World Journal of

Gastroenterology

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ABOUT COVER

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AIMS AND SCOPE

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The primary task of *WJG* is to rapidly publish high-quality original articles, reviews, and commentaries in the fields of gastroenterology, hepatology, gastrointestinal endoscopy, gastrointestinal surgery, hepatobiliary surgery, gastrointestinal oncology, gastrointestinal radiation oncology, *etc*. *WJG* is dedicated to become an influential and prestigious journal in gastroenterology and hepatology, to promote the development of above disciplines, and to improve the diagnostic and therapeutic skill and expertise of clinicians.

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RESPONSIBLE EDITORS FOR THIS ISSUE

Retrospective Study

Optimized protocol of multiple post-processing techniques improves diagnostic accuracy of multidetector computed tomography in assessment of small bowel obstruction compared with conventional axial and coronal reformations

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Abstract

BACKGROUND
Axial and coronal reformations have been a widely used image post-processing protocol for the ordinary multidetector computed tomography (MDCT) examination of patients with small bowel obstruction (SBO) or other abdominal diseases. The diagnostic accuracy of MDCT for assessing SBO is expected to be further improved through the use of multiple post-processing techniques.

AIM
To systemically evaluate the diagnostic accuracy and efficiency of an optimized protocol using multiple post-processing techniques for MDCT assessment of SBO and secondary bowel ischemia.

METHODS
This retrospective cross-sectional study included 106 patients with clinically suspected SBO. Two readers applied three protocols to image post-processing and interpretation of patients' MDCT volume data. We compared the three protocols based on time spent, number of images, diagnostic self-confidence, agreement, detection rate, and accuracy of detection of SBO and secondary bowel ischemia.

RESULTS
Protocol 2 resulted in more time spent and number of images than protocols 1

and 3 ($P < 0.01$), but the results of the two readers using the same protocol were not different ($P > 0.05$). Using protocol 3, both readers added multiple post-processing techniques at frequencies of 29.2% and 34.9%, respectively, for obstruction cause, and 32.1% and 30.2%, respectively, for secondary bowel ischemia. Protocols 2 and 3 had higher total detection rates of obstruction cause and secondary bowel ischemia than protocol 1 ($P < 0.01$), but no difference was detected between protocols 2 and 3 ($P > 0.05$). The accuracy, sensitivity, specificity, positive predictive value and negative predictive value of protocols 2 and 3 were superior to those of protocol 1 for evaluating obstruction cause and secondary bowel ischemia.

CONCLUSION
Our optimized protocol of multiple post-processing techniques can both guarantee efficiency and improve diagnostic accuracy of MDCT for assessing SBO and secondary bowel ischemia.

Key words: Intestine; Intestinal obstruction; Multidetector computed tomography; Diagnostic techniques and procedures

Core tip: Axial and coronal reformations are inadequate for multidetector computed tomography (MDCT) used to identify some causes of small bowel obstruction (SBO) and secondary bowel ischemia. In our study, both integrated and optimized protocols of multiple post-processing techniques can improve the diagnostic accuracy of MDCT for assessing SBO, but the integrated protocol necessitates a longer time spent and increases the workload of radiologists. The optimized protocol can both guarantee the time efficiency and improve the diagnostic accuracy of MDCT for assessing SBO and secondary bowel ischemia. The optimized protocol can be considered as a routine image post-processing approach of MDCT for assessment of patients with SBO.

INTRODUCTION

Acute small bowel obstruction (SBO) is a common disease with high morbidity and mortality. Early, accurate, and comprehensive assessment of this disease is critical for clinicians to determine treatment plans. Multidetector computed tomography (MDCT) is becoming popular for clinical SBO assessment, and is showing promising results[1-4]. MDCT has shown great potential in identifying SBO and its severity, site, cause, and complications. However, the diagnostic accuracy of MDCT can be improved further.

MDCT uses volume scanning to produce isotropic images that have been widely used for axial, coronal, and sagittal reformations in clinical radiology. The axial and coronal reformation post-processing protocols have been the standard for MDCT examination of abdominal diseases[2-6]. MDCT has been equipped with many kinds of image post-processing techniques with a wide range of clinical applications in human vascular disease diagnosis[7-10]. For many non-vascular diseases, if the axial, coronal, and sagittal images provide poor resolution of the anatomic details of a lesion, radiologists could add one or more post-processing techniques to improve diagnostic accuracy[11,12].

However, comprehensive studies about combining MDCT multiple post-processing techniques for SBO assessment are lacking[13-15]. Therefore, we aimed to integrate and optimize the multiple post-processing techniques, and designed a retrospective cross-sectional study to systemically evaluate diagnostic accuracy and efficiency of the optimized protocol using multiple post-processing techniques on MDCT to assess

SBO and secondary bowel ischemia.

MATERIALS AND METHODS

Patients

This study was approved by the ethics committee of our hospital, and waivers of informed consent were obtained from the patients. The inclusion criteria were adults (≥ 18 years) with complete clinical and MDCT volume data and patients with clinical symptoms and signs of SBO. A total of 106 patients were selected between June 2015 and May 2018 to cover a range of causes. Ninety patients were confirmed by surgery and/or pathology to have SBO with causes including adhesions (20, 18.9%), neoplasms (11, 10.4%), intussusception [neoplastic (9, 8.6%) and nonneoplastic (5, 4.7%)], volvulus (8, 7.5%), internal hernias (6, 5.7%), external hernias (9, 8.6%), bezoars/stones (7, 6.6%), vascular lesions (8, 7.5%), and inflammatory lesions (7, 6.6%). The remaining 16 patients without SBO were identified by clinical and imaging studies.

Of the 106 patients, 49 (46.2%) were men and 57 (53.8%) were women. The mean age was 54.4 ± 14.9 years (range, 19-84 years). Their clinical manifestations included abdominal distension (91, 85.8%), nausea and vomiting (94, 88.7%), constipation (78, 73.6%), abdominal pain (97, 91.5%), weariness (54, 50.9%), abdominal mass (16, 15.1%), bloody stools (13, 12.3%), and hematemesis (2, 1.9%). All the 90 patients with SBO underwent surgical treatment, and 16 patients without SBO received other treatments for other diseases.

MDCT scanning

All patients underwent unenhanced and dual-phase enhanced (hepatic arterial and portal venous phases) CT scans from the diaphragm to the symphysis pubis on a 64-row MDCT system (LightSpeed VCT, GE Healthcare, Milwaukee, United States). Patients did not receive any oral contrast agent prior to the routine scan. A dual-head power injector was used to administer the contrast agent (Ultravist; Bayer Schering Pharma, Berlin, Germany) at 370 mg iodine/mL followed by 30 mL of saline, with an injection rate of 4 mL/s through an antecubital vein. Contrast agent volumes were delivered at 2 mL/kg body weight, and the upper dose limit was set to 120 mL for each patient.

The scanning parameters were set as follows: detector configuration of 64 mm × 0.625 mm, slice thickness and reconstruction interval of 0.625 mm, table speed of 64 mm per rotation, pitch of 0.984, matrix of 512 × 512, field of view of 180-240 mm, tube voltage of 120 kV, and tube current of 300 mA. Two identical workstations (Advantage Windows 4.3; GE Medical Systems) were used for image post-processing and detailed review.

Image post-processing protocols

Figure 1 shows the flow chart of three protocols for disease assessment in patients with clinically suspected SBO. Protocol 1 consists of conventional axial (5-mm-thick sections at 5-mm intervals) and coronal (3-mm-thick sections at 3-mm intervals) reformations. Protocol 2 involves integration of multiple post-processing techniques, *i.e.*, after conventional axial and coronal reformations, readers perform multi-planar reformations (MPR), curved planar reformations (CPR), maximum intensity projection (MIP), and volume rendering (VR) to assess SBO and secondary bowel ischemia (Figure 2). Protocol 3 is an optimization of the multiple post-processing techniques. The readers first perform the conventional axial and coronal reformations. If all assessment parameters can be evaluated with high self-confidence and satisfaction, the readers will not continue with the multiple post-processing techniques (Figure 3). If any of the assessment parameters are difficult to identify, the readers selectively add and perform MPR, CPR, MIP, or VR, until they are satisfied with the disease assessment (Figure 4).

Two radiologists with subspecialty training in abdominal imaging served as independent readers blinded to patient identification and clinical information. Training sessions were held for each reader including post-processing and review of five SBO patients on the workstation before the interpretation sessions, to allow them to become familiar with the three protocols and to freely perform the multiple post-processing techniques. Readers were first asked to independently perform protocol 1, then one month later to perform protocol 2, and again one month later to perform protocol 3 and image interpretation on a workstation (Figure 1).

Assessment parameters

Readers were asked to identify whether SBO was present, the obstruction site,

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│    106 patients with suspected SBO selected  │
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                    ↓
┌─────────────────────────────────────────┐
│  All patients had complete unenhanced and  │
│  dual-phase enhanced (hepatic arterial and  │
│  portal venous phases) MDCT volume data  │
└─────────────────────────────────────────┘

         Designed 3 different post-processing protocols
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Protocol 1, conventional axial and coronal reformations	Protocol 2, integrated protocol of multiple post-processing techniques	Protocol 3, optimized protocol of multiple post-processing techniques
Reader 1 / Reader 2	Reader 1 / Reader 2	Reader 1 / Reader 2
Independently performed protocol 1 and image interpretation; assessment parameters included whether a SBO was present, the obstruction severity, site and cause, as well as the findings of secondary bowel ischemia and other complications	Independently performed protocol 2 and image interpretation; assessment parameters included whether a SBO was present, the obstruction severity, site and cause, as well as the findings of secondary bowel ischemia and other complications	Independently performed protocol 3 and image interpretation; assessment parameters included whether a SBO was present, the obstruction severity, site and cause, as well as the findings of secondary bowel ischemia and other complications
Recorded/calculated the time spent, number of images, diagnostic self-confidence, agreement, detection rate, accuracy, sensitivity, specificity, PPV, and NPV of the protocol used to assess SBO and secondary bowel ischemia	Recorded/calculated the time spent, number of images, diagnostic self-confidence, agreement, detection rate, accuracy, sensitivity, specificity, PPV, and NPV of the protocol used to assess SBO and secondary bowel ischemia	Recorded/calculated the time spent, number of images, diagnostic self-confidence, agreement, detection rate, accuracy, sensitivity, specificity, PPV, and NPV of the protocol used to assess SBO and secondary bowel ischemia

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│            Comparative analysis          │
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Figure 1 Flow chart showing three protocols for disease assessment in patients with clinically suspected small bowel obstruction. SBO: Small bowel obstruction; MDCT: Multidetector computed tomography; PPV: Positive predictive value; NPV: Negative predictive value.

severity, and cause, as well as secondary bowel ischemia based on a list of imaging findings on a worksheet (Table 1). The diagnostic self-confidence for each assessment parameter was determined using a continuous five-grade scoring system from 1 to 5 (1 = worst, 5 = best). The obstruction severity based on bowel distension was graded as none (< 2.5 cm), mild (2.5 to < 3 cm), moderate (3 to < 4 cm), or severe (≥ 4 cm). The obstruction site was categorized as proximal (duodenum to proximal jejunum), middle (distal jejunum to middle ileum), distal (distal ileum), or multi-segmental (involving more than one segment) according to the modified Cole's method[16].

Statistical analysis
The diagnostic self-confidence, agreement, detection rate, sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and accuracy were calculated for the three protocols. The agreement was determined by using κ values ranging from 0 to 1 that were graded as follows: poor (< 0.40), moderate (0.40 to < 0.60), good (0.60 to < 0.80), or very good (0.80-1.00) agreement.

Results are given as the mean ± standard deviation. Continuous variables were tested for normality and equality of variances using the Kolmogorov-Smirnov-test and the Levene F test, respectively. The Student's *t*-test, Pearson $\chi2$ test, and Fisher exact test were used, as appropriate. The significance of the differences in all data among the three protocols was evaluated by either one-way or two-way analysis of variance. All statistical tests were performed with software (SPSS, version 20; SPSS, Chicago, IL, United States), and two-tailed $P < 0.05$ was considered to indicate a significant difference.
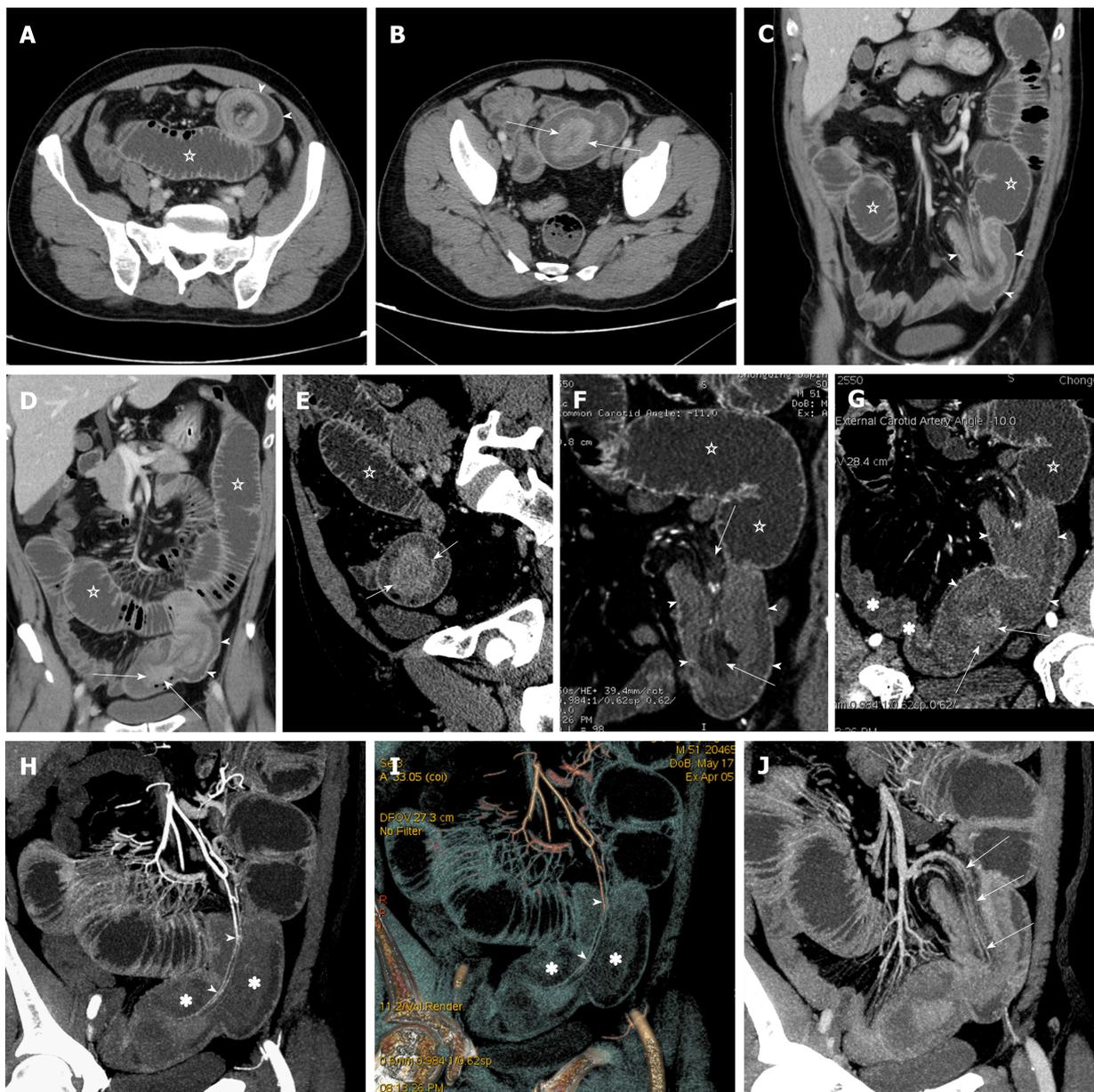
Figure 2 Protocol 2 applied in a 51-year-old man with a gastrointestinal stromal tumor causing intussusception and small bowel obstruction. A-D: Multidetector computed tomography conventional axial and coronal reformations of the abdomen display a lamellar structure arranged in a concentric circle (arrowheads) and a mass (arrows) with a size of 4.8 cm × 2.9 cm × 1.9 cm at the distal end of the intussusception, and the bowel loops (pentagram) proximal to the intussusception are severely dilated with a maximum diameter of 5.1 cm. E and F: Multi-planar reformation images obtained from any direction and angle could clearly reveal the mass (short arrows), intussusception (arrowheads) and dilated proximal bowel loops (pentagram), and mesenteric haziness (long arrows) in the invaginating mesentery. G: Curved planar reformation image more clearly defining the anatomical relationship among the mass (arrows), intussusception (arrowheads), dilated proximal bowel loops (pentagram), and collapsed distal bowel loops (asterisk). H and I: Maximum intensity projection (MIP) and volume rendering images obtained in the arterial phase clearly showing the invaginating mesenteric artery branches (arrowheads) with superior contrast enhancement, and decreased bowel wall enhancement in the invaginating bowel (asterisk). J: MIP image obtained in the portal venous phase revealing poor contrast enhancement in the invaginating mesenteric veins (arrows) compared with the adjacent mesenteric vein branches. The poor contrast enhancement of the invaginating mesenteric veins and the decreased bowel wall enhancement of the invaginating bowel segment imply the presence of secondary bowel ischemia.

RESULTS

Time spent and number of images

Protocol 2 took longer to perform than protocols 1 and 3 ($P < 0.01$) (Figure 5A). The two readers spent almost the same time using the same protocol ($P > 0.05$). Similarly, protocol 2 resulted in significantly more images than protocols 1 and 3 ($P < 0.01$) (Figure 5B), but the two readers produced an almost equal number of images for the same protocol ($P > 0.05$).

Use of multiple post-processing techniques in protocol 3

The frequencies at which the two readers used multiple post-processing techniques in
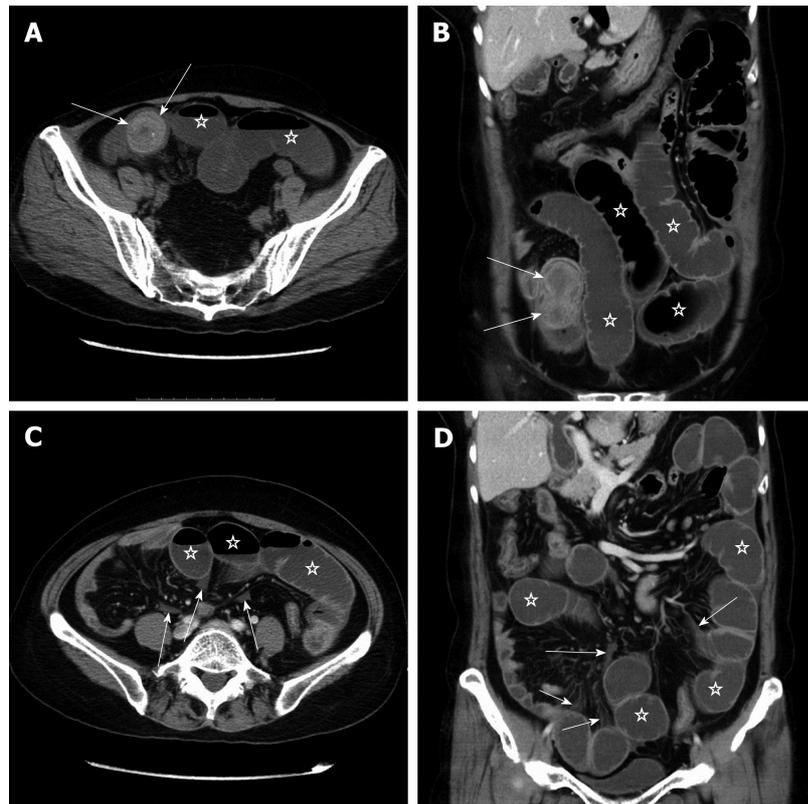
Figure 3 Protocol 3 applied in a 57-year-old woman with a bezoar causing small bowel obstruction. Because all assessment parameters could be evaluated with high self-confidence and satisfaction using the conventional axial and coronal reformations, the reader did not perform the multiple post-processing techniques. A and B: Multidetector computed tomography (MDCT) axial and coronal images of the abdomen reveal a well-defined, dumbbell-shaped bezoar (arrows) with a size of 5.8 cm × 3.5 cm × 3.5 cm in the distal segment of the small bowel. The bowel loops (pentagram) proximal to the bezoar are severely dilated with a maximum diameter of 4.5 cm. C and D: Additional MDCT axial and coronal images indicate small patchy mesenteric haziness and fluid (arrows), as well as the dilated bowel loops (pentagram), but no more signs of secondary bowel ischemia were found in the patient.

protocol 3 are summarized in Table 2. The two readers seldom or never used multiple post-processing techniques to determine whether SBO was present or obstruction severity. The two readers added multiple post-processing techniques for 6 (5.7%) and 7 patients (6.6%), respectively, for obstruction site identification. Most of these focused on distal and middle obstructions. The two readers added multiple post-processing techniques when evaluating the causes in 31 (29.2%) and 37 patients (34.9%), respectively. These causes were mainly diagnosed as vascular lesions, internal hernias, volvulus, and neoplastic intussusception. Multiple post-processing techniques were added to evaluate secondary bowel ischemia by reader 1 in 34 (32.1%) patients and by reader 2 in 32 (30.2%). In these patients, they were mainly used to observe vascular stenosis, occlusion, embolus and thrombosis, and mesenteric vascular engorgement.

Self-confidence scores
Table 3 shows the readers' self-confidence scores for each protocol. Overall, the two readers showed no difference in self-confidence scores for any assessment parameter within the same protocol ($P > 0.05$). However, for assessment parameters including middle-segmental SBO, adhesions, neoplasms, intussusception, volvulus, internal hernia and vascular diseases in the obstruction causes, vascular embolus/thrombosis, vascular stenosis/occlusion, mesenteric haziness/fluid, and mesenteric vascular engorgement in the findings of secondary bowel ischemia, there were differences in the self-confidence scores between the three protocols ($P < 0.01$ or 0.05). Protocols 2 and 3 had higher self-confidence scores than protocol 1, but there was no difference between protocols 2 and 3.

Reader agreement
There was a very good agreement (κ range: 0.830-0.967) in the identification of SBO and obstruction severity and site among the three protocols by both readers. The overall inter- and intra-reader agreement was good or very good (κ range: 0.733-0.924)
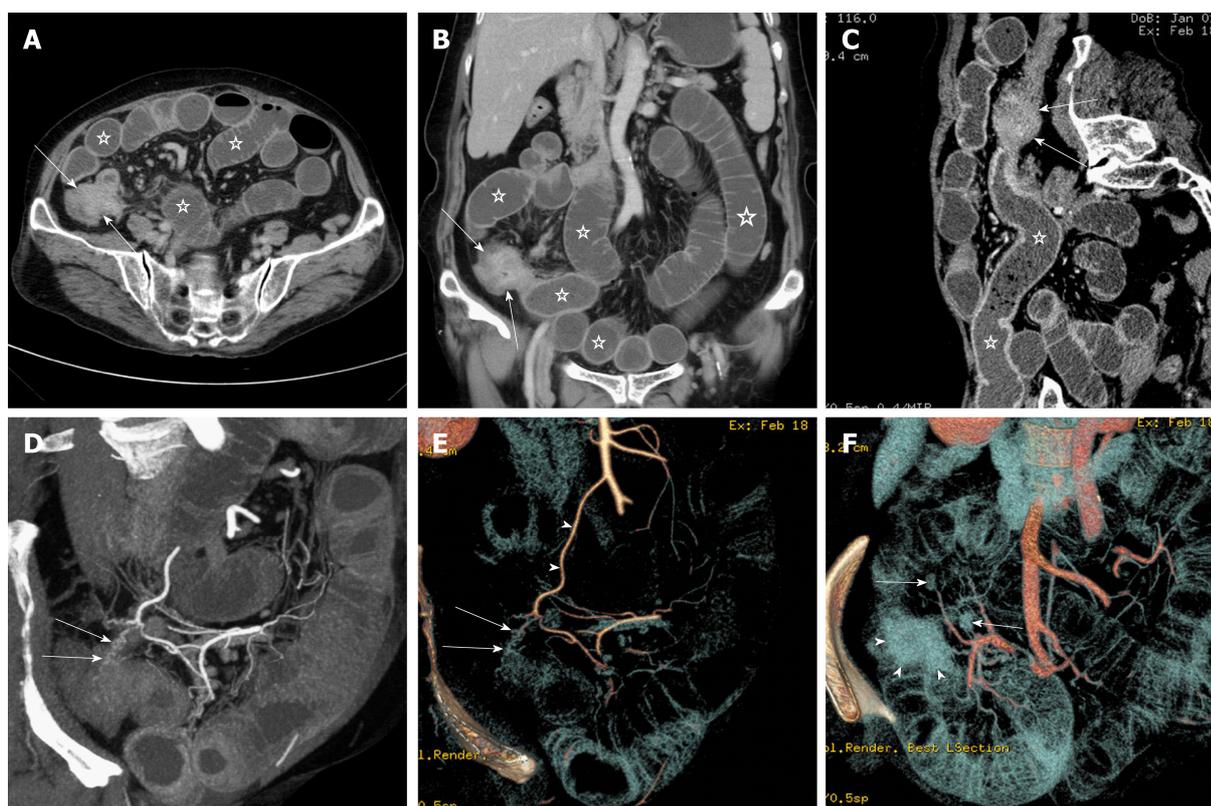
Figure 4 Protocol 3 applied in a 72-year-old woman with an adenocarcinoma at the end of the small bowel causing small bowel obstruction. Because it was difficult to identify the relationship between the mass and the dilated small bowel loops by conventional axial and coronal reformations, the reader selectively performed multiple post-processing techniques. A and B: Multidetector computed tomography axial and coronal images of the abdomen reveal an irregular, obviously enhanced mass (arrows) with a size of 4.4 cm × 4.2 cm × 3.7 cm in the right lower abdomen, and the small bowel loops (pentagram) in the abdominal cavity are moderately dilated with a maximum diameter of 3.6 cm. C: Curved planar reformation image clearly shows the location of the mass (arrows), dilated proximal bowel loops (pentagram), and collapsed distal bowel loops (arrowheads). D and E: Maximum intensity projection and volume rendering (VR) images obtained in the arterial phase indicate the mass with distorted and enlarged neovascular structures (arrows) arising from the ileocolic branch (arrowheads) of the superior mesenteric artery. F: VR image obtained in the portal venous phase reveals an obviously stained mass (arrowheads) and lymph nodes (arrows) in the adjacent mesentery.

in the evaluation of cause. There was a moderate or good agreement (κ range: 0.572-0.696) between the two readers in protocol 1, and between protocols 1 and 2 and protocols 1 and 3 for each reader for evaluating secondary bowel ischemia. Also for secondary bowel ischemia evaluation, there was a very good agreement (κ range: 0.795-0.863) between the two readers in protocols 2 and between protocols 2 and 3 for each reader (Table 4).

However, there were some differences among the inter- and intra-reader agreement results in determining a few of specific causes. For internal hernias, the agreement between the two readers in protocol 1 was only moderate, but a good or very good agreement was found between the two readers in protocols 2 and 3. Similarly, for vascular lesions, protocols 2 and 3 had better inter-reader agreement than protocol 1, and the intra-reader agreement between protocols 2 and 3 was also superior to that between protocols 1 and 2 and protocols 1 and 3. Especially for inflammatory lesions, a good agreement was only found between the two readers in protocol 3 and between protocols 2 and 3 for each reader (Table 4).

Diagnostic accuracy

The detection rate for the three protocols used to assess SBO is presented in Table 5. Overall, for the same protocol, the detection rate was not different between the two readers for any assessment parameter ($P > 0.05$). However, comparison of the detection rate among the three protocols revealed a difference in the total detection rate for causes and secondary bowel ischemia ($P < 0.01$). Protocols 2 and 3 gave a higher detection rate than protocol 1, but no difference was seen between protocols 2 and 3 ($P > 0.05$). For each specific cause, protocols 2 and 3 had a higher detection rate than protocol 1 for evaluating internal hernia and vascular lesions ($P < 0.01$ or 0.05).

The sensitivity, specificity, PPV, NPV, and accuracy of the three protocols for assessment of SBO are shown in Table 6. Protocol 1 had high sensitivity, PPV, and accuracy for determining the presence or absence of SBO, whereas protocols 2 and 3 appeared to have slightly better specificity and NPV. Both protocols 2 and 3 improved

Table 1 Worksheet for readers to use for interpretation of multidetector computed tomography post-processing images	
Presence or absence of obstruction	External hernias
Presence (≥ 2.5 cm)	Bezoars/stones
Absence (< 2.5 cm)	Vascular lesions
Severity of obstruction	Inflammatory lesions
Mild (2.5 to < 3 cm)	Others (*e.g.*, foreign body, abdominal cocoon, hematoma and so on)
Moderate (3 to < 4 cm)	**Findings of secondary bowel ischemia**
Severe (≥ 4 cm)	Main sings
Obstruction site	Increased bowel wall attenuation
Proximal (duodenum to proximal jejunum)	Decreased bowel wall enhancement
Middle (distal jejunum to mid-ileum)	Vascular embolus/thrombosis
Distal (distal ileum)	Vascular stenosis/occlusion
Multisegmental (more than one segment)	Pneumatosis/portomesenteric gas
Cause	Secondary sings
Adhesions	Bowel wall thickening
Neoplasms	Increased bowel wall enhancement
Intussusception	Mesenteric fluid/haziness
Neoplasms	Mesenteric vascular engorgement
Non-neoplasms	Small bowel feces sign
Volvulus	Ascites
Hernias	Others (solid organ infarction, free gas and so on)
Internal hernias	**Other findings** (fistula, leakage or perforation, pneumoperitoneum and so on)

the sensitivity, specificity, PPV, NPV, and accuracy in the identification of the obstruction sites, and had clearly superior specificity and NPV. Protocol 1 had high sensitivity for the evaluation of causes, whereas protocols 2 and 3 showed greater advantages in increasing specificity, PPV, NPV, and accuracy. Protocol 1 gave high specificity and PPV in evaluating secondary bowel ischemia, and the main advantages of protocols 2 and 3 were to substantially improve sensitivity, NPV, and accuracy. However, all the above parameter values were relatively close when comparing protocol 2 with protocol 3.

DISCUSSION

Our study is the first to integrate and optimize the MDCT multiple post-processing techniques to develop a more accurate post-processing protocol for SBO assessment. The protocols mainly used MPR and CPR to show the obstruction site and its connected proximal and distal bowel segments[13,14,17-20]. MIP and VR were mainly used to reveal local mesenteric changes and mesenteric vascular diseases, as well as the obstruction site. We designed two new post-processing protocols: protocol 2, which integrates multiple post-processing techniques, and protocol 3, which optimizes the multiple post-processing techniques. By designing a retrospective cross-sectional study to compare their respective advantages and disadvantages with protocol 1, we systemically evaluated the diagnostic accuracy and efficiency of the optimized protocol to exploit the greatest potential of the MDCT post-processing techniques for assessment of SBO and secondary bowel ischemia.

We found that the main deficiency of protocol 2 was that it was inefficient. It took too long to complete and produced more images, which will inevitably increase the workload of radiologists. Therefore, it would be difficult to implement protocol 2 for routine use for assessing each patient in daily clinical practice. Protocol 3 only required slightly more time than protocol 1. Therefore, our findings suggest that protocol 3 is more suitable for the pre-treatment assessment of SBO.

Both readers seldom or never added multiple post-processing techniques when using protocol 3 to evaluate whether SBO was present and the obstruction severity and site. However, they added multiple post-processing techniques at frequencies of 29.2% and 34.9%, respectively, for causes, and 32.1% and 30.2%, respectively, for secondary bowel ischemia. This suggests that protocol 1 is inadequate for identifying secondary bowel ischemia and some causes, but it is not necessary to use the multiple post-processing techniques for all patients with SBO.
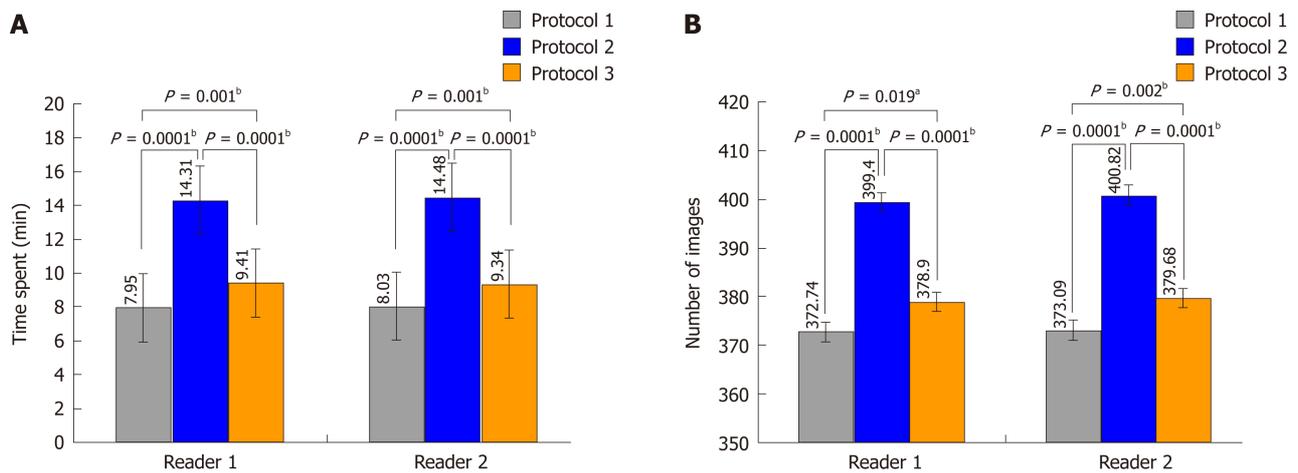
Figure 5 Graphs showing (A) time spent and (B) number of images used for three protocols for disease assessment in patients with clinically suspected small bowel obstruction. Student's *t* test and one-way analysis of variance were used to compare the mean of each result in both the inter and intrareader data sets. [a]$P < 0.05$, [b]$P < 0.01$.

Several studies[13-15,20] have reported that MPR or/and CPR can improve diagnostic self-confidence in determining the transition zone of SBO, but fail to define in which specific segment of the small intestine the transition zone is located. In addition, the post-processing techniques used in these studies were incomplete compared with the multiple post-processing techniques in our study. Therefore, the results of these studies[13-15,20] may not truly reflect the value of multiple post-processing techniques in SBO assessment.

Furthermore, our study compared the diagnostic efficacy of our three protocols for each assessment parameter. For evaluating whether SBO was present and obstruction severity, there were no differences among the three protocols with respect to diagnostic self-confidence, agreement, detection rate, and accuracy. These results are consistent with previous findings[5,6,13,14,19,20] and suggest that the conventional axial and coronal reformations may be sufficient to evaluate whether SBO is present and the obstruction severity without the need for additional post-processing techniques.

In contrast with previous studies[13-15,20], our results showed significant differences among the three protocols for the diagnostic self-confidence in locating the obstruction site in middle-segmental SBO. Protocols 2 and 3 had better inter- and intra-reader agreement and improved the diagnostic accuracy. This difference is likely because the previous studies[13-15,20,21] failed to identify in which specific segment of the small intestine the transition zone was located, and when a transition zone was adjacent to the segment boundaries of the small intestine, on conventional post-processing images it may be difficult to determine whether it is in the proximal or middle and middle or distal segment. However, using the multiple post-processing techniques, locating the obstruction sites became relatively easy.

MDCT exhibits excellent diagnostic accuracy compared with plain abdominal radiography and is especially superior in ascertaining the obstruction cause[22-25]. The results of our study showed that both protocols 2 and 3 gave the reader greater self-confidence compared with protocol 1 in the diagnosis of causes, but there was no difference between protocols 2 and 3. Overall, there was also very good inter- and intra-reader agreement, detection rate, accuracy, sensitivity, specificity, PPV and NPV in protocols 2 and 3. With further analysis of each specific cause, it is clear that the main advantage of the multiple post-processing techniques is that they can significantly improve the diagnostic accuracy of both internal hernias and vascular lesions.

The diagnosis of secondary bowel ischemia in the presence of SBO, however, remains more challenging. Reported CT sensitivities are 75%-100% with specificities of 61%-100%[26-29]. Consistent with this, we found that protocol 1 had poor sensitivity and accuracy in the evaluation of secondary bowel ischemia. However, when the readers used protocols 2 and 3, the detection rate, diagnostic accuracy, sensitivity, and NPV were strongly improved to almost the same extent, which we attribute to the use of the multiple post-processing techniques.

The results of our study also showed that protocols 2 and 3 both increased self-confidence in evaluating vascular embolus/thrombosis, vascular stenosis/occlusion, mesenteric haziness/fluid, and mesenteric vascular engorgement as signs of secondary bowel ischemia, and had a very good overall inter- and intra-reader

Table 2 Use frequencies of multiple post-processing techniques in the protocol 3 *n* (%)

Assessment parameter	Reader 1	Reader 2	*P*-value
Presence or absence of SBO (*n* = 106)	1 (0.9)	2 (1.9)	1.000
Severity (*n* = 106)	0	0	
Obstruction site			
No (*n* = 16)	1 (6.3)	2 (12.5)	1.000
Proximal (*n* = 9)	0	0	
Middle (*n* = 37)	2 (5.4)	1 (2.7)	0.556
Distal (*n* = 44)	3 (6.8)	4 (9.1)	0.694
Total (*n* = 106)	6 (5.7)	7 (6.6)	1.000
Cause			
No (*n* = 16)	1 (6.3)	2 (12.5)	1.000
Adhesions (*n* = 20)	2 (10.0)	1 (5.0)	0.548
Neoplasms (*n* = 11)	1 (9.1)	3 (27.3)	0.269
Intussusception			
Neoplasms (*n* = 9)	2 (22.2)	2 (22.2)	1.000
Nonneoplasms (*n* = 5)	3 (60.0)	2 (40.0)	0.527
Volvulus (*n* = 8)	6 (75.0)	7 (87.5)	0.522
Hernias			
Internal hernias (*n* = 6)	6 (100)	6 (100)	1.000
External hernias (*n* = 9)	1(11.1)	2 (22.2)	0.527
Bezoars/stones (*n* = 7)	0	2 (28.6)	0.127
Vascular lesions (*n* = 8)	8 (100)	8 (100)	1.000
Inflammatory lesions (*n* = 7)	1 (14.3)	2 (28.6)	0.515
Total (*n* = 106)	31 (29.2)	37 (34.9)	0.377
Findings of secondary bowel ischemia			
Increased bowel wall attenuation	0	0	
Decreased bowel wall enhancement	0	0	
Vascular embolus/thrombosis	5 (4.7)	5 (4.7)	1.000
Vascular stenosis/occlusion	18 (17)	15 (14.2)	0.570
Pneumatosis/portomesenteric gas	1 (0.9)	2 (1.9)	1.000
Bowel wall thickening	0	0	
Increased bowel wall enhancement	0	0	
Mesenteric haziness/fluid	2 (1.9)	0	0.477
Mesenteric vascular engorgement	8 (7.5)	10 (9.4)	0.622
Small bowel feces sign	0	0	
Ascites	0	0	
Total (*n* = 106)	34 (32.1)	32 (30.2)	0.767

SBO: Small bowel obstruction.

agreement. Therefore, protocols 2 and 3 are highly accurate in evaluating secondary bowel ischemia, which may be mainly because the multiple post-processing techniques increase the display rate of the above-mentioned signs.

Our study had several limitations, including the fact that it was performed retrospectively and thus failed to evaluate the improvement on the optimized protocol in guiding clinical treatment. Second, although our study had a large sample size, the causes of SBO included were limited and did not represent the MDCT characteristics of SBO for all causes. Third, all patients with SBO included in our study were patients who required surgery, which is inconsistent with the need for conservative treatment for most patients with SBO. Thus, the advantages of the optimized protocol relative to the conventional protocol should be considered with caution in clinical practice of MDCT assessment of SBO.

In conclusion, this is the first study that has established and evaluated an optimized protocol of multiple post-processing techniques on MDCT in SBO assessment. The optimized protocol can both guarantee efficiency and comprehensively improve diagnostic accuracy of MDCT for assessing SBO and secondary bowel ischemia,

Table 3 Average confidence scores among three protocols for assessment of small bowel obstruction (*n* = 106)

Assessment parameter	Protocol 1			Protocol 2			Protocol 3			*P*-value
	Reader 1	Reader 2	*P*-value	Reader 1	Reader 2	*P*-value	Reader 1	Reader 2	*P*-value	
Presence or absence of SBO										
Presence	4.8 ± 0.5	4.7 ± 0.6	0.070	4.8 ± 0.4	4.9 ± 0.3	0.103	4.9 ± 0.4	4.8 ± 0.4	0.184	0.110
Absence	4.6 ± 0.7	4.8 ± 0.6	0.270	4.9 ± 0.3	4.8 ± 0.4	0.164	4.7 ± 0.5	4.9 ± 0.3	0.188	0.341
Severity of obstruction										
No	4.6 ± 0.7	4.8 ± 0.6	0.270	4.9 ± 0.3	4.8 ± 0.4	0.164	4.7 ± 0.5	4.9 ± 0.3	0.188	0.341
Mild	4.4 ± 0.7	4.5 ± 0.7	0.162	4.8 ± 0.5	4.7 ± 0.5	0.428	4.7 ± 0.6	4.6 ± 0.6	0.666	0.753
Moderate	4.8 ± 0.4	4.7 ± 0.4	0.323	4.8 ± 0.4	4.8 ± 0.4	0.710	4.7 ± 0.6	4.8 ± 0.4	0.133	0.418
Severe	4.9 ± 0.4	4.8 ± 0.4	0.326	4.9 ± 0.4	4.9 ± 0.4	1.000	4.9 ± 0.3	4.9 ± 0.4	0.663	0.872
Obstruction site										
Proximal	4.4 ± 0.7	4.4 ± 0.5	1.000	4.8 ± 0.4	4.9 ± 0.3	0.594	4.7 ± 0.5	4.8 ± 0.4	0.681	0.323
Middle	4.2 ± 0.9	4.3 ± 0.8	0.054	4.6 ± 0.5	4.7 ± 0.5	0.058	4.4 ± 0.7	4.6 ± 0.6	0.710	0.004[b]
Distal	4.4 ± 1.0	4.5 ± 0.9	0.083	4.7 ± 0.5	4.7 ± 0.5	0.570	4.6 ± 0.6	4.6 ± 0.6	0.660	0.221
Cause										
Adhesions	3.6 ± 0.8	3.7 ± 0.8	0.083	4.7 ± 0.5	4.8 ± 0.4	0.428	4.5 ± 0.6	4.6 ± 0.6	0.163	0.001[b]
Neoplasms	4.1 ± 0.7	4.2 ± 0.6	0.341	4.9 ± 0.3	4.8 ± 0.4	0.588	4.7 ± 0.5	4.6 ± 0.5	0.588	0.001[b]
Intussusception										
Neoplasms	4.1 ± 1.1	4.2 ± 1.0	0.594	4.9 ± 0.3	4.8 ± 0.4	0.594	4.7 ± 0.5	4.6 ± 0.5	0.594	0.019[a]
Nonneoplasms	4.2 ± 0.8	4.0 ± 0.7	0.374	4.8 ± 0.4	4.8 ± 0.4	1.000	4.6 ± 0.5	4.8 ± 0.4	0.374	0.029[a]
Volvulus	4.4 ± 0.7	4.5 ± 0.8	0.351	5.0 ± 0.0	4.9 ± 0.4	0.351	4.6 ± 0.5	4.8 ± 0.5	0.598	0.041[a]
Hernias										
Internal hernias	3.3 ± 1.4	3.5 ± 1.0	0.611	4.7 ± 0.5	4.8 ± 0.4	0.611	4.3 ± 0.8	4.5 ± 0.5	0.695	0.002[b]
External hernias	4.7 ± 0.5	4.6 ± 0.7	0.347	4.9 ± 0.3	5.0 ± 0.0	0.347	4.9 ± 0.3	4.9 ± 0.3	1.000	0.054
Bezoars/stones	4.6 ± 0.5	4.7 ± 0.5	0.356	5.0 ± 0.0	4.9 ± 0.4	0.356	4.9 ± 0.4	4.7 ± 0.5	0.356	0.492
Vascular lesions	3.2 ± 1.3	3.3 ± 1.1	0.594	4.7 ± 0.5	4.6 ± 0.5	0.594	4.4 ± 0.5	4.3 ± 0.5	0.681	0.001[b]
Inflammatory lesions	3.9 ± 1.3	4.1 ± 1.1	0.356	4.7 ± 0.5	4.4 ± 0.5	0.172	4.3 ± 1.0	4.4 ± 0.5	0.604	0.581
Findings of secondary bowel ischemia										
Increased bowel wall attenuation	4.4 ± 0.5	4.5 ± 0.5	0.539	4.7 ± 0.5	4.7 ± 0.5	1.000	4.7 ± 0.5	4.6 ± 0.5	0.664	0.819
Decreased bowel wall enhancement	4.5 ± 0.5	4.4 ± 0.5	0.572	4.6 ± 0.5	4.7 ± 0.5	0.536	4.6 ± 0.5	4.7 ± 0.5	0.721	0.282
Vascular embolus/thrombosis	4.0 ± 0.9	4.1 ± 1.0	0.598	4.9 ± 0.4	4.8 ± 0.5	0.598	4.6 ± 0.5	4.5 ± 0.5	0.598	0.010[a]
Vascular stenosis/occlusion	3.8 ± 0.8	3.9 ± 0.9	0.503	4.8 ± 0.4	4.7 ± 0.5	0.265	4.4 ± 0.5	4.5 ± 0.6	0.574	0.001[b]
Pneumatosis/portomesenteric gas	4.1 ± 0.3	4.3 ± 0.7	0.447	4.4 ± 0.5	4.7 ± 0.4	0.081	4.6 ± 0.5	4.7 ± 0.5	0.681	0.814
Bowel wall thickening	4.5 ± 0.5	4.6 ± 0.5	0.321	4.6 ± 0.5	4.7 ± 0.5	0.109	4.6 ± 0.5	4.7 ± 0.5	0.254	0.059
Increased bowel wall enhancement	4.6 ± 0.5	4.8 ± 0.4	0.231	4.7 ± 0.5	4.8 ± 0.4	0.161	4.8 ± 0.4	4.7 ± 0.5	0.536	0.441
Mesenteric haziness/fluid	4.3 ± 0.6	4.3 ± 0.6	0.571	4.7 ± 0.5	4.8 ± 0.4	0.292	4.6 ± 0.5	4.7 ± 0.5	0.571	0.003[b]
Mesenteric vascular engorgement	4.2 ± 0.6	4.1 ± 0.6	0.748	4.8 ± 0.4	4.9 ± 0.4	0.494	4.7 ± 0.5	4.8 ± 0.4	0.716	0.001[b]
Small-bowel feces sign	4.4 ± 0.5	4.6 ± 0.6	0.329	4.7 ± 0.5	4.6 ± 0.5	0.576	4.5 ± 0.5	4.6 ± 0.6	0.428	0.748
Ascites	4.7 ± 0.5	4.6 ± 0.5	0.583	4.9 ± 0.4	4.8 ± 0.4	0.671	4.8 ± 0.4	4.7 ± 0.5	0.583	0.848

[a]*P* < 0.05,
[b]*P* < 0.01. SBO: Small bowel obstruction.

which are critical because these imaging parameters can guide patient care. The widespread use of this protocol should be supported by further prospective, larger-sample clinical trials including identification of its indications.

Table 4 Inter- and intra-reader agreement (κ value) among three protocols for assessment of small bowel obstruction

Assessment parameter	Inter-reader agreement			Intra-reader agreement					
	Protocol 1	Protocol 2	Protocol 3	Reader 1			Reader 2		
	Reader 1-2	Reader 1-2	Reader 1-2	Protocol 1-2	Protocol 1-3	Protocol 2-3	Protocol 1-2	Protocol 1-3	Protocol 2-3
Presence or absence of SBO (*n* = 106)	0.902	0.897	0.966	0.866	0.902	0.964	0.933	0.897	0.967
Severity of obstruction (*n* = 106)	0.868	0.869	0.894	0.830	0.882	0.895	0.881	0.907	0.921
Obstruction site (*n* = 106)	0.873	0.926	0.925	0.855	0.890	0.925	0.908	0.870	0.963
Cause									
No (*n* = 16)	0.902	0.897	0.966	0.866	0.902	0.964	0.933	0.897	0.967
Adhesions (*n* = 20)	0.725	0.820	0.820	0.725	0.786	0.759	0.820	0.820	1.000
Neoplasms (*n* = 11)	0.946	1.000	0.946	0.946	0.946	1.000	1.000	0.946	0.946
Intussusception									
Neoplasms (*n* = 9)	0.927	0.935	0.935	0.863	0.927	0.935	0.863	0.935	0.935
Nonneoplasms (*n* = 5)	0.738	0.883	0.883	0.883	0.738	0.883	0.738	0.883	0.883
Volvulus (*n* = 8)	0.927	0.927	0.927	0.845	0.927	0.927	1.000	0.927	0.927
Hernias									
Internal hernias (*n* = 6)	0.554	0.903	0.788	0.789	0.649	0.903	0.739	0.739	1.000
External hernias (*n* = 9)	0.935	0.935	1.000	0.935	1.000	0.935	0.935	0.935	1.000
Bezoars/stones (*n* = 7)	0.917	0.917	1.000	0.917	1.000	0.917	0.917	0.917	1.000
Vascular lesions (*n* = 8)	0.554	0.927	0.751	0.522	0.419	0.845	0.518	0.711	0.845
Inflammatory lesions (*n* = 7)	0.371	0.586	0.637	0.444	0.411	0.637	0.363	0.333	0.751
Total (*n* = 106)	0.733	0.861	0.848	0.748	0.760	0.848	0.772	0.797	0.924
Presence or absence of secondary bowel ischemia (*n* = 106)	0.572	0.863	0.840	0.675	0.645	0.795	0.690	0.696	0.863

SBO: Small bowel obstruction.

Table 5 Detection rates for assessment parameters among three protocols for assessment of small bowel obstruction *n* (%)

Assessment parameter	Protocol 1			Protocol 2			Protocol 3			*P*-value
	Reader 1	Reader 2	*P*-value	Reader 1	Reader 2	*P*-value	Reader 1	Reader 2	*P*-value	
Presence or absence of SBO										
Presence (*n* = 90)	85 (94.4)	87 (96.7)	0.469	89 (98.9)	87 (96.7)	0.312	88 (97.8)	88 (97.8)	1.000	0.378
Absence (*n* = 16)	15 (93.8)	14 (87.5)	0.544	15 (93.8)	16 (100)	0.310	15 (93.8)	16 (100)	0.310	0.430
Obstruction site										
No (*n* = 16)	15 (93.8)	14 (87.5)	0.544	15 (93.8)	16 (100)	0.310	15 (93.8)	16 (100)	0.310	0.430
Proximal (*n* = 9)	8 (88.9)	7 (77.8)	0.527	9 (100)	8 (88.9)	0.303	8 (88.9)	8 (88.9)	1.000	0.570
Middle (*n* = 37)	34 (91.9)	33 (89.2)	0.691	34 (91.9)	35 (94.6)	0.643	35 (94.6)	34 (91.9)	0.643	0.775
Distal (*n* = 44)	40 (90.9)	41 (93.2)	0.694	43 (97.7)	43 (97.7)	1.000	42 (95.5)	43 (97.7)	0.557	0.160
Total (*n* = 106)	97 (91.5)	95 (89.6)	1.000	101 (95.3)	102 (96.2)	1.000	100 (94.3)	101 (95.3)	1.000	0.129
Cause										
No (*n* = 16)	15 (93.8)	14 (87.5)	0.544	15 (93.8)	16 (100)	0.310	15 (93.8)	16 (100)	0.310	0.430
Adhesions (*n* = 20)	18 (90.0)	19 (95.0)	0.548	19 (95.0)	20 (100)	0.311	19 (95.0)	20 (100)	0.311	0.434
Neoplasms (*n* = 11)	10 (90.9)	11 (100)	0.306	11 (100)	11 (100)	1.000	11 (100)	10 (90.9)	0.306	0.597
Intussusception										
Neoplasms (*n* = 9)	7 (77.8)	8 (88.9)	0.527	9 (100)	8 (88.9)	0.303	8 (88.9)	9 (100)	0.303	0.414
Nonneoplasms (*n* = 5)	4 (80.0)	4 (80.0)	1.000	5 (100)	4 (80.0)	0.292	4 (80.0)	5 (100)	0.292	0.749
Volvulus (*n* = 8)	7 (87.5)	8 (100)	0.302	7 (87.5)	8 (100)	0.302	8 (100)	7 (87.5)	0.302	1.000
Hernias										
Internal hernias (*n* = 6)	4 (66.7)	3 (50.0)	0.558	6 (100)	5 (83.3)	0.296	5 (83.3)	5 (83.3)	1.000	0.045[a]
External hernias (*n* = 9)	9 (100)	8 (88.9)	0.303	8 (88.9)	9 (100)	0.303	9 (100)	9 (100)	1.000	0.595
Bezoars/stones (*n* = 7)	7 (100)	6 (85.7)	0.299	6 (85.7)	7 (100)	0.299	7 (100)	7 (100)	1.000	0.592
Vascular lesions (*n* = 8)	3 (37.5)	4 (50.0)	0.614	8 (100)	7 (87.5)	0.302	6 (75.0)	7 (87.5)	0.522	0.004[b]
Inflammatory lesions (*n* = 7)	6 (85.7)	6 (85.7)	1.000	6 (85.7)	5 (71.4)	0.515	6 (85.7)	5 (71.4)	0.515	0.857
Total (*n* = 106)	90 (84.9)	91 (85.8)	1.000	100 (94.3)	100 (94.3)	1.000	98 (92.5)	100 (94.3)	1.000	0.001[b]
Presence or absence of secondary bowel ischemia										
Presence (*n* = 38)	28 (73.7)	27 (71.1)	1.000	36 (94.7)	35 (92.1)	0.644	34 (89.5)	36 (94.7)	0.395	0.001[b]
Absence (*n* = 68)	65 (95.6)	67 (98.5)	0.308	65 (95.6)	66 (97.1)	0.647	66 (97.1)	65 (95.6)	0.647	0.928

[a]*P* < 0.05,
[b]*P* < 0.01. SBO: Small bowel obstruction.

Table 6 Sensitivity, specificity, positive predictive value, negative predictive value, and accuracy of three protocols for assessment of small bowel obstruction

Assessment parameter	Protocol 1		Protocol 2		Protocol 3	
	Reader 1	Reader 2	Reader 1	Reader 2	Reader 1	Reader 2
Presence or absence of SBO						
Sensitivity	94.4%	96.7%	98.9%	96.7%	97.8%	97.8%
Specificity	93.8%	87.5%	93.8%	100%	93.8%	100%
PPV	98.8%	97.8%	98.9%	100%	98.9%	100%
NPV	75.0%	82.4%	93.8%	84.2%	88.2%	88.9%
Accuracy	94.3%	95.3%	98.1%	97.2%	97.2%	98.1%
Obstruction site						
Sensitivity	94.3%	96.4%	98.9%	96.6%	97.7%	97.7%
Specificity	78.9%	63.6%	78.9%	94.1%	78.9%	84.2%
PPV	95.3%	91.0%	95.6%	98.9%	95.5%	96.6%
NPV	75.0%	82.4%	93.8%	84.2%	88.2%	88.9%
Accuracy	91.5%	89.6%	95.3%	96.2%	94.3%	95.3%
Cause						
Sensitivity	93.8%	96.3%	98.8%	96.6%	97.6%	97.7%
Specificity	57.7%	53.8%	75.0%	84.2%	71.4%	80.0%
PPV	87.2%	86.5%	94.4%	96.6%	93.3%	95.5%
NPV	75.0%	82.4%	93.8%	84.2%	88.2%	88.9%
Accuracy	84.9%	85.8%	94.3%	94.2%	92.5%	94.3%
Secondary bowel ischemia						
Sensitivity	73.7%	71.1%	94.7%	92.1%	89.5%	94.7%
Specificity	95.6%	98.5%	95.6%	97.1%	97.1%	95.6%
PPV	90.3%	96.4%	92.3%	94.6%	94.4%	92.3%
NPV	86.7%	85.9%	97%	95.7%	94.3%	97%
Accuracy	87.7%	88.7%	95.3%	95.3%	94.3%	95.3%

SBO: Small bowel obstruction; PPV: Positive predictive value; NPV: Negative predictive value.

ARTICLE HIGHLIGHTS

Research background

Acute small bowel obstruction (SBO) is a common clinical syndrome for which effective treatment depends on a rapid and accurate diagnosis. Despite advances in imaging and a better understanding of small bowel pathophysiology, SBO is often diagnosed late or misdiagnosed, resulting in significant morbidity and mortality. Nowadays, multidetector computed tomography (MDCT) with multiple post-processing techniques has shown great potential in assessment of SBO and related complications, and the accuracy and agreement are expected to be further improved.

Research motivation

On the applications of MDCT multiple post-processing techniques in the assessment of SBO, only a few studies on multi-planar reformations have been reported in the current literature. In the MDCT assessment of SBO, how to reasonably apply these post-processing techniques to further improve the diagnostic accuracy is an important issue worth exploring further to radiologists.

Research objectives

This study aimed to integrate and optimize MDCT multiple post-processing techniques, and designed a retrospective cross-sectional study to systemically evaluate diagnostic accuracy and efficiency of the optimized protocol using multiple post-processing techniques on MDCT to assess SBO and secondary bowel ischemia.

Research methods

This retrospective cross-sectional study was conducted in a single center of China for evaluation of an optimized protocol on multiple post-processing techniques for MDCT assessment of SBO and secondary bowel ischemia. Two radiologists applied three protocols to image post-processing and interpretation for MDCT volume data of 106 patients with clinically suspected

SBO. We compared the optimized protocol with the other two protocols based on time spent, number of images, diagnostic self-confidence, agreement, and accuracy of detection of SBO and secondary bowel ischemia.

Research results

Using the optimized protocol, two radiologists added multiple post-processing techniques at frequencies of 29.2% and 34.9%, respectively, for obstruction cause, and 32.1% and 30.2%, respectively, for secondary bowel ischemia. The integrated protocol resulted in more time spent and number of images than the conventional and optimized protocols ($P < 0.01$), for the optimized protocol, the time spent and the number of images were only slightly more than those for the conventional protocol. The integrated and optimized protocols had higher total detection rates of obstruction cause and secondary bowel ischemia than the conventional protocol ($P < 0.01$), but no difference was detected between the two ($P > 0.05$). The accuracy, sensitivity, specificity, positive predictive value, and negative predictive value of the integrated and optimized protocols were superior to the conventional protocol for evaluating obstruction cause and secondary bowel ischemia, but these parameters between the two protocols were very close.

Research conclusions

This is the first study to establish and evaluate an optimized protocol of the multiple post-processing techniques on MDCT used to assess SBO. The main deficiency of the integrated protocol was that it was inefficient. It took too long to complete and produced more images, which will inevitably increase the workload of radiologists. The optimized protocol can both guarantee the time efficiency and effectively control the number of images, and comprehensively improve the diagnostic self-confidence, agreement, accuracy of MDCT for determining the SBO severity, site and causes, and secondary bowel ischemia, which are critical because these imaging parameters can guide patient care.

Research perspectives

Although the present study has several limitations, the optimized protocol can be considered for widespread recommendation in clinical practice of MDCT assessment of SBO and secondary bowel ischemia. Future studies should focus on applying this protocol to prospective, larger-sample clinical trials to further identify its advantages, disadvantages, and indications so that it can be continuously modified and improved.

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