The accuracy of multidetector computed tomography in the diagnosis of non-occlusive mesenteric ischaemia in patients after cardiovascular surgery

Henry C K Kwok, Ilse Dirkzwager, David S Duncan, Michael J Gillham and David G Milne

ABSTRACT

Objective: To determine the accuracy of multidetector computed tomography (MDCT) in the diagnosis of non-occlusive mesenteric ischaemia (NOMI) among patients after cardiovascular surgery.

Design, setting and participants: A retrospective review of 38 patients in a cardiothoracic intensive care unit who underwent MDCT examination before laparotomy for suspected NOMI between January 2001 and December 2012.

Intervention and main outcome measures: The MDCT studies were examined independently by three radiologists, who were asked to make a determination on the presence or absence of NOMI. The radiological diagnosis was compared against the surgical and/or histological outcome to determine the diagnostic accuracy of MDCT.

Results: The sensitivity and specificity of MDCT in the diagnosis of NOMI were 96% and 33%–60%, respectively. The positive and negative likelihood ratios and diagnostic odds ratio were 1.43–2.39, 0.072–0.13 and 11–33.2, respectively. The inter-rater agreement was 68%, with a Fleiss κ of 0.43.

Conclusions: MDCT has high sensitivity but lacks specificity in the diagnosis of NOMI. Its main value is in selection of patients for non-operative management, at least in the short-to-medium term.

Crit Care Resusc 2014; 16: 90–95

Non-occlusive mesenteric ischaemia (NOMI) refers to hypoperfusion of the splanchnic circulation in the absence of mesenteric vascular occlusion,[1] and may range from frank bowel gangrene and ischaemic colitis to intramucosal acidosis and mucosal hypoperfusion.[2] Although NOMI is considered rare in the general population (ocurring at the rate of two cases/100 000 person-years),[3,4] its incidence after cardiovascular surgery is over 350 in 100 000 cases (0.35%).[5] This patient group is thought to be susceptible to NOMI because of risk factors including advanced age, low cardiac output state, inotrope use, concurrent sepsis and effects of haemodialysis and recent surgery.[6-9]

The diagnosis of NOMI is difficult because of its insidious onset, the non-specific physical findings and unreliable laboratory markers.[8-11] Historically, catheter angiography (CA) was considered the gold standard in diagnosis of NOMI,[6,11] and diagnostic criteria and a management algorithm based on angiographic findings have been reported.[8,9,11] However, CA is not universally offered or performed, is invasive and may not be practical in critically ill patients after cardiovascular surgery. This may lead to diagnostic delay or a worse outcome.[12] Multidetector computed tomography (MDCT) is rapid, less invasive and readily available, so may overcome the limitations of CA, but results of assessment of its diagnostic accuracy have been mixed and conflicting.[5,8,12-16]

In our hospital, we have routinely used MDCT for investigating possible NOMI in patients after cardiovascular surgery. The aims of our study were to investigate:

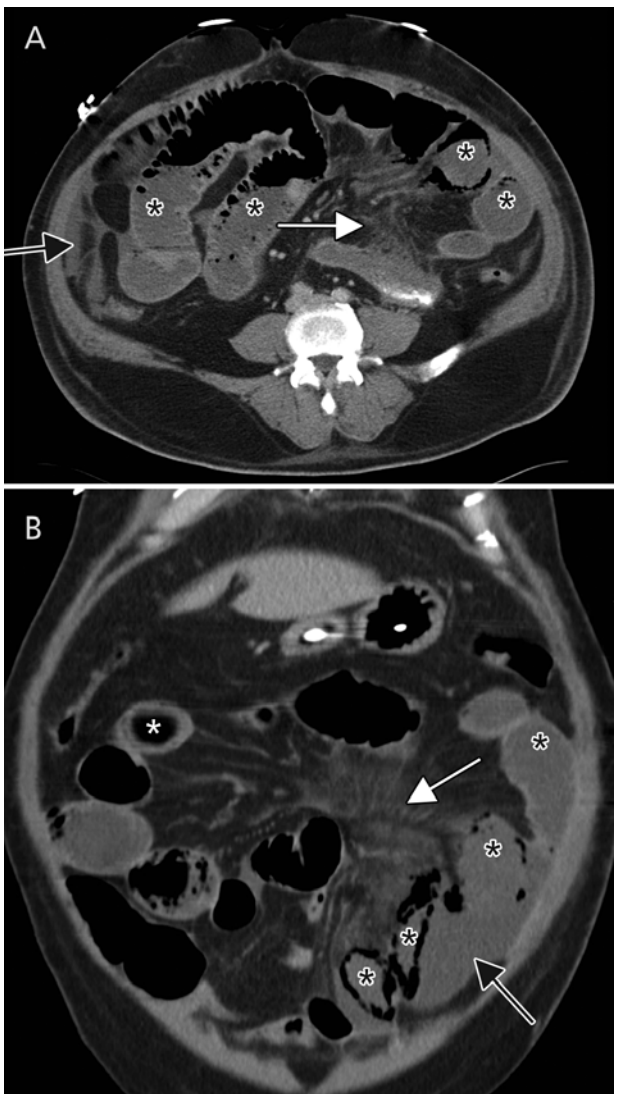
- diagnostic accuracy of MDCT in patients suspected of developing NOMI after cardiovascular surgery
- interobserver agreement between three independent and blinded radiologists
- significant limitations in the use of MDCT in this context.

Methods

Patients who were admitted to the cardiovascular intensive care unit (CVICU) after cardiovascular surgery and subsequently had a laparotomy for suspected NOMI were identified from the operating room database for the period between January 2001 and December 2012. Those who had received MDCT within 48 hours before surgery were included for analysis. The patient demographics, admission indications and clinical outcome were retrieved from case notes. The intraoperative findings were classified as positive or negative for bowel ischaemia. When bowel resection had also taken place, the pathological diagnosis was also recorded.

Each MDCT study was independently assessed by three abdominal radiologists (D M, I D and D D) who were blinded to the original reports, surgical findings and final clinical

Figure 1. A 48-year-old man developed abdominal symptoms 2 weeks after mitral valve surgery. Portal venous phase multidetector computed tomography images in axial (A) and coronal (B) planes show bowel dilatation, mural thickening and intramural gas affecting multiple small bowel loops (*). Intraperitoneal free fluid (black arrow) and mesenteric oedema (white arrow) were also present. Radiological appearances were in keeping with small bowel ischaemia. Laparotomy confirmed the presence of gangrenous small bowel requiring resection. The patient was subsequently discharged alive.



outcome. The radiologists were asked to make a determination on the presence or absence of NOMI. The studies were examined for imaging features of small and large intestinal ischaemia, which included bowel wall thickening or oedema, bowel dilatation, pneumatosis, portal venous gas, and intraperitoneal free fluid and free air (Figure 1). These variables were dichotomised and recorded on proformas. Bowel wall contrast enhancement was not consistently assessable, due to variations in imaging techniques, and was therefore not included as a factor. An MDCT study was excluded if there was an "arterial cut-off" sign, described as an abrupt termination of a mesenteric vessel,[17] because of the implied occlusive (ie, thromboembolic) aetiology.

For the purpose of data analysis, the MDCT assessments from individual radiologists were combined by "majority rule". In other words, each dichotomised variable was assigned a value based on consensus from at least two of the three radiologists. The radiological diagnosis was compared against the surgical and/or histological outcome to determine the accuracy of MDCT, expressed in terms of sensitivity, specificity, positive likelihood ratio (PLR), negative likelihood ratio (NLR) and diagnostic odds ratio (DOR). Likelihood ratios and DOR are preferred over predictive

Table 1. Patient demographics, admission indications and multidetector computed tomography (MDCT) type

Variable	Data
No of patients	38
Mean age, years	69
Male, *n* (%)	28 (74%)
Indication for admission to cardiovascular intensive care unit, *n* (%)	
Coronary bypass	16 (42%)
Valvular surgery	11 (29%)
Coronary bypass and valvular surgery	5 (13%)
Aortic surgery	6 (16%)
Deaths, *n* (%)	19 (50%)
Type of MDCT, *n* (%)	
Angiographic phase only	2 (5%)
Angiographic and venous phase	19 (50%)
Venous phase only	13 (34%)
Non-contrast	4 (11%)

Table 2. Multidetector computed tomography (MDCT) v operative findings

Ischaemia detected on MDCT	Ischaemia detected at surgery or in pathological specimen	No ischaemia detected at surgery or in pathological specimen
Yes	22	10
No	1	5

Table 3. Review of patients with "false-positive" MDCT for non-occlusive mesenteric ischaemia (NOMI)

Age (sex)	Background	Surgical finding	Outcome
65 y (M)	Aortic dissection repair	No ischaemia	Ischaemic colon at second surgery 2 days later
82 y (M)	Coronary artery bypass	Emphysematous bowel wall, but not resected	Survived
60 y (M)	Aortic valve surgery	Turbid fluid	Died 3 days later
69 y (M)	Aortic valve surgery, coronary bypass graft	Thickened caecal wall with perforated ulcer	Cytomegalo-virus-related ulcer*
74 y (M)	Aortic dissection repair	No ischaemia	Died; presumptive NOMI diagnosis
69 y (F)	Aortic valve surgery	No ischaemia	Survived
77 y (M)	Aortic and mitral valve surgery	No ischaemia	Survived
59 y (M)	Aortic valve surgery	No ischaemia	Survived
68 y (M)	Aortic valve surgery, coronary bypass graft	No ischaemia	Survived
74 y (M)	Coronary artery bypass	No ischaemia	Survived

y = years. M = male. F = female. * Diagnosed by histological examination.

values as they are independent of the disease prevalence, which was unknown in our cohort because only patients who had MDCT followed by surgery were included.

Logistic regression was used to identify imaging features that were predictive of the clinical outcome. The inter-rater agreement between the radiologists was evaluated using Fleiss κ statistics for multiple raters. All statistical procedures were performed using R (R Foundation), with $P < 0.05$ considered statistically significant. Our study was approved by the Auckland City Hospital research committee (registration A+6081).

Results

Between January 2001 and December 2012 there were 38 cardiovascular surgical patients who had MDCT examinations before laparotomy for suspected NOMI. Patient demographics and indications for admission to the CVICU are listed in Table 1. Of the 38 patients, 23 had mesenteric ischaemia shown on laparotomy and 18 required resection. Four patients had extensive ischaemia at laparotomy, precluding resection, and one patient had ischaemia due to volvulus,

Figure 2. A 67-year-old woman developed an increasing inotropic requirement on Day 7 after coronary artery bypass surgery. Portal venous phase multidetector computed tomography images in axial (A) and coronal (B) planes show extensive intramural gas (*) and bowel wall thickening (**) affecting the small bowel and colon. Portal venous gas (black arrow) and intraperitoneal free fluid (white arrows) were also present. Radiological appearances were consistent with extensive bowel ischaemia. At laparotomy, the right colon was found to be ischaemic and required resection; the small bowel was considered satisfactory. The patient later died. An autopsy was not performed and it remained unclear whether the radiological change of the small bowel represented partial thickness ischaemia undetected at surgery.

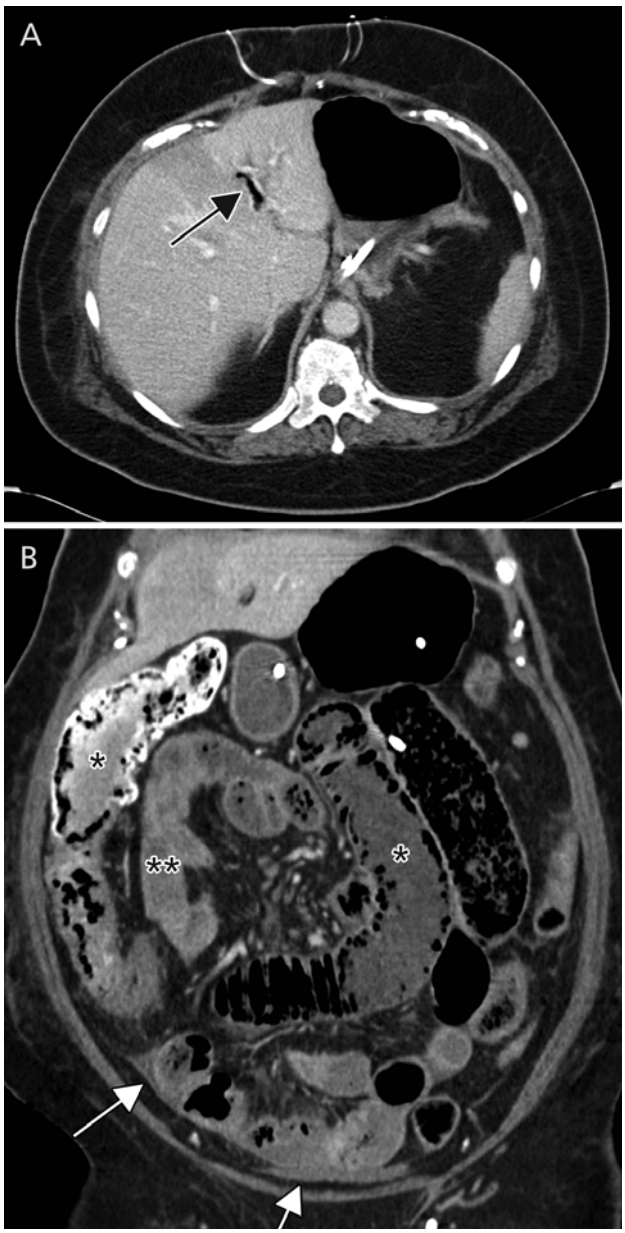


Table 4. Agreement and inter-rater reliability for findings

Imaging features	Agreement	Fleiss kappa	*P*
Wall oedema or thickening	55%	0.310	< 0.001
Bowel dilatation	79%	0.646	< 0.001
Intramural gas	71%	0.613	< 0.001
Portal venous gas	95%	0.802	< 0.001
Free air	87%	0.534	< 0.001
Free fluid	63%	0.432	< 0.001
Non-occlusive mesenteric ischaemia	68%	0.432	< 0.001

Table 5. A review of patients who had multidetector computed tomography (MDCT) not followed by surgery

Age (years), sex	Background	NOMI found on MDCT	Clinical outcome
55, F	Aortic dissection repair	Yes	Survived
74, M	Aortic dissection repair	Yes	Died of presumed NOMI
70, M	Aortic valve surgery, coronary artery bypass	Yes	Died of presumed NOMI
70, M	Aortic valve surgery, coronary artery bypass	Yes	Died of presumed NOMI
64, F	Coronary artery bypass, Bentall procedure	Yes	Later surgery confirmed NOMI
72, M	Coronary artery bypass	No	Initial improvement; died 5 days later
76, M	Coronary artery bypass	No	Survived
64, M	Aortic and mitral valve surgery, coronary artery bypass	No	Survived

M = male. F = female. NOMI = non-occlusive mesenteric ischaemia.

which did not require resection once the underlying cause was remedied. The overall mortality rate was 50%.

The MDCT assessment against surgical outcome is shown in Table 2. The sensitivity and specificity of MDCT in allowing detection of surgically apparent mesenteric ischaemia were 96% and 33%, respectively. The PLR, NLR and DOR were 1.43, 0.13 and 11, respectively. There was only one patient for whom MDCT failed to identify ischaemia: in this patient, MDCT identified a caecal volvulus correctly but not the associated bowel ischaemia. Although technically this patient had occlusive rather than non-occlusive ischaemia, the patient was included as a false-negative MCDT result because we considered the detection of ischaemia, regardless of the aetiology, as the primary goal of MDCT.

Table 6. The accuracy of multidetector computed tomography (MDCT) in the diagnosis of non-occlusive mesenteric ischaemia (NOMI): summary of literature*

Study first author	Number of NOMI patients	MDCT performance
Alpern[14]	23	Correctly diagnosed 6 cases (26%)
Hasan[5]	4	Correctly diagnosed 1 case (25%)
Ofer[15]	3 (of 4 examined)	Sensitivity 75%; specificity 98.8%
Woodhams[16]	4	"Irregular narrowing" of superior mesenteric artery shown in all cases
Our study	23 (of 38 examined)	Sensitivity 96%; specificity 33%–60%

* All studies were retrospective.

There were 10 patients for whom MDCT reported NOMI but for whom laparotomy was negative (Table 3). One of these patients was subsequently found to have NOMI at a second laparotomy 2 days later. Two patients died shortly after surgery, one due to NOMI diagnosed on clinical grounds, although an autopsy was not performed. In one instance, surgery confirmed the presence of intramural gas as shown on the preoperative MDCT but it was not associated with visible full-thickness infarction and resection was not performed. It was possible that NOMI might have been present but was not full thickness and was therefore reversible (Figure 2). If these four cases were adjusted for, the sensitivity and specificity would increase to 96% and 60% respectively. The corrected PLR, NLR and DOR would be 2.39, 0.072 and 33.2 respectively.

There was a moderate level of inter-rater reliability between the radiologists, with a median agreement of 75% (range, 55%–95%) with respect to the imaging features, and 68% agreement ($\kappa = 0.432$) with respect to the diagnosis of NOMI (Table 4). Although bowel dilatation and intramural gas appear to predict NOMI on bivariate analysis, only bowel dilatation remains a significant predictive factor on multivariate logistic regression (odds ratio, 12.3; $P = 0.043$) due to significant interactions between these factors. The presence of bowel wall thickening or oedema, portal venous gas, intraperitoneal free air or free fluid does not predict NOMI.

Since November 2011, the CVICU has maintained a database of cardiovascular surgical patients who had suspected NOMI. This database enabled identification of an additional eight patients who had MDCT but did not proceed to laparotomy. Six of these patients did not have a laparotomy because the original MDCT assessment did not support a diagnosis of NOMI. Surgery was not offered to the remaining two patients because their clinical status had deteriorated significantly or the extent of ischaemia seen on MDCT was considered non-survivable. Although the lack of laparotomy precluded quantitative determination of MDCT accuracy in this cohort, the radiological assessments were correlated qualitatively with the clinical outcome (Table 5).

Discussion

We examined the accuracy of MDCT in the diagnosis of NOMI. MDCT has been in routine use in our hospital for over a decade. In our cohort, which is among the largest reported to date, MDCT was associated with a sensitivity of 96% when compared with surgery. This corresponded to an NLR of between 0.072 and 0.13 and a DOR of between 11 and 33.2. There was moderate concordance between the radiologists, with an overall agreement of 68% ($\kappa = 0.432$). Our results compare favourably to those in the literature (Table 6).

Nevertheless, MDCT lacks specificity, with high rates of false-positive results. This may reflect the non-specific nature of many of the imaging features, which are reportedly present in only 20%–60% of cases.[13] In our multivariate analysis, only bowel dilatation is shown to be a significant predictor of NOMI, although it is also arguably one of the least specific. Contrary to classical radiology teaching, our observations suggest that portal venous gas does not reliably predict NOMI at laparotomy. Such a discrepancy may reflect the relative rarity (three out of 23 patients) of this finding in our series. It is also possible that portal venous gas may occur in partial-thickness ischaemia, which can be occult at surgery.[18]

Table 7. Novel biomarkers for intestinal ischaemia

Test	Sensitivity	Specificity	PLR	NLR	DOR
l-FABP	72%	73%	2.44	0.51	7.6
GST	68%	85%	3.38	0.40	8.8
d-Lactate	82%	48%	3.04	0.35	10.8
d-Dimer	89%	40%	1.48	0.30	5.8
MDCT	96%	33%–60%	1.43–2.39	0.072–0.13	11–33.2

PLR = positive likelihood ratio. NLR = negative likelihood ratio. DOR = diagnostic odds ratio. FABP = fatty acid binding protein. GST = glutathione S-transferase. MDCT = multidetector computed tomography.

Some authors have argued against the use of MDCT due to its modest accuracy,[5,13,14] but it should be noted that clinical assessment and other non-invasive tests in current use are unreliable.[8-11,19] Splanchnic angiography, which has been touted as the diagnostic test of choice,[13,20] is not universally offered or performed and may only detect a subset of NOMI showing vasoconstriction.[2] In a prospective study, Mitsuyoshi reported a reduction of NOMI-related mortality from 70% to 11% after switching from angiography to early MDCT in all patients.[12] One of the reasons cited for this apparent improvement was the reduction of diagnostic delay with the adoption of routine MDCT.

In practice, the value of MDCT appears to lie in its ability to select patients for non-operative management. At our institution, MDCT is performed on patients who have an intermediate pretest probability for NOMI. Patients for whom MDCT assessment is negative for NOMI are managed with best supportive care and reviewed 48 hours later, at which point laparotomy is performed if there remains concern for NOMI. On the other hand, patients who have a high pretest probability for NOMI or for whom MDCT assessment is positive for NOMI are managed with emergency surgery. Other relevant advantages of MDCT include its speed, wide availability and ability to exclude non-NOMI causes of abdominal pain.[13]

A potential confounder in our study was the heterogeneity in imaging technologies and protocols among the cohort, which was partly a reflection of the long time frame of the study. A shortcoming arising from these technical variations is the inability to consistently assess for bowel wall contrast hypoenhancement, a factor we have excluded in the interests of clarity. Many in our cohort were also on inotropic agents, which affect the splanchnic vasculature and hence, theoretically, bowel wall contrast enhancement, further complicating interpretation. However, the remaining imaging features examined were relatively unaffected by these technical factors. Although it is generally agreed that angiographic phase imaging should be included when assessing for acute, occlusive mesenteric ischaemia,[13,15,16,21] its value in NOMI is not well established, as demonstration of arterial occlusion is not required for the diagnosis of NOMI.

It became apparent during the course of our study that laparotomy may not reliably diagnose NOMI, probably because partial thickness ischaemia may not be apparent intraoperatively, particularly when there is associated mucosa-to-serosa vascular shunting.[9] In our series, there were a small number of cases in which surgery was initially negative for NOMI but the patients died shortly afterwards or were diagnosed with NOMI subsequently. The implications of this observation are twofold: a negative laparotomy

does not necessarily exclude NOMI, especially if the clinical picture or MDCT suggests otherwise; and the accuracy, particularly the specificity, of MDCT may be underestimated when compared with surgery, as shown in our study. In diagnosing NOMI, there is no gold standard, and surgery is probably better considered as a "silver" standard along with clinical assessment and imaging.

In searching for better diagnostic accuracy, several alternative techniques have been investigated. A detailed account of these is beyond the scope of this article but we note that most of these modalities either have limited applications (eg, endoscopy and tonometry) or have disappointing results (eg, duplex sonography, magnetic resonance angiography and doppler flowmetry).[9,13] Novel biomarkers such as intestinal fatty acid binding protein and glutathione S-transferase are more specific than traditional serum markers and have reasonable accuracy (Table 7).[22,23] In particular, it may be worthwhile combining MDCT with biomarkers that have higher specificity, to improve our overall diagnostic accuracy.

In summary, MDCT has high sensitivity and a clinically useful NLR, which are most relevant in selecting patients for non-operative management, at least in the short to medium term. As with any imperfect test, its application requires good clinical judgement. A high clinical index of suspicion remains paramount in the diagnosis of NOMI.

Acknowledgements

We thank John Windsor (Department of Surgery, University of Auckland) for his critical appraisal of and contribution to our article.

Competing interests

None declared.

Author details

Henry C K Kwok, Registrar[1]
Ilse Dirkzwager, Radiologist[1]
David S Duncan, Radiologist[1]
Michael J Gillham, Intensivist[2]
David G Milne, Radiologist[1]

1 Department of Diagnostic Radiology, Auckland District Health Board, Auckland, New Zealand.

2 Cardiovascular Intensive Care Unit, Auckland District Health Board, Auckland, New Zealand.

Correspondence: DMilne@adhb.govt.nz

References

1 Ende N. Infarction of the bowel in cardiac failure. *N Engl J Med* 1958; 258: 879-81.

2 Kolkman JJ, Mensink PB. Non-occlusive mesenteric ischaemia: a common disorder in gastroenterology and intensive care. *Best Pract Res Clin Gastroenterol* 2003; 17: 457-73.

3 Acosta S, Ogren M, Sternby NH, et al. Fatal nonocclusive mesenteric ischaemia: population-based incidence and risk factors. *J Intern Med* 2006; 259: 305-13.

4 Siciliani L, Riccardi L, Favuzzi A, et al. A case of non-occlusive mesenteric ischemia and hepatic portal venous gas: not everyone knows that…. *Intern Emerg Med* 2011; 6: 563-5.

5 Hasan S, Ratnatunga C, Lewis CT, Pillai R. Gut ischaemia following cardiac surgery. *Interact Cardiovasc Thorac Surg* 2004; 3: 475-8.

6 Dhoble A, Patel K, Khasnis A. Non-occlusive mesenteric ischemia leading to "pneumatosis intestinalis": a series of unfortunate hemodynamic events. *Cases J* 2008; 1: 60.

7 Björck M, Wanhainen A. Nonocclusive mesenteric hypoperfusion syndromes: recognition and treatment. *Semin Vasc Surg* 2010; 23: 54-64.

8 Kazui T, Yamasaki M, Abe K, et al. Non-obstructive mesenteric ischemia: a potentially lethal complication after cardiovascular surgery: report of two cases. *Ann Thorac Cardiovasc Surg* 2012; 18: 56-60.

9 Kozuch PL, Brandt LJ. Review article: diagnosis and management of mesenteric ischaemia with an emphasis on pharmacotherapy. *Aliment Pharmacol Ther* 2005; 21: 201-15.

10 Howard TJ, Plaskon LA, Wiebke EA, et al. Nonocclusive mesenteric ischemia remains a diagnostic dilemma. *Am J Surg* 1996; 171: 405-8.

11 Maruyama Y, Yamauchi S, Imura H, et al. Nonocclusive mesenteric ischemia after aortic surgery in a hemodialysis patient. *Ann Thorac Cardiovasc Surg* 2008; 14: 129-32.

12 Mitsuyoshi A, Obama K, Shinkura N, et al. Survival in nonocclusive mesenteric ischemia: early diagnosis by multidetector row computed tomography and early treatment with continuous intravenous high-dose prostaglandin E(1). *Ann Surg* 2007; 246: 229-35.

13 Trompeter M, Brazda T, Remy CT, et al. Non-occlusive mesenteric ischemia: etiology, diagnosis, and interventional therapy. *Eur Radiol* 2002; 12: 1179-87.

14 Alpern MB, Glazer GM, Francis IR. Ischemic or infarcted bowel: CT findings. *Radiology* 1988; 166 (1 Pt 1): 149-52.

15 Ofer A, Abadi S, Nitecki S, et al. Multidetector CT angiography in the evaluation of acute mesenteric ischemia. *Eur Radiol* 2009; 19: 24-30.

16 Woodhams R, Nishimaki H, Fujii K, et al. Usefulness of multidetector-row CT (MDCT) for the diagnosis of non-occlusive mesenteric ischemia (NOMI): assessment of morphology and diameter of the superior mesenteric artery (SMA) on multi-planar reconstructed (MPR) images. *Eur J Radiol* 2010; 76: 96-102.

17 Shih MC, Hagspiel KD. CTA and MRA in mesenteric ischemia: part 1, Role in diagnosis and differential diagnosis. *AJR Am J Roentgenol* 2007; 188: 452-61.

18 Wiesner W, Mortelé KJ, Glickman JN, et al. Pneumatosis intestinalis and portomesenteric venous gas in intestinal ischemia: correlation of CT findings with severity of ischemia and clinical outcome. *AJR Am J Roentgenol* 2001; 177: 1319-23.

19 Kurland B, Brandt LJ, Delany HM. Diagnostic tests for intestinal ischemia. *Surg Clin North Am* 1992; 72: 85-105.

20 Brandt LJ, Boley SJ. AGA technical review on intestinal ischemia. American Gastrointestinal Association. *Gastroenterology* 2000; 118: 954-68.

21 Kirkpatrick ID, Kroeker MA, Greenberg HM. Biphasic CT with mesenteric CT angiography in the evaluation of acute mesenteric ischemia: initial experience. *Radiology* 2003; 229: 91-8.

22 Acosta S, Nilsson T. Current status on plasma biomarkers for acute mesenteric ischemia. *J Thromb Thrombolysis* 2012; 33: 355-61.

23 Evennett NJ, Petrov MS, Mittal A, Windsor JA. Systematic review and pooled estimates for the diagnostic accuracy of serological markers for intestinal ischemia. *World J Surg* 2009; 33: 1374-83. ❑