1998[24]	L	U	U	U	L	L	H
Makanjuola 1998[42]	L	U	U	U	L	L	L
Regan 1998[43]	L	L	U	L	L	L	L
Walsh 1998[47]	U	U	L	U	H	L	L
Daneshmand 1999[40]	L	L	H	L	L	L	L
Peck 1999[44]	L	L	U	L	L	L	L
Suri 1999[22]	L	L	U	L	L	L	L
Beall 2002[25]	L	L	U	L	L	L	L
Musoke 2003[34]	L	H	H	L	L	L	L
Obuz 2003[41]	U	U	H	U	L	L	L
Atri 2009[45]	L	L	H	H	L	L	L
Pongpornsup 2009[48]	L	L	L	L	L	L	L
Jang 2011[36]	L	L	L	L	L	U	L
Shakil 2011[23]	H	L	H	L	H	L	L
Ünlüer 2011[37]	H	L	L	L	L	L	L
Kappa	0.694	0.697	0.820	0.697	0.621	1	1

H = high-risk; L = low-risk; QUADAS-2 = Quality Assessment of Diagnostic Accuracy Studies 2; U = unclear risk.

X-ray

Five studies were included that looked at the usefulness of plain radiography in diagnosing SBO (Table 4, Figure 2).[22,34–36,40] Three were prospective case studies,[22,34,36] and two were retrospective case studies.[35,40] All of the studies used the previously defined criteria of SBO on x-ray to be greater than or equal to two air fluid levels in dilated loops of bowel (>2.5 cm).[52] A majority of the studies used two or more radiologists reading the images to ensure reliability. None of the studies provided kappa scores to assess reliability. All of the studies were small, with patient numbers in the range of 32 to 108. The criterion standard used was always surgical findings or eventual clinical outcome.

There was some heterogeneity across the included studies with a +LR 1.64 (95% confidence interval [CI] = 1.07 to 2.52) and an I^2 = 25%. With the removal of Musoke et al.,[34] the +LR and –LR had an I^2 = 0 and values of 1.55 (95% CI = 1.10 to 2.19) and 0.59 (95% CI = 0.43 to 0.82), respectively.

CT

Fourteen studies in total were examined that looked at the usefulness of CT for the diagnosis of SBO (Table 5, Figure 3). Six were prospective studies[22,25,38,41,44,46] and eight were retrospective studies.[23,35,40,42,45,47–49] All studies used surgical findings or diagnosis at time of discharge as the criterion standard.

Due to the significant advancement in CT technology over the past 20 years, there was tremendous variability between the studies in terms of the type of CT scanner used, the thickness of slices (ranging from 50 to 0.75 mm), and the use and timing of both IV and oral contrast. The most commonly used CT scanner was the General Electric 9800CT (Fairfield, CT).[42,47,49] Other models included the General Electric Helical[44,45,48] and the Seimens Somatom series (Siemens Medical Solution USA, Inc., Malvern, PA).[22,38,41] Two studies did not list the type of CT scanner used.[35,40] In terms of contrast, two studies used oral exclusively,[35,47] while two others did not mention the use of contrast.[23,40] All remaining studies used both oral and IV contrast for their CT scans.

Thinner CT slices improve diagnostic accuracy in bowel obstruction,[31] and therefore studies were grouped according to the thickness of slices that were taken. An SBO was diagnosed if continuous dilated loops of bowel >2.5 cm were present proximal to collapsed loops of bowel. These criteria were first described by Maglinte et al.[49] and were consistent across all studies. A majority of the studies used two radiologists for image interpretation as a measure of reliability. Only the study by Atri et al.[45] provided a kappa score for the reviewers, which was recorded as 0.68 to 0.80.

Several studies did not state the thickness of CT slices that were taken and are listed in Table 5.[23,35,40,47] These studies had sensitivities ranging from 50% to 92% and specificities ranging from 78% to 94%. Makanjuola et al.[42] used a very large slice size of 50 mm for their study. They reported a sensitivity and specificity of 79% (95% CI = 64% to 90%) and 67% (95% CI = 22% to 95%).

There was a large range of sensitivities (63% to 100%) and specificities (57% to 100%) for the studies that used slice sizes of 5 to 10 mm. These data were

Table 2
Statistical Measures of Performance of SBO History Characteristics

Risk Factor	Sensitivity, %	Specificity, %	+LR	–LR
Location pain initially (upper/lower/mid/general)				
Eskelinen[33]	87	41	1.47	0.22
Böhner[24]	23	93	3.28	0.83
Location pain at diagnosis (upper/lower/mid/general): Eskelinen[33]	78	61	2.0	0.36
Duration of pain > 6 hours: Eskelinen[33]	48	66	1.41	0.79
Intensity of pain (moderate-intolerable): Eskelinen[33]	80	35	1.23	0.57
Progression of pain (same/worse): Eskeline[33]	78	34	1.18	0.65
Type of pain (colic/intermittent):				
Eskelinen[33]	68	56	1.57	0.55
Böhner[24]	31	89	2.82	0.35
No aggravating factors: Eskelinen[33]	37	74	1.42	0.85
Relieved with vomiting:				
Eskelinen[33]	19	93	2.71	0.87
Böhner[24]	27	94	4.50	0.78
Previous similar pain: Eskelinen[33]	40	66	1.18	0.91
Vertigo: Eskelinen[33]	8	97	2.67	0.95
Nausea: Eskelinen[33]	80	43	1.40	0.35
Vomiting: Böhner[24]	75	65	2.14	0.38
No appetite: Eskelinen[33]	93	28	1.29	0.25
Previous indigestion: Eskelinen[33]	33	80	1.65	0.84
No jaundice: Eskelinen[33]	98	2	1.00	1.00
Constipation:				
Eskelinen[33]	37	90	3.7	0.70
Böhner[24]	44	95	8.8	0.59
Normal micturition: Eskelinen[33]	96	7	1.03	0.57
Used drugs for abdominal pain: Eskelinen[33]	8	78	2.00	0.96
Previous abdominal surgery:				
Eskelinen[33]	85	78	3.86	0.19
Böhner[24]	69	74	2.65	0.42
Previous abdominal disease: Eskelinen[33]	35	83	2.06	0.78
No use of alcohol: Eskelinen[33]	98	5	1.03	0.40
Increased pain on eating: Böhner[24]	17	94	2.83	0.88
Age > 50 yr: Böhner[24]	60	73	2.22	0.55

+LR = positive likelihood ratio; –LR = negative likelihood ratio; SBO = small bowel obstruction.

Table 3
Statistical Measures of Performance of SBO Physical Examination Characteristics

	Physical Examination			
Risk Factor	Sensitivity %	Specificity %	+LR	–LR
Abnormal mood: Eskelinen[33]	26	83	1.53	0.89
Abnormal color: Eskelinen[33]	89	13	1.02	0.85
Abnormal abdominal movement:				
Eskelinen[33]	19	94	3.17	0.86
Böhner[24]	27	91	3.00	0.80
Scar on abdomen: Eskelinen[33]	85	77	3.70	0.19
Distention:				
Eskelinen[33]	67	96	16.8	0.34
Böhner[24]	62	89	5.64	0.43
Tenderness (generalized):				
Eskelinen[33]	69	73	2.56	0.42
Böhner[24]	35	93	5.00	0.70
No rebound: Eskelinen[33]	59	48	1.13	0.85
Guarding: Eskelinen[33]	63	47	1.19	0.79
No rigidity: Eskelinen[33]	83	22	1.06	0.77
Rigidity: Böhner[24]	15	95	3.00	0.89
No Murphy's sign: Eskelinen[33]	98	10	1.09	0.20
Abnormal bowel sounds: Eskelinen[33]	76	88	6.33	0.27
Increased bowel sounds: Böhner[24]	40	89	3.63	0.67
Decreased bowel sounds: Böhner[24]	23	93	3.29	0.83
No renal tenderness: Eskelinen[33]	81	27	1.11	0.70
Absent rectal digital tenderness: Eskelinen[33]	80	28	1.11	0.71
Temperature < 37.1°C: Eskelinen[33]	80	44	1.43	0.45
Leukocyte count > 10×10^9/L: Eskelinen[33]	45	57	1.05	0.96
Normal urine: Eskelinen[33]	100	6	1.06	0
Visible peristalsis: Böhner[24]	6	100	∞	0.94
Abdominal mass: Böhner[24]	19	91	2.11	0.89

+LR = positive likelihood ratio; –LR = negative likelihood ratio; SBO = small bowel obstruction.

pooled together because the largest proportion of studies used this range for their scans. The pooled studies had a +LR of 3.6 (95% CI = 2.3 to 5.4) and a –LR of 0.18 (95% CI = 0.09 to 0.35). There was significant heterogeneity that could not be eliminated with the removal of any single study or series of studies. The heterogeneity likely can be attributed to the fact that these studies were completed in different years, in a variety of centers, and with different equipment.

The most technologically advanced scanners, those with thin slices and fast scanning times, had significantly superior sensitivities and specificities. Pongpornsup et al.[48] was the only study found to use a 64-slice multidetector with cuts of 0.75 mm. They had a sensitivity of 96% (95% CI = 80% to 100%) and a specificity of 100% (95% CI = 69% to 100%). Shakil et al.[23] used a 64-slice scanner with presumably thin slices and found a sensitivity of 93% (95% CI = 87% to 97%) and specificity of 93% (95% CI = 88% to 96%).

Table 4
Statistical Measures of Performance of X-ray for SBO Diagnosis

Study	Sensitivity,%	Specificity,%	+LR	–LR
Maglinte 1996[35]	69	57	1.6	0.54
Daneshmand 1999[40]	76	53	1.6	0.46
Suri 1999[22]	77	50	1.5	0.47
Musoke 2003[34]	86	100	∞	0.16
Jang 2011[36]	46	67	1.4	0.81
Summary estimate, (95% CI)	75 (68–80)	66 (55–76)	1.6 (1.1–2.5)	0.43 (0.24–0.79)

+LR = positive likelihood ratio; –LR = negative likelihood ratio; SBO = small bowel obstruction.

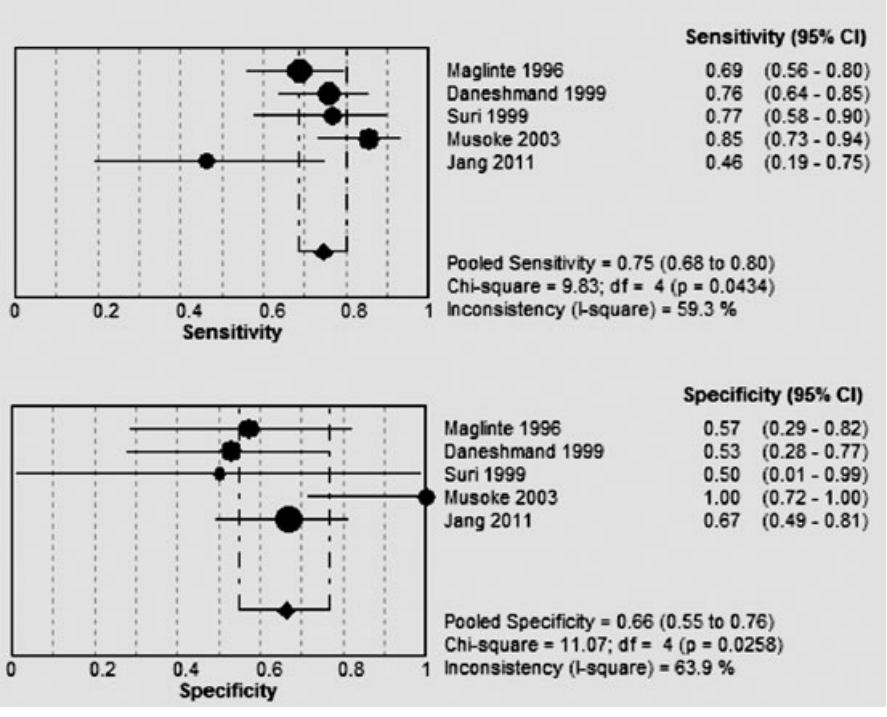

Figure 2. Meta-analysis of studies assessing x-ray performance for SBO diagnosis. SBO = small bowel obstruction.

MRI

Two studies were identified that examined the use of MRI for SBO (Table 6, Figure 4).[25,43] One was a prospective study,[25] and one was a retrospective study.[43] Both used HASTE (Half-Fourier acquisition single-shot turbo spin-echo) MR without any contrast material. Both used two radiologists for image interpretation. The study by Beall et al.[25] had an inter-rater kappa of 0.77, and the study by Regan et al.[43] had an inter-rater kappa of 0.76, indicating good reliability. Surgical findings or diagnosis at discharge were used as criterion standards.

Beall et al.[25] had a sensitivity of 95% (95% CI = 75% to 100%) and a specificity of 100% (95% CI = 40% to 100%), while Regan et al.[43] had a sensitivity of 90% (95% CI = 73% to 98%) and a specificity of 86% (95% CI = 57% to 98%). Together, the pooled +LR was 6.77 (95% CI = 2.13 to 21.55; I^2 = 0%) and –LR was 0.12 (95% CI = 0.04 to 0.26; I^2 = 0%).

US

All six studies using US were prospective studies (Table 7).[22,26,34,36,37,39] Four of these consisted of formal US that was interpreted by more than one radiologist.[22,34,37,39] One study consisted of formal US interpreted by only one radiologist.[26] Two studies looked at the use of bedside US in the ED for the diagnosis of SBO.[36,37] In Jang et al.[36] the residents who took part had completed a prior US course with a minimum of 10 US scans and had a 10-minute teaching session and five US scans for the diagnosis of SBO before taking part in the study. In Ünlüer et al.,[37] four residents with an unstated amount of previous US experience took part in the study and completed a 6-hour training course prior to beginning.

All of the studies used a 3.5-MHz curved or linear probe. A diagnosis of SBO was made if there were >2.5-cm dilated loops of bowel that were proximal to collapsed loops of bowel and there was absent or

Table 5
Statistical Measures of Performance of CT for SBO Diagnosis

Study	Sensitivity,%	Specificity,%	+LR	–LR
No slice size listed				
Maglinte 1996[35]	64	79	3.0	0.46
Walsh 1998[47]	50	94	9.0	0.53
Daneshmand 1999[40]	92	71	3.2	0.11
Shakil 2011[23]	93	93	13.0	0.07
50-mm slice size				
Makanjuola 1998[42]	79	67	2.4	0.31
5- to 10-mm slice size				
Fukuya 1992[38]	90	100	Infinity	0.16
Maglinte 1993[52]	63	78	2.8	0.48
Frager 1994[46]	100	83	5.5	<0.001
Suri 1999[22]	93	100	Infinity	0.10
Peck 1999[44]	90	57	2.1	0.17
Beall 2002[25]	71	71	2.5	0.40
Obuz 2003[41]	84	80	4.2	0.20
Atri 2009[45]	88	76	3.7	0.16
Summary estimate (95% CI)	87 (83–90)	81 (74–87)	3.6 (2.3–5.4)	0.18 (0.09–0.35)
0.75-mm slice size				
Ponpornsup 2009[51]	96	100	Infinity	0.04

+LR = positive likelihood ratio, –LR = negative likelihood ratio; SBO = small bowel obstruction.

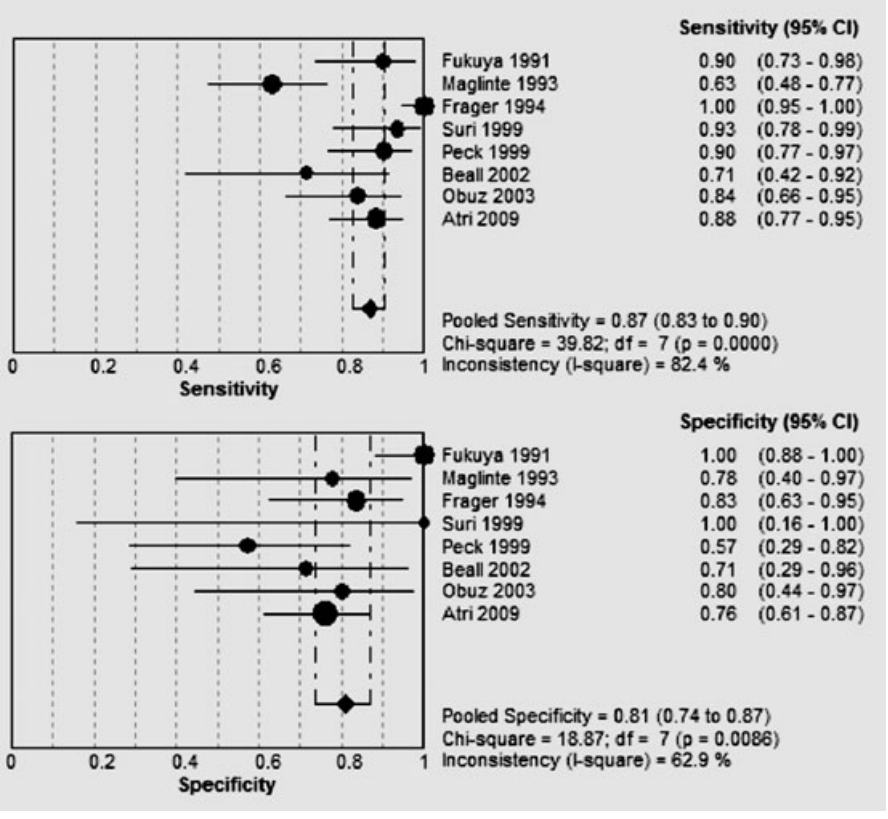

Figure 3. Meta-analysis of studies assessing CT performance for SBO diagnosis (5- to 10-mm slice size). SBO = small bowel obstruction.

decreased peristalsis activity. These criteria were described in Ogata et al.[26] The criterion standard used for the tests was either surgical findings or diagnosis at time of discharge. Ünlüer reported an inter-rater kappa of 0.81 for both the reviewers of bedside US and for the US completed in radiology.[37]

For the formal US pooled results (Figure 5), there was a significant amount of heterogeneity (I^2 = 59% and

Table 6
Statistical Measures of Performance of MRI for SBO Diagnosis

Study	Sensitivity,%	Specificity,%	+LR	–LR
Regan 1998[43]	95	100	Infinity	0.08
Beall 2002[25]	90	85	6.3	0.12
Summary estimate (95% CI)	92 (80–98)	89 (65–99)	6.7 (2.1–21.5)	0.11 (0.04–0.26)

+LR = positive likelihood ratio, –LR = negative likelihood ratio; SBO = small bowel obstruction.

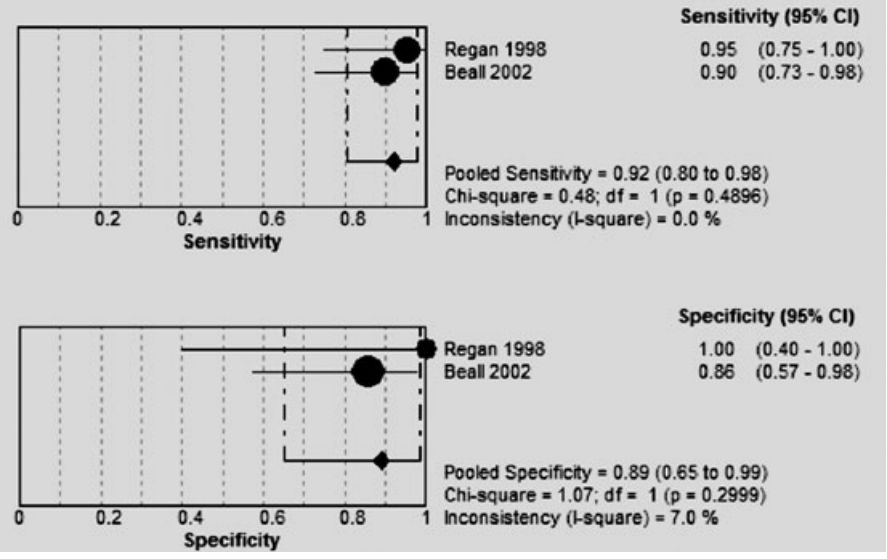

Figure 4. Meta-analysis of studies assessing MRI performance for SBO diagnosis. SBO = small bowel obstruction.

Table 7
Statistical Measures of Performance of US for SBO Diagnosis

Study	Sensitivity,%	Specificity,%	+LR	–LR
Formal US				
Ogata 1996[26]	79	96	20.6	0.22
Schmutz 1997[39]	95	82	5.3	0.06
Suri 1999[22]	83	100	Infinity	0.21
Musoke 2003[34]	93	100	Infinity	0.08
Ünlüer 2011[37]	88	100	Infinity	0.12
Summary estimate (95% CI)	90 (86–93)	96 (91–99)	14.1 (3.6–55.6)	0.13 (0.08–0.20)
Emergency US				
Ünlüer 2011[37]	98	95	19.5	0.02
Jang 2011[36]	94	81	5.0	0.07
Summary estimate, (95% CI)	97 (92–99)	90 (84–95)	9.5 (2.1–42.2)	0.04 (0.01–0.13)

+LR = positive likelihood ratio, –LR = negative likelihood ratio; SBO = small bowel obstruction; US = ultrasound.

36% for the +LR and –LR). The +LR was 14.1 (95% CI = 3.57 to 55.66) and a –LR was 0.13 (95% CI = 0.08 to 0.20). The bedside US pooled estimate (Figure 6) had a +LR of 9.55 (95% CI = 2.16 to 42.21; I^2 = 85%) and –LR 0.04 (95% CI = 0.1 to 0.13; I^2 = 25%).

Test-Treatment Threshold Estimates

The test-treatment threshold calculation relies on diagnostic test sensitivity and specificity, estimates of the benefits and risks of treatment, and estimates of the risks of the diagnostic test. These estimates are based solely on the best available evidence and, as such, are open to interpretation and scrutiny.

Management options for a patient with suspected SBO on history and physical examination are to continue with further testing in hopes of improving diagnostic accuracy or to begin treatment. Recent guidelines suggest a trial of conservative management for SBO for 3 to 5 days if there are no signs or symptoms suggestive of sepsis or peritonitis.[17] This involves

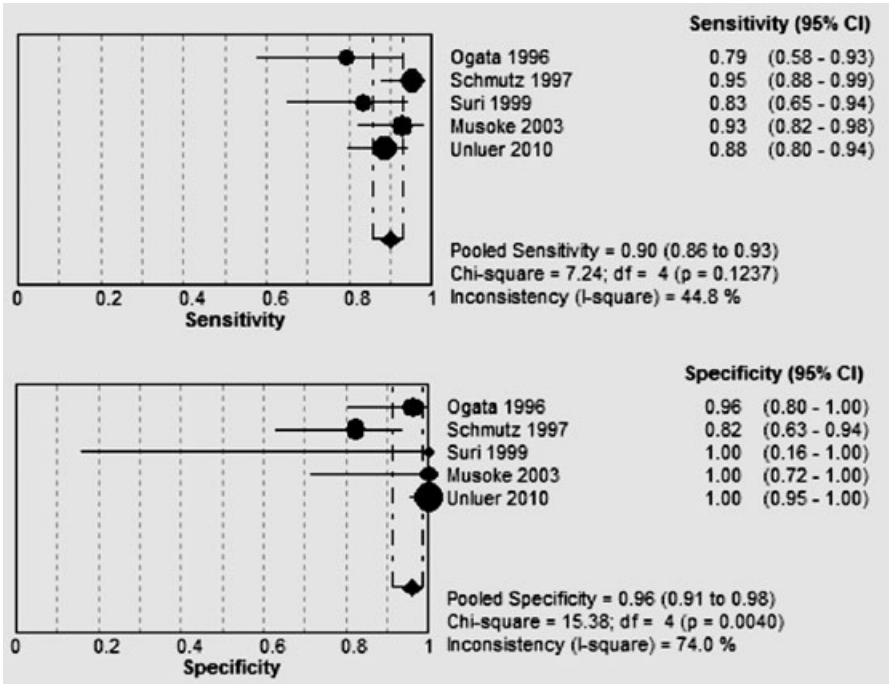

Figure 5. Meta-analysis of studies assessing formal US for SBO diagnosis. SBO = small bowel obstruction; US = ultrasound.

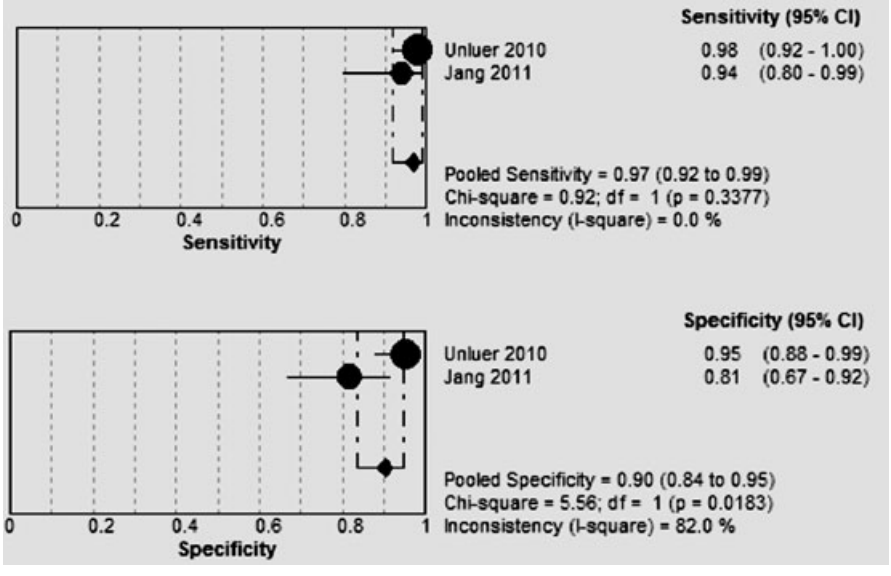

Figure 6. Meta-analysis of studies assessing emergency US for SBO diagnosis. SBO = small bowel obstruction; US = ultrasound.

administering IV fluids, implementing bowel rest, and decompressing the gastrointestinal tract with an NG tube.[18] The highest risk feature of this regimen is the NG tube, as neither IV fluids nor bowel rest carry any measurable risk. Unfortunately, there are no good randomized controlled trials that examine the use and risk of NG tube in SBO or whether there is harm in delaying this treatment measure until a definitive diagnosis is made. A Cochrane review on NG decompression after abdominal surgery, however, looked at the rate of pneumonia that occurred postdecompression from 27 separate studies.[53] The rate of pneumonia was approximately 3% higher in the patients who received an NG tube compared to those who did not. This estimate was used as our "risk of treatment."

The potential benefits of the conservative approach to SBO are many. It has been estimated that the conservative approach is effective to avoid the need for surgical intervention in approximately 65% of cases.[54–56] This is important, as the risk of mortality with an operation for SBO is approximately 5%, and the risk of postoperative complications is 23%.[8] It is presumed that patients with an NG tube also receive some pain relief and decreased nausea/vomiting, although it is difficult to quantify given

the fact that the procedure itself is known to be uncomfortable.[57] An estimate for the benefit of NG tube was made at 75% to estimate for both the avoidance of surgery and the potential benefits to the above symptoms. Because this number is highly open to interpretation, the calculation is included in the study so that different values may be incorporated (Figure 7). An online Excel calculator is also available to facilitate this task (Data Supplement S2, available as supporting information in the online version of this paper).

A definitive test in the ED has often been a CT. This involves the administration of either ionic or nonionic IV and/or oral contrast. Risk of a serious allergic reaction was estimated to be approximately 0.1% of those receiving the contrast.[58–61] The risk of an ionic contrast reaction was quoted as being 10 times higher than nonionic contrast reaction. This risk was chosen because it was immediate and much better quantified than other adverse outcomes such as the risk of future cancer from a CT.

Based on the test-treatment threshold calculation, there was a very low threshold of 1.5% to continue testing. This means that if the pretest probability of the patient having a SBO is <1.5%, then more testing may actually be riskier for the patient's health. On the other hand, if patients have a pretest probability of >20.7%, then they would benefit more from having treatment started as opposed to getting more investigations. These findings should be reassuring that early treatment is very low risk, even in the context of further testing. Although these findings are highly open to interpretation, they are comparable to those of other diagnoses in the literature such as pulmonary embolism. The testing thresholds for pulmonary embolism have been around 1.5%,[62] while the treatment thresholds have been determined to be around 25% to 30%.[63]

DISCUSSION

The Bayesian approach to the undifferentiated patient in the ED is a very effective method for improving clinical diagnosis and preventing unnecessary testing.[64] This approach involves plotting, on a hypothetical continuum of 0% to 100%, the clinical certainty that a patient has a given diagnosis based on both pre- and posttest probabilities.[65] Authors such as Kline et al.[66] have even advocated for the use of a Bayesian network consisting of a comprehensive computer-based analysis of variables for conditions that are difficult to diagnose, such as venous thromboembolism. Although there have been criticisms of the intuitiveness of using the Bayesian approach,[67] it is something that can be taught and learned with measurable results.[68] However, the ultimate usefulness of the Bayesian approach for conditions such as SBO relies on having accurate diagnostic data to develop the pre- and posttest probabilities. The pretest probability for SBO is a value that is based on the prevalence of the disease, as well as any history and physical examination findings. The best estimate for prevalence of SBO was 2% of all abdominal pains seen in the ED.[3] It does not, however, make intuitive sense to use 2% as a pretest probability because it negates any of the history or physical examination findings and includes all-comers for abdominal pain. Using a pretest probability of 15%, which is the percentage of patients that get admitted to a surgical unit from an ED who are ultimately diagnosed with a SBO,[1] likely better incorporates the

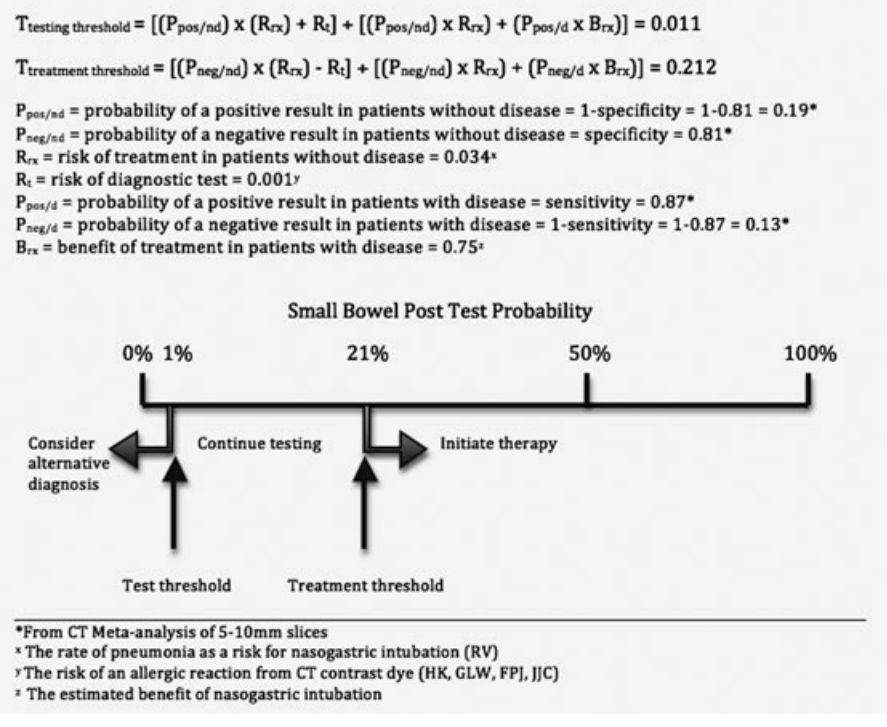

Figure 7. Test and treatment threshold formulas.

physician's clinical gestalt and therefore could be used for calculating posttest probabilities.

Overall, there are very few history and physical examination characteristics that by themselves lead to a significant increase in pretest probability of SBO. Both studies that examined these characteristics were not EM-exclusive and had relatively small numbers of approximately 40 subjects.[24,33] The potentially useful history and physical examination findings were a previous history of abdominal surgery (+LR = 2.65 to 3.86), constipation (+LR = 3.7 to 8.8), abdominal distention (+LR = 5.6 to 16.8), and abnormal bowel sounds (+LR = 6.33). Böhner et al.[24] combined prior abdominal surgery, constipation, and abdominal distention to yield a good specificity of 99%, but sensitivity of only 23%. The positive predictive value was 50%, making it essentially as effective as a coin toss. Additionally, an absence of several elements of history and physical examination findings showed promise to reduce the probability of SBO, including no appetite (–LR = 0.25), nausea (–LR = 0.35), no Murphy's sign (–LR = 0.20), and scar on the abdomen (–LR = 0.19).

Developing an accurate posttest probability relies on minimally biased, widely applicable, and reliable diagnostic data. The imaging modality studies included in this meta-analysis are of moderate quality at best. Roughly half of them are retrospective in design, and most have relatively small patient numbers. Lijmer et al.[69] noted no bias in diagnostic accuracy estimates with retrospective study designs. However, these studies were subject to different forms of bias. Specifically, spectrum bias was present and likely significant, as there were very few studies that exclusively looked at EM populations.[70] Spectrum bias, when skewed toward those patients who have a higher severity of disease, can falsely elevate the sensitivity.[71] An example of spectrum bias in the literature can be seen with dipstick testing for urinary tract infections (UTIs), where higher test sensitivity was found in those patients who had a high probability of having a UTI versus those who had a low probability.[72] Double-criterion standard bias was also quite prevalent in regard to the criterion standard for most studies, as they included "clinical outcome" as an alternative to surgical diagnosis. Double-criterion standard bias falsely elevates the sensitivities and specificities.[71] An example of this can be seen with the use of prostate-specific antigen screening tests for prostate cancer, where men who have lower levels do not get the criterion standard biopsy test.[73] Perhaps the largest issue in regard to the heterogeneity of studies had to do with the diagnostic imaging equipment utilized. Given the large time span for when the studies were undertaken and published, there is an enormous amount of diversity in regard to machinery, technique, interpretive equipment, and time to testing. This diversity leads to difficulty in pooling data for meta-analysis.

Plain radiography, which is often the first imaging modality used in the ED, has a summary +LR ratio of 1.55 (95% CI = 1.10 to 2.29). The study by Musoke et al.[34] was removed to completely eliminate heterogeneity. The likely reason that this study had a high sensitivity and specificity is because the plain radiographic findings when recorded were not blinded to the clinical and laboratory data according to this author's methods section. Using the above findings and an SBO prevalence of 15% for all abdominal pain patients who are ultimately going to be admitted, then the posttest probability is only 20% for a positive abdominal radiograph when plotted on a Fagan nomogram.[14] Although this may be good enough to start treatment according to the test-treatment threshold, it is not entirely useful for SBO diagnosis. It is still suggested as the first imaging test in guidelines, however, likely because of its rapid availability, ease of use, and lack of complications.[16,17]

The most challenging imaging modality to incorporate into this meta-analysis was the CT scan. There are studies that were conducted at different times over the span of 17 years (1992 to 2011) with sensitivities and specificities in the ranges of 50% to 100% and 57% to 100%, respectively. Over the course of that time, the CT scanner has seen drastic changes in terms of the additions of helical rotation, rotation speeds, multidetectors, and high-quality computer monitors for viewing.[74] These changes create a level of temporal bias in which the diagnostic test itself improves over time and therefore the results from the test are also likely to change over time.[75] Some of the other reasons for the wide range of outcomes likely result from the technical challenges of interpretation that exist with CT and SBO.[76] The diagnosis of a SBO on CT relies on the ability to find the transition point or the point where dilated bowel loops are proximal to decompressed loops.[77] Determining the transition point is a very meticulous endeavor, and the expertise of the radiologist should not be underestimated.[44] Furthermore, less discrepancy between the bowel diameters at the transition point makes diagnosis difficult.[78] This is problematic in that many of the studies examined did not differentiate partial from complete bowel obstructions, the latter of which are easier to diagnose.

Pooling all individual studies together would be misleading and unhelpful because of their marked differences. However, the one variable that likely resulted in the largest difference in making a diagnosis of SBO was the thickness of slices. Improved accuracy with smaller slice thickness has been seen in cardiac,[79] pulmonary,[80] orthopedic,[81] renal,[82] and liver studies.[83] Unfortunately, we were unable to find any studies that assessed the accuracy of slice thickness particularly in SBO. Some studies did, however, advocate for taking additional 5-mm slices at the transition zone,[44] demonstrating their usefulness in SBO. We therefore chose to combine studies into groups based on the slice size that was taken in their CT scans, as it was both the most reported variable and the most likely variable to contribute to diagnostic accuracy.

The summary +LR for studies that used 5- to 10-mm slices was 3.62 (95% CI = 2.47 to 5.30), with heterogeneity of 15.5%. Plotting this value on the Fagan nomogram gives a posttest probability of 40% using a 15% pretest prevalence. The results of the pooled CT analysis, although superior to plain radiography, suggest that CT is not as accurate of a modality as once thought. It must be kept in mind, however, that the amount of variability that existed between studies was very large and could in no way be accounted for in pooled analysis.

In contrast to the pooled estimates, the two most recent studies with the most advanced CT scanners had the best individual results. Pongpornsup et al.[48] used a 64-slice multidetector CT with slices of 0.75 mm and examined 35 people with suspected SBO. They found a +LR of infinity and a –LR of 0.04 (95% CI = 0.006 to 0.273). Shakil et al.[23] also used a 64-slice scanner with no mention of slice size and studied 271 patients with suspected bowel obstruction. They found a +LR of 13 (95% CI = 7.5 to 22.4). These findings suggest that multidetector CT scans account for marked improvement in sensitivity and specificity for the diagnosis of SBO.

There were only two studies that we found that looked at the use of MRI for SBO diagnosis. Together, they had a summary +LR of 6.77 (95% CI = 2.13 to 21.55) giving a posttest probability of 54% (95% CI = 50% to 59%). However, given the increased time needed to perform a scan and the limited availability in certain centers, this would be a much less optimal choice for an EP.

Perhaps the most surprising outcome from the meta-analysis was the diagnostic accuracy of US, an imaging modality whose use in the ED is relatively new. Two of the studies were ED-specific and looked at the ability of residents to diagnose SBO with bedside US after a formal training and practice program was completed.[36,37] Together, the two studies had a summary +LR of 9.55 (95% CI = 2.16 to 42.21) and a –LR of 0.04 (95% CI = 0.01 to 0.13) for the ED residents, which give a posttest probability of 63% (95% CI = 58% to 68%). Ünlüer et al.[37] found that radiology residents at the same level of training as the EM residents performed similarly in terms of sensitivity and specificity. The usefulness of the US was confirmed in the several "formal" (radiologist-performed) studies that had +LR of 14.1 (95% CI = 3.6 to 55.6) and a –LR of 0.13 (95% CI = 0.08 to 0.20). Although US may have some role in the diagnosis of SBO, it does require additional training and maintenance of skills. Furthermore, there is currently no evidence that ED US would be able to make interpretations on areas such as SBO transition point or etiology. Future cost-effectiveness analyses could assess whether the time invested in developing US competence for SBO weighed against the inferior diagnostic accuracy of x-ray is sufficient for US to supplant x-ray as the first-line imaging test for SBO to queue patients for the most costly and generally less available advanced imaging options, such as CT.

Implications for Future Research

There are very few ED-specific research studies on the diagnosis of SBO. This is despite the fact that EPs have identified SBO as an area where diagnosis should not be missed and where further research is necessary.[84] EM-related diagnostic research on SBO should be considered an important area of research for several reasons. First, the majority of patients with possible SBO present to the ED as their first contact point with the health care system.[2] Second, the lack of data on diagnosis likely breeds the variability in EM practice that is often seen in dealing with undifferentiated abdominal pain.[85] This varied approach presumably leads to an increase in health care costs, but data in this area are lacking as well. Last and most importantly, there is significant morbidity and mortality related to the delayed diagnosis of SBO.[86,87] Hwang et al.[87] found an odds ratio of 6.91 (95% CI = 1.85 to 24.80) for surgical resection for those patients who had longer times to surgery consult, while Bickel et al.[86] found that patients who had a longer time between symptom onset and management had a higher risk of resection (4% for <24 hours, 10% to 14% for 24 to 72 hours).

Clinicians and researchers need additional ED-based studies to fully understand the diagnostic accuracy of history, physical examination, and imaging modalities for SBO. Future SBO diagnostic researchers should conform to the STARD criteria when designing investigations to ensure comprehensive and replicable study methods, while minimizing bias.[88,89] Based on our systematic review, we recommend that future investigators consider several design issues. First, inclusion of multiple disparate ED settings in prospectively recruiting consecutive abdominal pain patients with suspicion of SBO is essential to enhance external validity and to reduce spectrum bias. Second, a more thorough description of imaging methods, as recommended by the STARD criteria, will permit future investigators and clinicians to more confidently compare one study to another. For example, providing details about imaging equipment specifications, collection processing, and whether interventions like the NG tube are initiated before imaging, would help to ensure a more complete understanding of research reports and clinical applicability. Finally, it is difficult to avoid double-criterion standard bias when the initial treatment of choice for SBO is conservative management. Attempts should be made, however, to collect and report as much information on "clinical outcome" as possible to provide the most accurate picture of the patient's courses in the hospital. For example, reporting on the number of days until resolution of abdominal pain, vomiting, and distention, in addition to all other interventions provided, would allow a much clearer picture of whether SBO was indeed present in these patients.

There are two potential areas of EM research that deserve mention based on the findings of this meta-analysis. One of these is a revisit of the history and physical examination studies and the second is new research on the use of US for the diagnosis of SBO.

One of the important research areas that was deficient in this meta-analysis is the usefulness of the history and physical examination. The two studies that were included were not EM-specific and were confined to relatively few hospitals in Germany and Finland.[24,33] Given the importance of developing a solid pretest probability, an EM-specific study that incorporated several departments would provide a much-needed perspective on the matter and perhaps yield more comprehensive results. Ultimately, combinations of findings from history and physical examination should be assessed, and there might be a role for a clinical decision rule to be derived and validated.

Perhaps the most exciting revelation from this meta-analysis is the performance of US in the diagnosis of SBO. The superiority of the few US studies, along with

the availability of this modality in a majority of EDs, makes this an area where future research is desperately needed. To improve the knowledge of using this modality and alter the SBO management pathway with its use, additional research is needed regarding the areas of US machine choice, scanning techniques, and EM personnel training and performance. It is reasonable to speculate that with this added evidence, US may play some role in the ED diagnosis of SBO. That role currently remains undefined, but may lead to more timely diagnosis and theoretically decrease the number of CT scans performed on patients prior to a 3- to 5-day trial of conservative therapy is attempted.

LIMITATIONS

There were several limitations of this meta-analysis. First, it is possible that some studies relating to SBO diagnostics were missed given the strategy of our search. We opted to perform the electronic search on our own without the assistance of a medical librarian. We used PUBMED and EMBASE primarily with limitations to English-language, which may have excluded some non-English studies. Additionally, the search terms that we used may have also failed to find specific studies. Second, we limited our searches to generalized SBO in adults and therefore our meta-analysis cannot comment on pediatric SBO or specific entities such as Crohn's disease, carcinoma, or volvulus. We also did not specifically include studies that looked to diagnose strangulation alone, as they often involved different diagnostic criteria. A few of our studies contained and did not discriminate for a minor number of large bowel obstructions in their findings.[22–26]

The quality of the studies in this meta-analysis was highly variable and was subject to several biases. These should be kept in mind when assessing the interpretation of the results.

Several of the studies provide a reproducible description of the types of scanners used and the procedures employed to perform the scans. Others unfortunately provided few details in terms of image capturing techniques and equipment used. As seen in Table 1, several studies were unclear as to their patient selection process, criterion standard usage, or the flow and timing of their testing.

The criterion standard used for the majority of the studies is a combination of either surgical findings or eventual clinical outcomes. Unfortunately, many of the studies did not go into further detail explaining what surgical findings were used to make the diagnosis and did not provide timelines for when a clinical diagnosis was made. The accuracy of surgery to diagnose is presumably very high, with some findings suggesting 100%.[90] Eventual clinical outcome is fraught with bias, however, as many variables could play into what ultimately happens to a patient in the hospital. For example, perhaps a patient initially presents like a bowel obstruction, gets that diagnosis on the chart, and then improves without any further diagnostic certainty. The actual diagnosis may be SBO or something completely different. There would be no way to know for certain based on looking solely at the chart.

One of the limitations to the pooled meta-analysis groups is the large heterogeneity seen in the studies. Some of this was controlled for by removing certain outliers, but was not always completely eliminated. The nature of diagnostic imaging studies, especially CT scans, lends itself to heterogeneity given the very wide range of machines and scanning techniques used, as well as the tools used for interpretation. Comparing these studies from the early 1990s with those around 2010 without controlling for accuracy of the scans would be like comparing computer performance and speed from the same time eras and probably yields a skewed summary estimate of diagnostic accuracy.

Last, the test-treatment threshold calculation relied on several best estimates. The lack of quantity of prevalence, history, and physical examination studies means that the pretest probability is highly open to interpretation (Data Supplement S2). Furthermore, the benefits and risks of NG placement did not take into account patient preference or pain relief and were derived from lower-quality, potentially biased primary studies. The benefits of 75% may be overestimated, while the risks of treatment in a patient without SBO may be overestimated at 3%. Moreover, the risk of CT scan may be underestimated at 0.1%, because this does not take into account the risk of potential future cancers, for example. The equation was included to ensure that readers can apply their own numbers to generate a test-treatment threshold.

CONCLUSIONS

Small bowel obstruction is an uncommon, but serious, presentation to the ED, with an estimated prevalence of approximately 2% of all patients whose chief complaint is abdominal pain. The most useful aspects of the history and physical examination are a previous history of abdominal surgery, constipation, abnormal bowel sounds, and abdominal distention. There is marked variability in the usefulness of the different imaging modalities. X-ray is the least useful with the lowest positive likelihood ratio (+LR). On the other hand CT, MRI, and ultrasound are all relatively good at making the diagnosis, with high +LRs. Although lacking in study numbers, the findings for those studies involving ultrasound suggest that it is a good diagnostic imaging modality that could potentially improve the ED diagnosis. More EM-specific studies are needed in this area. In terms of the test-treatment threshold, emergency physicians should not hesitate to use nasogastric intubation for symptomatic relief early on, as there is very low risk of adverse events with this intervention.

The authors acknowledge Christopher R. Carpenter, MD, MS, for assistance.

References

1. Irvine TT. Abdominal pain: a surgical audit of 1190 emergency admissions. Br J Surg. 1989;76:1121–5.
2. Foster NM, McGory ML, Zingmond DS, Ko CY. Small bowel obstruction: a population-based appraisal. J Am Coll Surg. 2006;203:170–6.

3. Hastings RS, Powers RD. Abdominal pain in the ED: a 35 year retrospective. Am J Emerg Med. 2011;29:711–6.
4. Torrey SP, Henneman PL. Disorders of the small intestine. In: Marx JA, Hockberger RS, Walls RM, et al. (eds). Rosen's Emergency Medicine Concepts and Clinical Practice. 7th ed. Philadelphia, PA: Mosby, 2010, pp 1184–8.
5. Vicario SJ, Price TG. Bowel obstruction and volvulus. In: Tintinalli JE, Stapczynski JS, Ma OJ, Cline DM, Cydulka RK, Meckler GD (eds). Tintinalli's Emergency Medicine: A Comprehensive Study Guide. 7th ed. New York, NY: McGraw-Hill, 2011.
6. Menzies D, Ellis H. Intestinal obstruction from adhesions–how big is the problem? Ann R Coll Surg Engl. 1990;72:60–3.
7. Miller G, Boman J, Shrier I, Gordon PH. Etiology of small bowel obstruction. Am J Surg. 2000;180:33–6.
8. Fevang BT, Fevang J, Stangeland L, Soreide O, Svanes K, Viste A. Complications and death after surgical treatment of small bowel obstruction: a 35-year institutional experience. Ann Surg. 2000; 231:529–37.
9. Cheadle WG, Garr EE, Richardson JD. The importance of early diagnosis of small bowel obstruction. Am Surg. 1988;54:565–9.
10. Cappell MS, Batke M. Mechanical obstruction of the small bowel and colon. Med Clin North Am. 2008;92:575–97.
11. Takeuchi K, Tsuzuki Y, Ando T, et al. Clinical studies of strangulating small bowel obstruction. Am Surgeon. 2004;70:40–4.
12. Cronk DR, Houseworth TP, Cuadrado DG, Herbert GS, McNutt PM, Azarow KS. Intestinal fatty acid binding protein (I-FABP) for the detection of strangulated mechanical small bowel obstruction. Curr Surg. 2006;63:322–5.
13. Hayden SR, Brown MD. Likelihood ratio: a powerful tool for incorporating the results of a diagnostic test into clinical decision making. Ann Emerg Med. 1999;33:575–80.
14. Fagan TJ. Nomogram for Bayes's theorem [letter]. N Engl J Med. 1975;293:257.
15. Mallo RD, Salem L, Lalani T, Flum DR. Computed tomography diagnosis of ischemia and complete small bowel obstruction: a systematic review. J Gastrointest Surg. 2005;9:690–4.
16. Jackson PG, Raiji M. Evaluation and management of intestinal obstruction. Am Fam Physician. 2011;83:159–65.
17. Diaz JJ, Bokhari F, Mowery NT, et al. Guidelines for management of small bowel obstruction. J Trauma. 2008;64:1651–64.
18. Hayanga AJ, Bass-Wilkens K, Bulkley GB. Current management of small-bowel obstruction. Adv Surg. 2005;39:1–33.
19. Pauker SG, Kassirer JP. The threshold approach to clinical decision making. N Engl J Med. 1980;302:1109–17.
20. Kastner M, Wilczynski NL, McKibbon AK, Garg AS, Haynes RB. Diagnostic test systematic reviews: bibliographic search filters ("Clinical Queries") for diagnostic accuracy studies perform well. J Clin Epidemiol. 2009;62:974–81.
21. Sackett DL, Straus SE, Richardson WS, et al. Evidence-based Medicine: How to Practice and Teach EBM. 2nd ed. Edinburgh: Churchill Livingstone, 2000.
22. Suri S, Gupta S, Sudhakar PJ, Venkataramu NK, Sood B, Wig JD. Comparative evaluation of plain films, ultrasound and CT in the diagnosis of intestinal obstruction. Acta Radiol. 1999;40:422–8.
23. Shakil O, Zafar SN, Rehman Z. The role of computed tomography for identifying mechanical bowel obstruction in a Pakistani population. J Pak Med Assoc. 2011;61:871–4.
24. Böhner H, Yang Q, Franke C, Verreet PR, Ohmann C. Simple data from history and physical examination help to exclude bowel obstruction and to avoid radiographic studies in patients with acute abdominal pain. Eur J Surg. 1998;164:777–84.
25. Beall DP, Fortman BJ, Lawler BC, Regan F. Imaging bowel obstruction: a comparison between fast magnetic resonance imaging and helical computed tomography. Clin Radiol. 2002;57:719–24.
26. Ogata M, Mateer JR, Condon RE. Prospective evaluation of abdominal sonography for the diagnosis of bowel obstruction. Ann Surg. 1996;223:237–41.
27. Whiting PF, Rutjes AW, Westwood ME, et al. QUADAS-2: a revised tool for quality assessment of diagnostic accuracy studies. Ann Intern Med. 2011;155:529–36.
28. Cohen J. Weighted kappa: nominal scale agreement with provision for scaled disagreement or partial credit. Psychol Bull. 1968;70:213–20.
29. Zamora J, Abraira V, Muriel A, Khan K, Coomarasamy A. Meta-DiSc: a software for meta-analysis of test accuracy. BMC Med Res Methodol. 2006; 6:e31.
30. DerSimonian R, Laird N. Meta-analysis in clinical trials. Control Clin Trials. 1986;7:177–88.
31. Aufort S, Charra L, Lesnik A, Bruel JM, Taourel P. Multidetector CT of bowel obstruction: value of post-processing. Eur Radiol. 2005;15:2323–9.
32. O'Malley ME, Halpern E, Mueller PR, Gazelle GS. Helical CT protocols for the abdomen and pelvis: a survey. Am J Roentgen. 2000;175:109–13.
33. Eskelinen M, Ikonen J, Lipponen P. Contributions of history-taking, physical examination, and computer assistance to diagnosis of acute small-bowel obstruction. Scand J Gastroenterol. 1994;29:715–21.
34. Musoke F, Kawooya MG, Kiguli-Malwadde E. Comparison between sonographic and plain radiography in the diagnosis of small bowel obstruction at Mulaga Hospital, Uganda. East Afr Med J. 2003;80:540–5.
35. Maglinte DD, Benedicto LR, Harmon BH, et al. Reliability and role of plain film radiography and CT in the diagnosis of small-bowel obstruction. Am J Roentgenol. 1996;167:1451–5.
36. Jang TB, Schindler D, Kaji AH. Bedside ultrasonography for the detection of small bowel obstruction in the emergency department. Emerg Med J. 2011;28:676–8.

37. Ünlüer EE, Yavasi O, Erogul O, Yilmaz C, Akarca FK. Ultrasonography by emergency medicine and radiology residents for the diagnosis of small bowel obstruction. Eur J Emerg Med. 2010;17:260–4.
38. Fukuya T, Hawes D, Lu C, Chang PJ, Barloon TJ. CT diagnosis of small-bowel obstruction: efficacy in 60 patients. AJR. 1992;158:765–9.
39. Schmutz G, Benko A, Fournier L, Peron JM, Morel E, Chiche L. Small bowel obstruction: role and contribution of sonography. Eur Radiol. 1997;7:1054–8.
40. Daneshmand S, Hedley C, Stain S. The utility and reliability of computed tomography scan in the diagnosis of small bowel obstruction. Am Surg. 1999;65:922–6.
41. Obuz F, Terzi C, Sökmen S, Yilmaz E, Tildiz D, Füzün M. The efficacy of helical CT in the diagnosis of small bowel obstruction. Eur J Radiol. 2003; 48:299–304.
42. Makanjuola D. Computed tomography compared with small bowel enema in clinically equivocal intestinal obstruction. Clin Radiol. 1998;53:203–8.
43. Regan F, Beall D, Bohlman M, Khazan R, Sufi A, Schaefer DC. Fast MR imaging and the detection of small-bowel obstruction. AJR. 1998;170:1465–9.
44. Peck J, Milleson T, Phelan J. The role of computed tomography with contrast and small bowel follow-through in management of small bowel obstruction. Am J Surg. 1999;177:375–8.
45. Atri M, McGregor C, McInnes M, et al. Multidetector helical CT in the evaluation of acute small bowel obstruction: comparison on non-enhanced (no oral, rectal or IV contrast) and IV enhanced CT. Eur J Radiol. 2009;71:135–40.
46. Frager D, Medwid S, Baer J, Mollinelli B, Freidman M. CT of small-bowel obstruction: value in establishing the diagnosis and determining the degree and cause. AJR. 1994;162:137–41.
47. Walsh D, Bender G, Timmons J. Comparison of computed tomography-enteroclysis and traditional computed tomography in the setting of suspected partial small bowel obstruction. Emerg Radiol. 1998;5:29–37.
48. Pongpornsup S, Tarachat K, Srisajjakul S. Accuracy of 64-slice multi-detector computed tomography in diagnosis of small bowel obstruction. J Med Assoc Thai. 2009;92:1651–61.
49. Maglinte D, Gage S, Harmon B, et al. Obstruction of the small intestine: accuracy and role of CT in the diagnosis. Radiology. 1993;188:61–4.
50. Welch J. General consideration and mortality in bowel obstruction. In: Welch J (ed.). Bowel Obstruction: Differential Diagnosis and Clinical Management. Philadelphia: WB Saunders, 1990, pp 59–95.
51. Petrovic B, Nikolaidi P, Hammond N, Grant TH, Miller FH. Identification of adhesions on CT in small-bowel obstruction. Emerg Radiol. 2006;12: 88–93.
52. Shrake PD, Rex DK, Lappas JC, Maglinte DD. Radiographic evaluation of suspected small bowel obstruction. Am J Gastroenterol. 1991;6:175–8.
53. Verma R, Nelson R. Prophytactic nasogastric decompression after abdominal surgery. Cochrane Database Syst Rev. 2007;3:1–48.
54. Mosley JG, Shoaib A. Operative versus conservative management of adhesional obstruction. Br J Surg. 2000;87:362–73.
55. Fevang BT, Jenson D, Svanes K, Viste A. Early operation or conservative management of patients with small bowel obstruction? Eur J Surg. 2002;168:475–81.
56. Williams SB, Greenspon J, Young HA, Orkin BA. Small bowel obstruction: conservative vs surgical management. Dis Colon Rectum. 2005;48:1140–6.
57. Cheatham ML, Chapman WC, Key SP, Sawyers JL. A meta-analysis of selective versus routine nasogastric decompression after elective laparotomy. Ann Surg. 1995;221:469–78.
58. Katayama H, Yamaguchi K, Kozuka T, Takashima T, Seez P, Matsuura K. Adverse reactions to ionic and nonionic contrast media. A report from the Japanese committee on the safety of contrast media. Radiology. 1990;175:621–8.
59. Wolf GL, Arenson RL, Cross AP. A prospective trial of ionic vs nonionic contrast agents in routine clinical practice: comparison of adverse effects. Am J Roentgenol. 1989;152:939–44.
60. Palmer FJ. The RACR survey of intravenous contrast media reactions final report. Australas Radiol. 1988;32:426–8.
61. Caro JJ, Trindade E, McGregor M. The risks of death and of severe nonfatal reactions with high vs low osmolality contrast media: a meta-analysis. Am J Roentgenol. 1991;156:825–32.
62. Lessler AL, Isserman JA, Agarwal R, Palevsky HI, Pines JM. Testing low-risk patients for suspected pulmonary embolism: a decision analysis. Ann Emerg Med. 2010;55:316–26.
63. Hogg KE, Brown MD, Kline JA. Estimating the pretest probability threshold to justify empiric administration of heparin prior to pulmonary vascular imaging for pulmonary embolism. Thromb Res. 2006;118:547–53.
64. Worster A, Innes G, Abu-Laban R. Diagnostic testing: an emergency medicine perspective. CJEM. 2002;4:348–54.
65. Parmigiani G. Modeling in Medical Decision Making: A Bayesian Approach. West Sussex, England: John Wiley and Sons Ltd, 2002.
66. Kline J, Novobilski A, Kabrhel C, Richman PB, Courtney DM. Derivation and validation of a Bayesian network to predict pretest probability of venous thromboembolism. Ann Emerg Med. 2005;45:282–90.
67. Phelps M, Levitt A. Pretest probability estimates: a pitfall to the clinical utility of evidence-based medicine? Acad Emerg Med. 2004;11:692–4.
68. Grant D, Keim S, Telfer J. Teaching Bayesian analysis to emergency medicine residents. J Emerg Med. 2006;31:437–40.
69. Lijmer JG, Mol BW, Heisterkamp S, et al. Empirical evidence of design-related bias in studies of diagnostic tests. JAMA. 1999;282:1061–6.
70. Sica GT. Bias in research. Radiology. 2006;238: 780–9.
71. Newman TB, Kohn MA. Evidence-based Diagnosis. New York, NY: Cambridge University Press, 2009, pp 99–107.

72. Lachs MS, Nachamkin I, Edelstein PH, Goldman J, Feinstein AR, Schwartz JS. Spectrum bias in the evaluation of diagnostic tests: lessons from the rapid dipstick test for urinary tract infection. Ann Intern Med. 1992;117:135–40.
73. Gupta A, Roehrborn CG. Verification and incorporation biases in studies assessing screening tests: prostate-specific antigen as an example. Urology. 2004;64:106–11.
74. Kelves B. Naked to the Bone: Medical Imaging in the Twentieth Century. New Brunswick, NJ: Rutgers University Press, 1997.
75. Begg C. Biases in the assessment of diagnostic tests. Stat Med. 1987;6:411–23.
76. Maglinte DD, Heitkamp DE, Howard TJ, Kelvin FM, Lappas JC. Current concepts in imaging of small bowel obstruction. Radiol Clin N Am. 2003;41:263–83.
77. Balthazar E. CT of small-bowel obstruction. AJR. 1994;162:255–61.
78. Scaglione M, Romano S, Pinto F, et al. Helical CT diagnosis of small bowel obstruction in the acute clinical setting. Eur J Radiol. 2004;50:15–22.
79. Hong C, Pilgram TK, Zhu F, Joe BN, Towler DA, Bae KT. Improving mass measurement of coronary artery calcification using threshold correction and thin collimation in multidetector row compurted tomography: in vitro experiment. Acad Radiol. 2003;10:969–77.
80. Schoepf U, Holzknecht N, Helmberger T, et al. Subsegmental pulmonary emboli: improving detection with thin-collimation multi-detector row spiral CT. Radiology. 2002;222:483–90.
81. Herzog C, Ahle H, Mack MG, et al. Traumatic injuries of the pelvis and thoracic and lumbar spine: does thin-slice multidetector-row CT increase diagnostic accuracy? Eur Radiol. 2004;14:1751–60.
82. Arac M, Celik H, Oner AY, Gultekin S, Gumas T, Kosar S. Distinguishing pelvic phleboliths from distal ureteral calculi: thin slice CT findings. Eur Radiol. 2005;15:65–70.
83. Weg N, Sheer MR, Gabor MP. Liver lesions: improved detection with dual-detector-array CT and routine 2.5 mm thin collimation. Radiology. 1998;209:417–26.
84. Mills AM, Dean AJ, Hollander JE, Chen EH. Abdominal pain: a survey of clinically important outcomes for future research. Can J Emerg Med. 2010;12:485–90.
85. Gerhardt R, Nelson B, Keenan S, MacKersie A, Lane MS. Derivation of a clinical guideline for the assessment of nonspecific abdominal pain: the guideline for abdominal pain in the ED setting (GAPEDS) phase 1 study. Am J Emerg Med. 2005;23:709–17.
86. Bickell N, Federman A, Aufses AH. Influence of time on risk of bowel resection in complete small bowel obstruction. J Am Coll Surg. 2005;201:847–54.
87. Hwang U, Aufses A, Bickell N. Factors associated with delays to emergency care for bowel obstruction. Am J Surg. 2011;202:1–7.
88. Bossuyt P, Reitsma J, Bruns D, et al. The STARD statement for reporting studies of diagnostic accuracy: explanation and elaboration. Ann Intern Med. 2003;138:w1–12.
89. Smidt N, Rutjes AW, van der Windt DA, et al. The quality of diagnostic accuracy studies since the STARD statement: has it improved? Neurology. 2006;67:792–7.
90. Franklin ME Jr, Gonzalez JJ Jr, Miter DB, Glass JL, Paulson D. Laparoscopic diagnosis and treatment of intestinal obstruction. Surg Endosc. 2004;18:26–30.

Supporting Information

The following supporting information is available in the online version of this paper:

Data Supplement S1. Summary of included studies.

Data Supplement S2. Online Excel calculator.